Is Hydrogen a Solution?

Teacher Guide

FORD PARTNERSHIP FOR ADVANCED STUDIES
Next Generation Learning
www.FordPAS.org

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Ford Partnership for Advanced Studies (Ford PAS)

Ford PAS (**www.FordPAS.org**) provides students with the content knowledge and skills necessary for future success in such areas as business, economics, engineering, and technology.

The Ford PAS curriculum consists of modules that link classroom learning with the challenges students will face in postsecondary education and the workplace of the future. The curriculum integrates academically rigorous, standards-based content with realistic applications in such areas as design and product development, information systems, environmental sustainability, global economics, business planning, personal finance, and marketing. Innovative partnerships that connect local high schools with colleges and universities, community organizations, and businesses provide real-world learning opportunities that are an essential component of the curriculum.

The Ford PAS curriculum modules are organized into seven themes, with some modules fitting into more than one theme:

Foundations in 21st-Century Skills
Working Toward Sustainability
Getting Smart About Business
Manufacturing for Tomorrow
Data, Decisions, and Design
Living in a Global Economy
Putting Math to Work

The module *Is Hydrogen a Solution?* falls under the Ford PAS theme Working Toward Sustainability.

WORKING TOWARD SUSTAINABILITY

The modules in this theme engage students in investigating *sustainability* as an important concept for both people and businesses around the globe. The modules explore changes that businesses are making to have their products and processes be more sustainable, as well as the shift toward fuel sources and technologies that can serve as alternatives to fossil fuels. Students look at why people worldwide are looking at alternative energy sources, and learn about the importance of research on stable and practical sources of energy. Because of their concerns over the impact we are having on our planet, individuals, governments, and companies all over the world are seeking alternative way to meet their needs—alternatives that are cost-effective and sustainable and will not further damage the environment or unduly impact one group more than another.

The following modules are in the Working Toward Sustainability theme:

We All Run on Energy

Energy from the Sun: Biomass

Is Hydrogen a Solution?

The Nuclear Revolution

Closing the Environmental Loop

Energy for the Future

USING THE MODULES

Several of the modules can together constitute the core of a physical science course. Individual modules may be used as part of various science or CTE courses or as part of a career academy, as shown in the following table.

Module	Academic Course or CTE Course/ Academy	Grade Levels
We All Run on Energy[1]	Physical Science, Earth Science	9, 10
Energy from the Sun: Biomass	Biology	9, 10
Is Hydrogen a Solution?	Chemistry, Earth Science	9, 10
The Nuclear Revolution	Physics	9, 10
Closing the Environmental Loop	Business, Engineering, Green Academies, Manufacturing	10, 11
Energy for the Future	Physics	11, 12

Visit the **Ford PAS Web site** for the latest curriculum news and updates.

[1] If this module is used it should be used first, but the other three modules for grades 9 and 10 may be used in any order.

Ford Partnership for Advanced Studies (Ford PAS)

The Ford PAS (www.FordPAS.org) curriculum consists of modules that link what you learn in the classroom to the skills and knowledge you will need in higher education and the workplace of the future. The curriculum is an academically challenging, standards-based program that will help you explore and develop your talents and prepare you to excel in both college and career.

The module *Is Hydrogen a Solution?* is part of the Working Toward Sustainability theme.

Working Toward Sustainability

What impact do people and businesses have on the world around them? What resources and sources of energy do people use, and how do people make these resources meet their needs? What challenges does humanity face as a result of its needs for particular resources and energy? How can people meet these challenges through scientific exploration and innovation?

In Working Toward Sustainability, you'll investigate how people and businesses around the globe are looking to make their practices more *sustainable*—causing less of a negative impact on the planet by using fewer resources and creating less waste and fewer by-products, while still meeting their own needs. You'll look at energy and energy sources, particularly those that can serve as alternatives to fossil fuels, and you'll learn the science concepts essential for understanding how businesses and people can meet their needs sustainably.

In *We All Run on Energy*, you'll examine the physical science behind energy, exploring its nature and how it is transformed and used to do work. *Energy from the Sun: Biomass*, *Is Hydrogen a Solution?*, and *The Nuclear Revolution* each focus on a particular fuel: biomass, hydrogen, and nuclear power. In these modules, you'll learn how each fuel is used to meet humans' energy needs, and research how these fuels might be used in the future. In *Closing the Environmental Loop*, you'll look at how products can be redesigned to be more environmentally sustainable. In *Energy for the Future*, you'll explore new energy technologies and how they might best be put to use.

Is Hydrogen a Solution?

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Module Overview

Notes:

INTRODUCTION

In Is *Hydrogen a Solution?*, students explore the possibilities of using hydrogen to meet some of our energy needs. Students take on the role of researchers at NuEnergy, a venture capital firm specializing in renewable energy. The firm has asked the researchers to work in Hydrogen Technology Research teams to consider several start-up companies that are looking into or already implementing hydrogen energy technologies. Research teams will recommend which company or companies NuEnergy should invest in.

To gain the knowledge needed to make this recommendation, students learn what hydrogen is and what obstacles currently prevent us from using hydrogen as a fuel on a large scale. They conduct research and scientific investigations to learn how hydrogen gas is produced, how it can be stored, and how fuel cells extract energy from hydrogen. As students experiment, research, and explore, they learn about several fundamental concepts in chemistry: the chemical and physical properties of compounds, how substances change during chemical reactions, and the properties of gases at different temperatures and pressures.

At the end of the module, each student team makes its decision about investing in the start-ups. Teams present their recommendations to their classmates and describe the science and the reasoning behind their recommendations.

Prerequisite Knowledge and Skills

- Have knowledge of and experience with basic laboratory safety procedures
- Know the basic structure and characteristics of atoms, including how they bond
- Understand that energy is stored in chemical bonds
- Understand that chemical bonds require energy to form, and release that energy when broken

Notes:

ACTIVITIES AT A GLANCE

Activity 1: A Hydrogen Economy? (4 sessions)

Students are introduced to the NuEnergy venture capital firm scenario and the role they will take on for the remainder of the module: In teams, they will work as researchers for NuEnergy, gathering information about hydrogen energy technologies in order to recommend which hydrogen energy technologies the firm should invest in. Students learn about the element *hydrogen*, reading a series of short vignettes about different uses of hydrogen as a fuel. Finally, teams get hands-on experience with fuel cells by assembling and operating fuel cell car kits.

Activity 2: Putting Hydrogen to Work (5 sessions)

Students learn about the two ways to make use of the energy in hydrogen: through combustion and in fuel cells. Students discover how atoms and compounds can be transformed through chemical reactions. They conduct scientific investigations in which they look at two different kinds of chemical reactions, exothermic and endothermic, and they learn how to write balanced equations that describe these reactions. Students learn more about the process by which fuel cells use the chemical reaction between hydrogen and oxygen to create electricity. They conduct a lab to find out more about reaction rates and catalysts, which are a crucial component of fuel cells. In their Hydrogen Technology Research teams, students look more closely at fuel cells by reading about how they work and looking at animations of fuel cells.

Activity 3: Fuel from Water? (8 sessions)

Students learn about oxidation-reduction reactions, focusing on electrochemical reactions in particular. After learning how to predict in which direction electrochemical reactions will run spontaneously, each Hydrogen Technology Research team researches one process or device that involves an electrochemical reaction; teams then present their process or device to the rest of the class. After reflecting on and evaluating what they have learned about hydrogen so far, student teams conduct a lab to extract hydrogen from water through electrolysis, measuring the amount of gas they are able to produce, and then use their data to calculate the efficiency of electrolysis. Finally, students research other methods of hydrogen production, creating Background Memos to share what they learn with their project teams.

Notes:

Activity 4: Under Pressure (4 sessions)

Students learn about the relationship between the microscopic and macroscopic properties of different states of matter, and the impact of temperature and pressure on the state of matter. They explore the properties of gases and consider how these properties might impact hydrogen gas storage, especially for personal vehicles. Students conduct research and create Background Memos on different methods of hydrogen storage—liquefaction, compression, metal hydrides, and emerging technologies—and then share what they've learned with their Hydrogen Technology Research teams.

Activity 5: Investing in the Future (4 sessions)

Hydrogen Technology Research teams make their final decisions about which hydrogen technologies show promise as an investment for NuEnergy. During a company meeting, each team shares its recommendation and the reasoning behind its decision with the class. The class discusses the viability of the various hydrogen-related technologies and votes on which start-ups NuENergy should invest in.

MODULE PLANNER

Activity 1: A Hydrogen Economy?

SESSION 1	SESSION 2
Is the Time Right for Hydrogen? All About Hydrogen	Properties of Hydrogen NuEnergy Investment Possibilities, Part 1

Activity 1

SESSION 3	SESSION 4
The Car of the Future?	Reality Check NuEnergy Investment Possibilities, Part 2

Activity 2: Putting Hydrogen to Work

SESSION 5	SESSION 6	SESSION 7
It's All About Bonding Considering Compounds	Creating a Chemical Reaction Diagram Looking at Reactions	Creating Equations

Activity 2

SESSION 8	SESSION 9
Discuss Reaction Rates Crucial Catalysts	Seeing How Fuel Cells Work

Activity 3: Fuel from Water

SESSION 10	SESSION 11	SESSION 12
Water from Fuel AND Fuel from Water	Current Predictions: Calculating Electrical Potentials Lights, Camera, Reaction!	Lights, Camera, Reaction! The Finale Tying It All Together What Do We Know Now?

Activity 3

Module Quiz Water, Water Everywhere, But Not a Drop of Hydrogen SESSION 13	Turning Water Into Fuel SESSION 14	Efficiency of Electrolysis Questions About Electrolysis Searching for Hydrogen SESSION 15

Activity 3

Questions About Hydrogen Production Terms The Search for Hydrogen Continues SESSION 16	The Search for Hydrogen Continues Reflect on Hydrogen Production SESSION 17

Activity 4: Under Pressure

What State? SESSION 18	Law-Abiding Gases SESSION 19	Discuss Hydrogen Storage The Storage Conundrum SESSION 20	Questions About Hydrogen Storage Terms Reflect on Hydrogen Storage SESSION 21

Activity 5: Investing in the Future

Hydrogen Savvy Answering the Key Questions SESSION 22	Making a Decision SESSION 23	Share Your Recommendations SESSION 24	**Module Test** SESSION 25

Notes:

MODULE LEARNING GOALS

The following is a summary of the learning goals for *Is Hydrogen a Solution?* The academic standards and core skills referenced are directly taught and assessed in this module. The table provides a number and/or letter designation for each skill and standard that corresponds to the full text of the standards and skills, available on the **Ford PAS Web site**.

Activity	Learning Goals	National Academic Standards	Core Skills	How Assessed
1	1.1 Describe the properties of the element *hydrogen* and of hydrogen gas.	NRC: A1, B1a, B1b, B2a, B2b, and B2c		Module Quiz
	1.2 Explain how decisions to develop or use technologies depend on a variety of factors, including the needs, wants, and values of individuals, businesses, and society.	NRC: F6d ITEA: 1 and 6		Product Assessment
2	2.1 Describe chemical reactions and what is taking place at the atomic level during those reactions.	NRC: A1, B3a, B3b, and B3c	B3: Use Logical Reasoning	Module Quiz
	2.2 Write and interpret balanced chemical equations for different chemical reactions.	NRC: A1, B3b, and B3c	A3: Interpret and Convey Ideas Visually	Module Quiz, Product Assessment
	2.3 Describe how different factors affect rates of chemical reaction, and the role that catalysts play in chemical reactions.	NRC: A1, B3c, B3d, and B3e	A1: Read with Understanding	Module Quiz, Product Assessment
	2.4 Describe the components of a fuel cell and the process by which fuel cells produce electricity.	NRC: A1, B3c, and B3e McREL: 1	B5: Understand Complex Systems	Module Test, Product Assessment
3	3.1 Describe the transfer of electrons in oxidation-reduction reactions.	NRC: B3c		Product Assessment, Peer Assessment

Notes:

Activity	Learning Goals	National Academic Standards	Core Skills	How Assessed
3	3.2 Analyze different methods of hydrogen gas production to identify the pros and cons of each method.	NCTE/IRA: 8 NRC: A1, E2c, F3a, F4b, F5b, F6b, and F6d	A1: Read with Understanding B2: Solve Problems and Make Decisions B5: Understand Complex Systems C1: Cooperate with Others D3: Learn Through Research	Product Assessment
4	4. 1 Describe the behavior of matter in different states and under different conditions.	NRC: A1 and B2e	B3: Use Logical Reasoning	Module Test
	4.2 Analyze different methods of hydrogen storage to determine the pros and cons of each.	NCTE/IRA: 8 NRC: A1, E2b, E2c, F6b, and F6d	A1: Read with Understanding B2: Solve Problems and Make Decisions B5: Understand Complex Systems C1: Cooperate with Others D3: Learn Through Research	Product Assessment
5	5.1 Apply scientific knowledge to decision-making about hydrogen energy technologies.	NCTE/IRA: 8 NRC: E1b, F3a, F3b, F3c, F4b, F4c, F6a, F6c, and F6d	B2: Solve Problems and Make Decisions B5: Understand Complex Systems C1: Cooperate with Others E4: Practice Leadership Skills and Practices	Module Test, Product Assessment
	5.2 Weigh the trade-offs among positive and negative consequences when making a decision about developing a technology.	NCTE/IRA: 8 NRC: F6a and F6d ITEA: 4, 5, and 16	B2: Solve Problems and Make Decisions	Module Test, Product Assessment

Notes:

CORRELATION WITH ACADEMIC STANDARDS AND CORE SKILLS

The following standards and core skills include those that are directly taught and assessed in *Is Hydrogen a Solution?* (and appear in the Learning Goals) as well as those that students apply in the course of their work in the module—work that helps students achieve the standards and master the skills. This list provides a brief description of each standard and skill, along with the number and/or letter designation that corresponds to the full text of the standards and skills, available on the **Ford PAS Web site**. Note: As national standards are revised periodically, check the **Ford PAS Web site** to obtain the most up-to-date list for *Is Hydrogen a Solution?*

English Language Arts: Standards for the English Language Arts

National Council of Teachers of English (NCTE) and the International Reading Association (IRA)

4. Adjust spoken, written, and visual language to communicate effectively with a variety of audiences and for different purposes.

7. Gather, evaluate, and synthesize data from a variety of sources to communicate a particular purpose or to a particular audience

8. Gather and synthesize information and create and communicate knowledge, using a variety of technological and information resources.

12. Use spoken, written, and visual language to accomplish own purposes.

English Language Arts: New Standards Performance Standards, English Language Arts

National Center on Education and the Economy and the University of Pittsburgh (NCEE/Pitt)

1. Reading

1c: Read and comprehend informational materials and produce written or oral work that summarizes information.

2. Writing

2a: Write a report appropriate for a purpose, audience, and context, with an organizing structure, appropriate facts and details, and a sense of closure.

3. Speaking, Listening, and Viewing

3b: Participate actively in group meetings, displaying appropriate turn-taking behaviors, offering and soliciting comments or opinions, responding appropriately, giving reasons, and expanding on responses when asked.

3c: Prepare and deliver a presentation that shapes information to achieve a particular purpose and to appeal to the interests and knowledge of audience members.

Notes:

Mathematics: Principles and Standards for School Mathematics

National Council of Teachers of Mathematics (NCTM)

2. Algebra

2.4: Analyze change in various contexts.

2.4a: Approximate and interpret rates of change from graphical and numerical data.

6. Problem-Solving

6.2: Solve problems that arise in mathematics and in other contexts.

Science: National Science Education Standards

National Research Council (NRC)

A. Science as Inquiry

A1: Develop abilities necessary to do scientific inquiry.

B. Physical Science

B1: Understand the structure of atoms.

B1a: Matter is made of minute particles called atoms, and atoms are composed of even smaller components. These components have measurable properties, such as mass and electrical charge. Each atom has a positively charged nucleus surrounded by negatively charged electrons. The electric force between the nucleus and electrons holds the atom together.

B1b: The atom's nucleus is composed of protons and neutrons, which are much more massive than electrons. When an element has atoms that differ in the number of neutrons, these atoms are called different isotopes of the element.

B2: Understand structure and properties of matter.

B2a: Atoms interact with one another by transferring or sharing electrons that are furthest from the nucleus. These outer electrons govern the chemical properties of the element.

B2b: An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattern of outermost electrons and their permitted energies.

B2c: Bonds between atoms are created when electrons are paired up by being transferred or shared. A substance composed of a single kind of atom is called an element. The atoms may be bonded together into molecules or crystalline solids. A compound is formed when two or more kinds of atoms bind together chemically.

Notes:

National Science Education Standards (continued)

B2d: The physical properties of compounds reflect the nature of the interactions among its molecules. These interactions are determined by the structure of the molecule, including the constituent atoms and the distances and angles between them.

B2e: Solids, liquids, and gases differ in the distances and angles between molecules or atoms and therefore the energy that binds them together. In solids the structure is nearly rigid; in liquids molecules or atoms move around each other but do not move apart; and in gases molecules or atoms move almost independently of each other and are mostly far apart.

B3: Understand chemical reactions.

B3a: Chemical reactions occur all around us, for example, in health care, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our bodies.

B3b: Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.

B3c: A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) between reacting ions, molecules, or atoms. In other reactions, chemical bonds are broken by heat or light to form very reactive radicals with electrons ready to form new bonds. Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels, the formation of polymers, and explosions.

B3d: Chemical reactions can take place in time periods ranging from the few femtoseconds (10–15 seconds) required for an atom to move a fraction of a chemical bond distance to geologic time scales of billions of years. Reaction rates depend on how often the reacting atoms and molecules encounter one another, on the temperature, and on the properties—including shape—of the reacting species.

B3e: Catalysts, such as metal surfaces, accelerate chemical reactions. Chemical reactions in living systems are catalyzed by protein molecules called enzymes.

B5: Understand conservation of energy and increase in disorder.

B5c: Heat consists of random motion and the vibrations of atoms, molecules, and ions. The higher the temperature, the greater the atomic or molecular motion.

E. Science and Technology

E1: Develop abilities for technological design.

E1b: Propose designs and choose between alternative solutions. Students should demonstrate thoughtful planning for a piece of technology or technique. Students should be introduced to the roles of models and simulations in these processes.

Notes:

National Science Education Standards (continued)

E2: Understand the relationship between science and technology.

E2b: Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend current levels of scientific understanding and introduce new areas of research.

E2c: Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.

F. Science in Personal and Social Perspectives

F3: Understand natural resources.

F3a: Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have and will continue to be used to maintain human populations.

F3b: The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.

F3c: Humans use many natural systems as resources. Natural systems have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

F4: Understand environmental quality.

F4a: Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.

F4b: Materials from human societies affect both physical and chemical cycles of the earth.

F4c: Humans use many natural systems as resources. Natural systems have the capacity to reuse waste, but that capacity is limited. Natural systems can change to an extent that exceeds the limits of organisms to adapt naturally or humans to adapt technologically.

F5: Understand natural and human-induced hazards.

F5b: Human activities can enhance potential for hazards. Acquisition of resources, urban growth, and waste disposal can accelerate rates of natural change.

F6: Understand science and technology in local, national, and global challenges.

F6a: Science and technology are essential social enterprises, but alone they can only indicate what can happen, not what should happen. The latter involves human decisions about the use of knowledge.

F6b: Understanding basic concepts and principles of science and technology should precede active debate about the economics, policies, politics, and ethics of various science- and technology-related challenges. However, understanding science alone will not resolve local, national, or global challenges.

Notes:

National Science Education Standards (continued)

F6c: Progress in science and technology can be affected by social issues and challenges. Funding priorities for specific health problems serve as examples of ways that social issues influence science and technology.

F6d: Individuals and society must decide on proposals involving new research and the introduction of new technologies into society. Decisions involve assessment of alternatives, risks, costs, and benefits and consideration of who benefits and who suffers, who pays and gains, and what the risks are and who bears them. Students should understand the appropriateness and value of basic questions–"What can happen?"–"What are the odds?"–and "How do scientists and engineers know what will happen?"

Engineering: Standards for Engineering Education

Mid-continent Research for Education and Learning (McREL)

1. Understand scientific principles related to electricity.

5. Understand energy and power types, sources, and conversions.

Educational Technology: National Educational Technology Standards

International Society for Technology in Education (ISTE)

1. Creativity and Innovation

1d. Identify trends and forecast possibilities.

2. Communication and Collaboration

2b. Communicate information and ideas effectively to multiple audiences using a variety of media and formats.

2d: Contribute to project teams to produce original works or solve problems.

3. Research and Information Fluency

3b. Locate, organize, analyze, evaluate, and ethically use information from a variety of sources and media.

3c: Evaluate and select information sources and digital tools based on the appropriateness to specific tasks.

3d. Process data and report results.

4. Critical Thinking, Problem Solving, and Decision Making

4b: Plan and manage activities to develop a solution or complete a project.

4c: Collect and analyze data to identify solutions and/or make informed decisions.

Notes:

Technological Literacy: Standards for Technological Literacy
International Technology Educational Association (ITEA)

1. Understand the characteristics and scope of technology.

4. Understand the cultural, social, economic, and political effects of technology.

5. Understand the effects of technology on the environment.

6. Understand the role of society in the development and use of technology.

7. Understand the influence of technology on history.

10. Understand the role of troubleshooting, research and development, invention and innovation, and experimentation in problem-solving.

16. Understand and be able to select and use energy and power technologies.

Core Skills

Based on Equipped for the Future (EFF), National Institute for Literacy (NIFL), SCANS 2000, The Secretary's Commission on Achieving Necessary Skills, U.S. Department of Labor, and Linking Leadership to Instruction, Leadership for the 21st Century, Virginia Board of Education

A—Communication Skills

A1—Read with Understanding: Determine reading purpose, select and adjust strategies, analyze and reflect on content, and integrate information with prior knowledge.

A3—Interpret and Convey Ideas Visually: Interpret and construct visual representations.

A4—Speak So Others Can Understand: Determine communication purpose; organize and relay information, paying attention to proper usage, pace, and gesture; and monitor comprehension.

A5—Listen Actively: Attend to oral communication, clarify purpose, use listening strategies, monitor comprehension, and integrate information with prior knowledge.

A6—Observe Critically: Determine purpose; use appropriate strategies for attending to different types of media and monitoring comprehension; analyze accuracy, bias, and usefulness of information; and integrate information with prior knowledge.

B—Thinking and Decision-Making Skills

B2—Solve Problems and Make Decisions: Identify problems, understand root causes, generate and evaluate consequences of alternative solutions, and establish criteria for evaluating effectiveness.

B3—Use Logical Reasoning: Discover rules or principles underlying relationships among objects or situations, draw conclusions, apply to new situations, and evaluate correctness of conclusions.

Notes:

Core Skills (continued)

B4—Think Creatively: Use imagination, combine ideas or information in new ways, reshape goals to reveal new possibilities, and make connections between seemingly unrelated ideas.

B5—Understand Complex Systems: Understand how social, organizational, and technological systems work; monitor and correct performance; suggest modifications; and develop alternative systems.

C—Interpersonal Skills

C1—Cooperate with Others: Interact with respect for others' ideas and contributions, seek and offer clear input, and adjust actions in order to jointly accomplish a task.

C2—Advocate and Influence: Define objectives, gather facts to build a case, assess and take into account others' interests and resources, present a clear case, and revise it in response to feedback.

D—Lifelong Learning Skills

D2—Reflect and Evaluate: Take stock of present situation and one's own knowledge, and make inferences, predictions, and judgments based on reflection.

D3—Learn Through Research: Pose questions to be answered, use multiple approaches to find information, and organize, evaluate, analyze, interpret, and report on findings.

E—Leadership Skills

E4—Practice Leadership Skills and Practices: Working with various people, motivate others, take initiative, communicate effectively, make decisions, and manage resources.

Notes:

TEACHING SUGGESTIONS

Coordinated Learning Experiences

Coordinated Learning Experiences (CLEs) are opportunities for students to learn firsthand about community-based, real-world applications of what they are learning in *Is Hydrogen a Solution?* CLEs provide regular, relevant, and timely reinforcement of the value that classroom knowledge has in the world outside the classroom. They help students place their own learning in a realistic context and understand that education continues beyond the confines of school and throughout one's working life. Suggested CLEs—such as touring a hydrogen production plant or meeting an engineer who works on hydrogen technologies—for each activity in *Is Hydrogen a Solution?* are listed on the **Ford PAS Web site**.

Classroom Visitors

To introduce the scenario of the module project in Session 1, invite a guest to play the role of the CEO of NuEnergy. Explain the role you would like your guest to take on and send the CEO script that is available on the **Ford PAS Web site**. You may want the guest to be someone who works in or knows about venture capital firms, so that he or she can speak to the students about firms that invest in sustainable energy companies, and how important fact-finding research is to such firms.

Hydrogen Technology Research Project

Throughout *Is Hydrogen a Solution?*, students work in research teams employed by NuEnergy, a fictional firm that invests in companies that are developing innovative solutions for energy issues. Teams apply what they learn through scientific investigations, research, and hands-on work with a real hydrogen fuel cell to make a well-reasoned recommendation as to which hydrogen energy technologies have promising applications that should be funded by NuEnergy.

Science Notebooks

Science notebooks support the development of scientific literacy and also serve as important assessment tools. Students should have appropriate notebooks before the module begins, as they need to set up and use their notebooks right away. The science notebook should have a sewn binding (such as in a composition notebook), contain graph paper (sometimes described as *quadrille ruled*), and be 100–125 pages long. For a more detailed description of the notebook and how it is used, see **Science Notebook Guidelines** in the Skill Appendix on pages 88–89 in the Student Guide (pages T 226–T 227).

Notes:

Literacy in Science

Just as students need help with conducting scientific investigations and interpreting results, they need support around the use of literacy tools that are an essential part of scientific inquiry. Whatever their proficiency in reading, students encountering scientific texts often need help with strategically reading, writing about, and discussing scientific information—for example, when recording results of scientific investigations, interpreting graphs, or gathering information for a team project. And all students can benefit from knowing how to adjust the way they read based on their purpose for reading (for research, fun, general information, and so on), the kind of text, and their prior knowledge of the content. *Is Hydrogen a Solution?* includes literacy tools to help you teach, model, and apply specific strategies that students can use to improve their ability to make sense of scientific texts. For example:

- **Reading Scientific Texts:** This optional session, available as a Skill Resource on the **Ford PAS Web site**, is a collaborative activity for in-class reading, designed to help students focus on specific ways to read complex text, share ideas and questions with one another, and summarize their thinking. This session can be helpful for both struggling and proficient readers. Depending on your students' needs, you may choose to use the reading in the Skill Resource or adapt the session to use with any reading in which students will benefit from the modeling and discussion of complex text.

- **Questioning the Text:** Students learn to recognize four types of questions that help them engage in active reading by determining if they will find needed information in the text or whether they need to think on their own to formulate an answer to a question:
  - **Right there:** The answer is within a paragraph or sentence in the text.
  - **Think and search:** The answer is in the text, but the reader must pull pieces from different paragraphs to answer the question.
  - **On my own:** The answer lies in the reader's own background knowledge or experience; it is not found in the text.
  - **Author and me:** The answer is not stated directly in the text; the reader must formulate ideas by using both prior knowledge and data from the text. These questions may begin with the words, "The author implies . . ." or "The text suggests . . ."

- **Literacy Tips:** Throughout the module there are tips and Skill Resources to use with your students, which include suggestions about reading scientific texts aloud to your students and directions for setting up a Word Wall in the classroom.

Notes:

All of these tools are available as Skill Resources on the **Ford PAS Web site**.

In addition, the Skill Appendix, located in the *Is Hydrogen a Solution?* Student Guide, contains the following literacy resources:

- **Science Notebook Guidelines** for setting up and using a science notebook
- **Lab Report Guidelines** for what to include in a lab report
- Pre-reading and during-reading Skill Resources titled **Preview the Text** (which is also used within the optional Reading Scientific Texts session) and **Reading Strategies to Use on Your Own**

These literacy tools are introduced in *We All Run on Energy*, the introductory module in the Ford PAS theme Working Toward Sustainability. If your students have completed that module, they have already learned to use these resources. In *Is Hydrogen a Solution?*, students have more opportunities to use the tools as needed.

Scientific Investigations

Students conduct a number of scientific investigations throughout *Is Hydrogen a Solution?* Read the description for each investigation carefully before conducting it with students.

Lab Safety

Lab safety is critical because students will be working with flammable and potentially hazardous materials and open flames. Before beginning this module, familiarize yourself with standard lab safety procedures and your own school's guidelines for lab safety training, and make sure that every student in the class is trained in lab safety. Go to the **Ford PAS Web site** for resources on lab safety.

Lab Reports

Lab Report Guidelines in the Student Guide Skill Appendix on pages 90–91 (pages T 228–T 229) provide information to students on what to include in lab reports. For each completed lab report, you can use the **Lab Report Assessment (RM 1.4)**. You can share this assessment with students in advance of the first lab so they can see how their lab reports will be assessed. You might also want to remind students to review the assessment criteria at the beginning of each lab.

Adaptations

Is Hydrogen a Solution? was designed to engage students in scientific inquiry throughout the module. Students have numerous opportunities to interpret data and to read, write, and talk about the scientific information they acquire through scientific investigation, reading, and class discussion.

Notes:

Research suggests that giving students an opportunity to develop their own procedures for conducting scientific investigations enhances their ability to construct meaning from the activity. The Water Electrolysis Lab in *Is Hydrogen a Solution?* provides just this opportunity. If you think students need help developing their own procedures, use the Skill Resource **Designing Experiments**. However, if students are unable to develop their own procedures, or you need to provide more structure for your students, more defined procedures are available on the **Ford PAS Web site**, along with articles about adapting scientific investigations to make them more inquiry-based. You may want to use these articles to adapt some of the other labs in this module.

Assigning Roles: An easy adaptation that can make investigations more inquiry-based and help engage all students (including students with learning disabilities and students who are not as strong academically) is to assign them different roles within their teams, for example:

Team Role	Description of Role
Lab Manager	Oversees the work of everyone—keeping the team on task and making sure that all members participate in completing the investigation—and sees that procedures are followed
Recorder	Records data from investigations and makes sure that everyone on the team gets the data before class is over
Reporter	Communicates to the teacher any issues the team is having and shares results with the class during whole-class discussions
Materials Manager	Makes sure that the team has all the necessary materials for the investigation and that everyone has access to the materials

You can assign roles based on students' strengths, or you can use them to help build students' skills. For example, you might assign a strong writer to the recorder role, or you might assign the role to a student who is not as skilled at taking notes, with the lab manager overseeing the student to make sure that he or she stays on task. You may want to have students remain in the same roles throughout this module to allow them to master specific skills, or rotate students for each investigation so they can build different skills.

Materials and Equipment

This module requires a variety of materials and equipment for conducting scientific investigations. It is assumed that you have access to a science lab and basic scientific equipment, such as beakers, balances, thermometers, and safety gear. For items that can be found at home, such as styrofoam coffee cups and marshmallows, you might request that students and other school staff help by bringing in some of them.

Notes:

A number of materials will need to be gathered or prepared in advance of the session for which they are needed, and some may need to be purchased or borrowed:

- In Sessions 1 and 5, filling latex balloons with hydrogen, helium, and methane is suggested. See Before You Teach on page T 39 and page T 66 and the **Ford PAS Web site** for recommendations on obtaining these gases. (A helium canister and balloons,
  for example, can be obtained from a party supply store.)
- In Session 3, The Car of the Future?, students work in teams to build and test a model fuel cell car, and you'll need to obtain model fuel cell car kits ahead of time. More information is available on the **Ford PAS Web site**.
- Investigations in which students develop their own procedures may require materials that are not included in the module Materials List.

Throughout the module, the quantities of materials needed are given on a per-team basis and are described in the Materials Needed section of each Activity Overview. Teams should consist of four or five students, so plan your purchase and collection of materials accordingly.

Go to the **Ford PAS Web site** to learn about acquiring a *Is Hydrogen the Solution?* materials kit.

Materials List

The following table lists materials needed for labs and demonstrations by session. This list is also located on the **Ford PAS Web site**.

Table TS 1: *Is Hydrogen a Solution?* Materials List

When Used	Materials Needed	Quantity
Ongoing	Safety goggles	One pair for each student
	Science notebooks (sewn binding composition notebook, contains graph paper)	One for each student
Activity 1: A Hydrogen Economy?		
Session 1	**If you will conduct the hydrogen-filled balloon demonstration in class:**	
	Ear plugs	One pair for each student and teacher
	Large latex rubber balloon	One for the class

Notes:

When Used	Materials Needed	Quantity
Activity 1: A Hydrogen Economy? (continued)		
Session 1	Small canister of hydrogen gas	One for the class
	String for balloon	One for the class
	Optional: Weight for string	One for the class
	Taper candle	One for the class
	Meter stick	One for the class
	Masking tape	One roll for the class
	Matches or lighter	One for the class
Sessions 1–4	Chart paper and markers	Enough for the class
Session 3	Fuel cell car kit (one that does NOT rely on solar cells)	One for each team
	Distilled water	1 L for each team
	Tape measure	One for each team or every two teams
	Air-tight plastic bags for storing fuel cells	One for each team
Activity 2: Putting Hydrogen to Work		
Session 5	**If you will conduct the balloon demonstrations in class:**	
	Taper candle attached to meter stick from Session 1	One for the class
	Large latex rubber balloons	Four (enough for four demonstrations)
	String for balloon	Enough for four balloons
	Optional: Weight for string	One for the class
	Matches or lighter	One lighter for the class
	For the hydrogen-filled balloon demonstration:	
	Ear plugs	One pair for each student and teacher

Notes:

When Used	Materials Needed	Quantity
Activity 2: Putting Hydrogen to Work (continued)		
Session 5	Small canister of hydrogen gas (from Session 1, if used)	One for the class
	For the helium-filled balloon demonstration:	
	Small canister of helium gas	One for the class
	For the air-filled balloon demonstration:	
	Optional: Balloon pump	One for the class
	For the methane-filled balloon demonstration:	
	Small canister of methane gas	One for the class
	If you're not conducting the methane-filled balloon demonstration:	
	Butane lighter	One for the class
Session 6	**For Chemical Reactions Lab 1:**	
	Styrofoam coffee cup	One for each team
	250 mL beaker	One for each team
	1.5 M citric acid solution ($H_3C_6H_5O_7$)	25 mL for each team
	Thermometer	One for each team
	Baking soda ($NaHCO_3$)	15 g for each team
	Stirring rod	One for each team
	Timer or watch with second hand	One for each team
	For Chemical Reactions Lab 2:	
	Styrofoam coffee cup	One for each team
	250 mL beaker	One for each team
	Optional (but highly recommended): Fume hood	One for the class

Notes:

When Used	Materials Needed	Quantity
Activity 2: Putting Hydrogen to Work (continued)		
Session 6	1.5–3 M hydrochloric acid (HCl)	100 mL for each team
	Thermometer	One for each team
	Granular zinc (Zn)	0.5 g for each team
	Stirring rod	One for each team
	Place to properly dispose of hydrochloric acid/ zinc solution	
Session 8	Hydrogen peroxide (H_2O_2), ideally, with a concentration higher than the 3 percent typically found at drugstores	90 mL for each team
	50 mL beakers	Three for each team
	Liquid dish soap	One bottle for the class
	Stirring rod	One for each team
	Small piece of potato (approximately 1 cm^3)	One for each team
	Optional: Small piece of beef liver (instead of or in addition to the potato)	One for each team
	Stopwatch or watch/clock with a second hand	One for each team
	Wooden splints	Three for each team
	Matches	One book for the class
	Scoopula	One for each team
	Powdered manganese dioxide (MnO_2)	0.5 g for each team
Activity 3: Fuel from Water		
Session 14	1000 mL beaker	One for each team
	Washing soda (sodium carbonate, or Na_2CO_3)	4 g for each team
	Test tubes (20 mL) with stoppers	Two for each team
	Grease pencil	One for each team

Notes:

When Used	Materials Needed	Quantity
Activity 3: Fuel from Water (continued)		
Session 14	Carbon electrodes, approximately 4 cm long	Two for each team
	30 cm long pieces of coated copper wire, with the coating removed from 4 cm of wire on both ends	Two for each team
	Insulated alligator clips	Two for each team
	6 V lantern battery	One for each team
	Ammeter (or multimeter) with appropriate wires and connectors	One for each team
	Other materials that might be useful, such as Burette clamps or utility clamps	Several for each team
	Optional: Voltmeter (or multimeter—students can use the one listed in this session if necessary) with appropriate wires and connectors	One for each team
Activity 4: Under Pressure		
Session 19	Small ballot box	Six for the class
	For Behavior of Gases Station 1:	
	Round balloons	Two for each team
	1 L beakers	Two for the station
	Ice	Enough to fill half a beaker for each team
	Hot plate	One for the station
	Tongs	One for the station
	For Behavior of Gases Station 2:	
	Plastic bottle with cap, such as a large soda bottle	One for the station
	Eyedropper	One for the station

Notes:

When Used	Materials Needed	Quantity
Activity 4: Under Pressure (continued)		
Session 19	**For Behavior of Gases Station 5:**	
	Large marshmallows	Five for each team
	Vacuum pumper	One for the station

Module Overview

What if someone told you that you could run a car on a fuel, and the only emissions would be water and heat—no carbon dioxide or other pollutants would be released into the atmosphere? Not only that, they tell you, but one of the ways this fuel can be made is with water and electricity—and if there were a reliable source of electricity that didn't rely on fossil fuels, then the entire process of making this fuel would release *no* greenhouse gas emissions! Would you think that this was the fuel of the future, or does it sound too good to be true? During this module, you'll learn enough to be able to answer this question for yourself.

In *Is Hydrogen a Solution?*, you'll learn all about the element *hydrogen* and the potential of hydrogen to meet some of our energy needs. You'll also see the many obstacles that keep hydrogen from being a practical solution—for the foreseeable future, at least. You'll conduct scientific investigations and work with a real hydrogen fuel cell to explore how they function and what the challenges are to using them on a large scale. Through these investigations, you'll learn about the science behind hydrogen production, storage, and use.

Throughout the module, you will work in a Hydrogen Technology Research team and take on the role of a researcher working for NuEnergy, a firm that invests in companies that are developing innovative solutions for energy issues. Your job is to figure out whether it makes sense for NuEnergy to invest in one or more companies that are developing hydrogen energy technologies. You will conduct research on the pros and cons of various hydrogen energy technologies, learn about the different ways that hydrogen gas can be produced and stored, and conduct scientific investigations to better understand the challenges underlying the use of hydrogen energy technologies. At the end of the module, you and your team will use what you have learned to decide which companies are worth investing in. You'll share your team's recommendations, and the reasoning behind them, with your classmates.

ACTIVITY 1:

A Hydrogen Economy?

Notes:

ACTIVITY OVERVIEW

Students are introduced to the NuEnergy venture capital firm scenario and the role they will take on for the remainder of the module: In teams, they will work as researchers for NuEnergy, gathering information about hydrogen energy technologies in order to recommend which hydrogen energy technologies the firm should invest in. Students learn about the element *hydrogen*, reading a series of short vignettes about different uses of hydrogen as a fuel. Finally, teams get hands-on experience with fuel cells by assembling and operating fuel cell car kits.

Sessions 1–4

Before You Teach

Before Starting the Module

- Order the fuel cell car kits for Session 3. Note: Do not purchase a kit that relies on solar cells. Go to the **Ford PAS Web site** to see a recommended kit.
- Give students time to read the **Science Notebook Guidelines** in the Skill Appendix on pages 88–89 in the Student Guide (pages T 226–T 227). Have them set up their science notebooks as described in the guidelines.
- Give students **RM 1.1 Science Notebook Assessment**. Explain that they will be assessed on the clarity, detail, and accuracy of their science notebooks.

Notes:

Session 1

- Decide whether to show the hydrogen ignition video or to conduct the demonstration yourself. If you decide to show the video, preview it on the **Ford PAS Web site**.
- If you are conducting the hydrogen-filled balloon demonstration in class:
  - Find a source for a hydrogen gas container or make the hydrogen yourself.
  - Attach a taper candle to the end of a sturdy meter stick with masking tape.

  Note that this demonstration will be repeated in Session 5.
- Download and print the **NuEnergy CEO Script** from the **Ford PAS Web site** to read aloud to the class.
- Decide whether to invite a guest, such as another teacher, a drama student, or a representative of one of your community partners who works in the field of sustainable energy, to play the role of the CEO of NuEnergy.

Session 2

- Download and print **NuEnergy Investment Opportunities 1** from the **Ford PAS Web site**.

Session 3

- Locate a "test track," such as a hallway or gymnasium with a long, smooth, uninterrupted stretch of floor, for students to test their model fuel cell cars.

Session 4

- Download and print **NuEnergy Investment Opportunities 2** from the **Ford PAS Web site**.

Materials Needed

Session 1

If showing the video of the hydrogen-filled balloon:

- Computer and projector OR one computer with access to the Internet for each team

If conducting the hydrogen-filled balloon demonstration:

- Safety goggles (one pair for each student and the teacher)
- Ear plugs (one pair for each student and the teacher)
- Large latex rubber balloon

Notes:

- Small canister of hydrogen gas
- String for balloon
- Optional: Weight (for string)
- Taper candle
- Meter stick
- Masking tape
- Matches or lighter

- A copy of the **NuEnergy CEO Script**
- Chart paper and markers
- Copies of **RM 1.2 Hydrogen Technology Research Project Assessment** (one for each student)

Session 2

- Chart paper and markers
- Copies of **NuEnergy Investment Opportunities 1** (one for each student)

Session 3

- Copies of **RM 1.3 Model Fuel Cell Car Lab** (one for each team)
- Fuel cell car kit (one for each team)
- 1 L distilled water (one for each team)
- Tape measure (one for each team or every two teams)
- Air-tight plastic bags for storing fuel cells (one for each team)
- Copies of **RM 1.4 Lab Report Assessment** (one for each student)

Session 4

- Chart paper and markers
- Copies of **NuEnergy Investment Opportunities 2** (one for each student)

VOCABULARY

Energy carrier	**Hydrogen fuel cell**
Fuel efficiency	Venture capital

Student Guide, p. 11

ACTIVITY 1:
A Hydrogen Economy?

INTRODUCTION

NuEnergy, which funds innovators in developing energy solutions, has decided to invest in hydrogen. As a researcher for NuEnergy, you need to learn all you can about hydrogen and its potential for meeting our energy needs. Some people say that hydrogen has great promise for meeting future energy needs because it can be used as a clean energy source. Others say that there are still too many obstacles for hydrogen to be put to use on a large scale, at least any time soon. So, is hydrogen part of the solution to our energy issues or not? In this activity, you'll learn more about the work you need to do for NuEnergy throughout the module. You'll explore different ways that hydrogen has been used over the past century, and discover some of the properties of hydrogen in the process. Finally, you'll put your own fuel cell car (well, a model of one) to the test.

Learning Goals

- Describe the properties of the element *hydrogen* and of hydrogen gas.
- Explain how decisions to develop or use technologies depend on a variety of factors, including the needs, wants, and values of individuals, businesses, and society.

FOR YOUR GLOSSARY

Energy carrier

Fuel efficiency

Hydrogen fuel cell

Notes:

SESSION 1

IS THE TIME RIGHT FOR HYDROGEN?

[Whole Class]

Students begin to learn about hydrogen and are introduced to the module project scenario. This project will provide the basis for learning about hydrogen and its potential as a sustainable energy source.

To begin the session, show students what happens to hydrogen when a flame is applied to it. Either demonstrate the ignition of a hydrogen-filled balloon or show the video available on the **Ford PAS Web site**.

Hydrogen-Filled Balloon Demonstration

1. Have students put on safety goggles and insert earplugs, and do so yourself.
2. Fill a balloon with hydrogen gas.
3. Connect a weighted string to the balloon or tie the balloon to a fixed location at the front of the classroom.
4. Light the candle that you have attached to the end of a meter stick, and touch the balloon with the candle flame. The balloon should explode into a cloud of flame.

Students should remain at least 3 meters from the balloon setup at all times.

Explain that this module, as its title suggests, is all about hydrogen and that now they have an inkling of the power of hydrogen. Explain that they will discuss this demonstration shortly, but that first you want them to understand a bit more about what they will be doing in this module.

Introduce the module project by playing the role of the CEO of NuEnergy, using the **NuEnergy CEO Script** located on the **Ford PAS Web site**.

Once you've explained the scenario to students, divide the class into Hydrogen Technology Research teams. Tell students that they will work in these teams for the rest of the module.

IS THE TIME RIGHT FOR HYDROGEN?

Congratulations! As a researcher working for NuEnergy, a venture capital firm based in Northern California, you have been given an important assignment: to help the company decide how to invest $20 million in hydrogen energy technologies. NuEnergy specializes in financially backing companies that are innovators in renewable energy technologies. Last year, for example, the firm invested in a company making solar panels for home installation.

There are many reasons that businesses are looking for alternatives to fossil fuels—including rising fossil fuel prices, the impact of fossil fuel use on global climate change, and concerns about fossil fuel supplies and energy security—but it's not yet clear which alternatives are going to eventually succeed in the marketplace.

NuEnergy
Investing in the Future

WHAT'S A VENTURE CAPITAL FIRM?

Venture capital firms invest in promising companies that need funding but may not be able to get it through more traditional sources, such as bank loans. A venture capital firm gives a company the money it needs to start out, usually in exchange for shares in the company. If the company succeeds and makes a profit, the venture capitalists make money. If the company fails, the venture capitalists lose money. Obviously, venture capital firms do their best to invest in companies that are going to succeed!

Your firm thinks that hydrogen technologies may be part of the solution to our energy challenges and is trying to decide which hydrogen technologies are a good investment. The list of possibilities has been narrowed down to four companies, each of which is developing a different technology.

To make a recommendation about which companies NuEnergy should invest in, you'll have to learn as much as you can about hydrogen and its potential as an alternative to fossil fuels.

Notes:

ALL ABOUT HYDROGEN

[Whole Class/Teams]

Survey students' knowledge of and conceptions about hydrogen and fuel cells, and explain more about the tasks that are part of the module project.

Begin by asking students to think about the hydrogen balloon demonstration and the reaction they saw when heat was applied to the hydrogen-filled balloon.

Ask students the following questions:

- What have you heard about hydrogen and fuel cells?
- What is hydrogen?
- Where do you find hydrogen?
- What questions do you have about hydrogen and fuel cells?

As students answer the questions, write their responses on chart paper, using a different piece of paper for each question. Post these pieces of paper around the classroom, and tell students that they will return to these questions throughout the module to add to or change their answers, and they'll look at them again at the end of the module to see what they've learned.

Students will probably not have correct answers for all of these questions—the point of the activity is to stimulate their thinking about the subject and to provide a way to assess their prior knowledge.

If possible, keep these questions and student responses posted in the room or otherwise accessible to students. Their responses will be revisited and updated during Session 12, What Do We Know Now? and Session 22, Hydrogen Savvy.

Have students read **Hydrogen Technology Research Project Guidelines** on pages 14–16 in the Student Guide (pages T 47–T 49). Discuss the guidelines. Give students the **Hydrogen Technology Research Project Assessment (RM 1.2)**.

ALL ABOUT HYDROGEN

What do you already know about hydrogen? Maybe you've seen a segment about hydrogen-powered fuel cells on the news or heard politicians talking about "the hydrogen economy." Or maybe you haven't heard anything at all.

Hydrogen gas is not a *primary* energy source, the way that coal or solar energy are. It's an **energy carrier**—a substance that transports energy in a usable form from one place to another. Energy carriers are produced by converting an energy source. Electricity is also an energy carrier—it is produced by burning fossil fuels or biomass or through nuclear reactions, and then "carries" energy to our homes.

People around the world are considering the best ways to use hydrogen to deliver energy. As you saw earlier, hydrogen releases a lot of energy, mostly in the form of heat, when it burns. However, the energy in hydrogen can also be released and harnessed in a **hydrogen fuel cell**—a device that converts chemical energy to electrical energy through a reaction between hydrogen and oxygen.

Read the **Hydrogen Technology Research Project Guidelines**, which describe what you'll need to learn to help NuEnergy make its decision. Be sure to refer to the **Hydrogen Technology Research Project Assessment** to see how your work will be assessed.

HOMEWORK 1.1

Read your assigned vignette, and list the properties of hydrogen mentioned in the vignette.

Think about the Hydrogen Technology Research project. Write down any ideas or questions that you want to discuss with your Hydrogen Technology Research team.

Notes:

If there is time remaining in the session, have students meet in their Hydrogen Technology Research teams to discuss the project assessment and guidelines and note any questions they have.

At the end of the session, assign three vignettes for homework, each to be read by a third of the class: **The Last Zeppelin**, **We Have Liftoff**, and **Next Stop, No Emissions**. Establish the purpose for reading the vignettes by asking students to look for and record information about the properties of hydrogen.

Hydrogen Technology Research Project Guidelines

This year, NuEnergy has set aside $20 million to invest specifically in a company (or companies) that is researching or implementing technologies to further the use of hydrogen as an alternative to fossil fuels. NuEnergy has narrowed down its possible investments to four companies, each of which is exploring a different technology. In order to make a well-reasoned recommendation about which company or companies NuEnergy should invest in, you will work as part of a research team to investigate hydrogen as a fuel source. These guidelines explain what your Hydrogen Technology Research team needs to do.

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What You'll Research

Each Hydrogen Technology Research team at NuEnergy will make recommendations about which company or companies NuEnergy should invest in. The firm needs your team to answer the following key questions:

1. How will the technology being developed work? What's the science behind it?
2. What are the challenges to widespread adoption of this technology?
3. What environmental consequences, positive or negative, are likely to result from widespread adoption of this technology?

What You Need to Know

In order to answer these questions, you will need to work with your team to conduct research in four key areas: hydrogen basics, hydrogen as a fuel, hydrogen gas production, and hydrogen storage.

Hydrogen Basics

You need to understand the basic science of hydrogen before you can understand exactly what is going on inside a fuel cell. Find the answers to the following questions:

1. What are the properties of hydrogen?
2. Why is hydrogen considered an energy *carrier* rather than an energy *source*?
3. What happens during the chemical reaction between hydrogen gas and oxygen gas?
4. What happens during the chemical reaction in which water molecules are split into hydrogen gas and oxygen gas?

Hydrogen as a Fuel

To make your recommendations, you'll need to understand exactly what's going on inside a fuel cell and be able to answer the following questions:

1. What are the different components of a hydrogen fuel cell, and what do they do?
2. What happens to hydrogen gas and oxygen gas in a fuel cell to create an electrical current?

Hydrogen Gas Production

One of the important facts about hydrogen gas is that it is extremely rare on Earth—it is so light that it floats out of Earth's atmosphere. This means that any hydrogen we use in fuel cells has to be produced from another substance, which creates potential challenges. You will need to learn about the various aspects of hydrogen gas production and be able to answer the following questions:

1. What are the different sources from which hydrogen gas can be produced?
2. What are the advantages and drawbacks of the different methods of hydrogen gas production?
3. What are the current obstacles to producing hydrogen gas on a commercial scale without any negative environmental effects, such as greenhouse gas emissions? How are scientists and engineers working to overcome these obstacles?

Hydrogen Storage

Hydrogen storage is one of the major challenges facing designers of hydrogen fuel cell vehicles. Hydrogen gas, at regular temperature and pressure, takes up a lot of space and therefore requires special storage methods. You will need to learn about these storage methods and be able to answer the following questions:

1. What are the different ways that hydrogen can be stored for use in a vehicle?
2. What are the challenges and benefits of the different methods of hydrogen storage?
3. What are the current obstacles to storing enough hydrogen on board a passenger vehicle to complete a 300-mile trip, and how are scientists working to overcome these obstacles?

Keeping Track of Your Research

You'll record all your lab notes and research in your science notebook. You will need to document your research in order to support your investment recommendations.

Background Memos

During the module you will research and write two Background Memos, one on hydrogen production and one on hydrogen storage. These memos will include information about how different methods of hydrogen production and storage work, and the pros and cons of methods that are currently used or are in development.

Hydrogen Technology Report

Your team will write a brief report answering the key questions about each investment opportunity. Based on your research, your team will formulate recommendations about which company (or companies) NuEnergy should invest in.

Making Your Recommendations

At the end of *Is Hydrogen a Solution?*, you'll have about five minutes to present your recommendations during a company meeting. You should have a clear rationale for your recommendations and be able to present evidence to support them. Other teams in the company are also considering the same key questions, and their decision may be different from your team's—so you need to be prepared to advocate for your point of view!

The Last Zeppelin

The first documented human flight was taken in a hot-air balloon in Paris in 1783. The balloon was filled with hot air because hot air is so easy to come by and is lighter than the surrounding cooler air (and therefore the balloon floated). Hydrogen gas is *even lighter* than hot air. Because hydrogen is the lightest of all gases, a hydrogen balloon has several times more lifting power than a hot-air balloon of the same size.

Pure hydrogen gas (with the molecular formula H_2) is very rare on Earth. This lighter-than-air gas too easily escapes Earth's gravity. But hydrogen is extremely common on Earth as part of compounds, such as water and methane. When it was discovered that hydrogen gas could be released from compound forms through chemical reactions, one of its first uses was to fill passenger balloons. Eventually, hydrogen gas was used to lift large passenger airships, like the German zeppelin LZ 129 Hindenburg.

The Hindenburg, constructed in 1931, was the last of more than 100 zeppelins built. These luxury airliners contained separate compartments for hydrogen gas and passengers within a fabric-covered rigid metal frame. The initial fame of the Hindenburg stemmed from the fact that it was the largest aircraft ever made. However, the Hindenburg became even more famous for the fiery explosion that marked the end of its final flight.

In 1937, the Hindenburg was destroyed by fire while landing in Lakehurst, New Jersey. To this day, experts continue to debate what created the spark that caused the fire, which killed 36 people. Hydrogen has long been blamed for the destruction of the Hindenburg. However, a combined knowledge of the details of the disaster and the nature of hydrogen have led to other theories about what happened.

It turns out that the bags of hydrogen gas that provided the lift for the Hindenburg may not have been the main contributor to the fire. The outer skin of the airship was coated with a highly flammable compound containing iron oxide and aluminum—sometimes used as components of rocket fuel! It has been hypothesized that this skin was ignited by a spark (perhaps from an electrical storm), and *that* caused the Hindenburg to be consumed in flames. The hydrogen gas may have fueled the fire, but it didn't necessarily start it.

We Have Liftoff

Ever wonder what thirsty astronauts drink when they're orbiting Earth in a space shuttle? The answer is . . . water. But it doesn't come from a faucet—it comes from the electrical system. The electrical systems on the space shuttle are powered by hydrogen fuel cells. The only by-product of these fuel cells is pure water, which the crew can drink.

Hydrogen has another very important use in the space program. Liquid hydrogen fuel is combined with liquid oxygen to propel the space shuttle into orbit. Of course, liquid hydrogen is difficult to come by. First, hydrogen gas (with the molecular formula H_2) is extremely rare on Earth. Second, liquid hydrogen doesn't even exist naturally on Earth! So, where does hydrogen come from? It has to be separated from other elements.

At standard temperature and pressure here on Earth, hydrogen and oxygen are gases. To get hydrogen into liquid form, it needs to be pressurized and cooled to a very chilly –252.87°C (–423.17°F). Oxygen needs to be cooled to –182.96°C (–297.328°F) in order to liquefy. When the shuttle is being propelled into space, the liquid is drawn from an external tank at a rate that is equivalent to emptying a family swimming pool every 10 seconds.

Even outside of the space program, hydrogen is often stored in a liquid form. Once liquefied, the hydrogen can be maintained as a liquid in pressurized and thermally insulated containers in much less space than is required to store hydrogen gas at normal temperature and pressure.

Next Stop, No Emissions

Between 1998 and 2000, three buses powered by hydrogen fuel cells drove more than 30,000 miles in and around Chicago as part of a trial program. Operating in near silence, these buses carried more than 100,000 passengers and emitted nothing more than water vapor.

As of 2010, there were between 200 and 300 hydrogen-fueled vehicles in the United States—primarily in California. Most of these vehicles are buses and automobiles powered by electric motors. Hydrogen gas or liquid is stored on board and converted into electricity for the motor using a fuel cell. Since hydrogen gas (with the molecular formula H_2) is rare on Earth, it has to be separated from other elements. Hydrogen gas can be produced at large central facilities or at small plants for local use.

A single atom of hydrogen consists of one proton (positive charge) and one electron (negative charge). Electricity is generated in a hydrogen fuel cell by stripping the electrons from the hydrogen, which creates a flow of negatively charged particles. When the electrons rejoin the hydrogen atoms and oxygen, they combine to form water.

Hydrogen gas supplies three times more energy than gasoline by weight, but only about one-fourth the energy content of gasoline by volume. Hydrogen is a gas at standard temperature and pressure on Earth, which means that tanks for hydrogen gas must be large. Even when the hydrogen gas is compressed to liquid form, storage can be an issue. Transit buses were chosen as an early field application for fuel cells because they are typically refueled at a central location, which means that fewer hydrogen facilities are needed. Cars, on the other hand, typically require an entire network of fueling stations. (Just think about how many gas stations are in your community alone!)

Notes:

SESSION 2

Properties of Hydrogen [Whole Class]

The class discusses the properties of hydrogen that students learned about from the vignettes they read for homework.

Ask students to share what they learned about hydrogen. As students share the properties of hydrogen that they learned about, have a volunteer record the information on chart paper. Post the list in the classroom along with the answers to the hydrogen questions from the previous session.

Possible Answers:

The Last Zeppelin: **Hydrogen gas is lighter than air; pure hydrogen gas is very rare on Earth; hydrogen is common on Earth as part of compounds; hydrogen gas is flammable.**

We Have Liftoff: **Hydrogen gas is rare on Earth; at standard temperature and pressure on Earth, hydrogen is a gas; hydrogen can be liquefied by pressurizing and cooling hydrogen gas to a very low temperature; liquid hydrogen takes up much less space than hydrogen gas.**

Next Stop, No Emissions: **Hydrogen gas is rare on Earth; a single atom of hydrogen consists of one electron and one proton; hydrogen gas supplies three times more energy than gasoline by weight; hydrogen gas supplies one-fourth the energy content of gasoline by volume; at standard temperature and pressure on Earth, hydrogen is a gas.**

SKILL RESOURCE

Is Hydrogen a Solution? contains challenging new vocabulary, which students will need multiple opportunities to practice using. As part of the class discussion of the vignettes, have students identify words they are unfamiliar with and list those words. These words can become part of a class *Word Wall*, a display of vocabulary words on large cards attached to a designated location, such as a bulletin board, wall, door, or white board in your classroom. Posting glossary words (and other words students identify) provides a visual reference for students to refer to, and they can more easily integrate these words into class discussions and their writing. For more information about creating and using a word wall in a science classroom, refer to **Word Walls Work**.

Notes:

NUENERGY INVESTMENT POSSIBILITIES, PART 1

[Whole Class]

Use **NuEnergy Investment Opportunities 1** to introduce the class to the first and second start-up companies seeking funding from NuEnergy. Have students write their impressions of each start-up and any questions they have in their science notebooks.

TIP...

You will introduce the two other start-ups in Session 4. Introducing two companies now and two later helps to limit the amount of information that students must absorb at one time.

NUENERGY INVESTMENT POSSIBILITIES, PART 1

Now that you've learned some of the basics about hydrogen, it's time to learn about two of the start-up companies that want money from NuEnergy. As you read, be sure to keep in mind the key questions from the **Hydrogen Technology Research Project Guidelines**:

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1. How will the technology being developed work? What's the science behind it?
2. What are the challenges to widespread adoption of this technology?
3. What environmental consequences, positive or negative, are likely to result from widespread adoption of this technology?

Does each company description include everything you need to know? If not, what else do you need to know, and how will you find the information you need?

Notes:

SESSION 3

THE CAR OF THE FUTURE?

[Teams]

Students explore hydrogen fuel cells by working with a model fuel cell car, which allows them to test a real fuel cell that runs on hydrogen and oxygen. Students also collect data for calculating fuel efficiency.

A vehicle's *fuel efficiency*, also called *fuel economy*, is the distance a vehicle can travel per unit of fuel used. In the United States, fuel efficiency is most often reported in miles per gallon, giving rise to the informal synonym "mileage."

Before having students begin to work with the model fuel cell car kits, help them think about fuel efficiency by asking the following questions:

- How do people who are concerned about saving energy compare one gasoline-powered car to another?

  Answer: They compare how many miles they can drive on one gallon of gas (that is, miles per gallon), which indicates the vehicle's fuel efficiency.

- How could you calculate the fuel efficiency of a model car? What data will you need to collect?

  Answer: The distance traveled and the amount of hydrogen used (initial volume minus final volume).

Give each Hydrogen Technology Research team **Model Fuel Cell Car Lab (RM 1.3)** and the materials needed for this lab.

Each team needs to read the kit instructions carefully, lay out the materials in the kit, and assemble the car as instructed. Once the car is assembled, have the students test their car by connecting the power source, letting the tanks fill with oxygen and hydrogen, and running the car as instructed in the manual.

Once the cars have had a few trials and any problems have been corrected, it's time for students to put the cars to the test by running them on a track and determining their fuel efficiency.

THE CAR OF THE FUTURE?

From the collections of Ford Motor Company.

Ford's plug-in hybrid fuel cell-concept car, the Airstream

So, now you know everything there is to know about hydrogen, right? (OK, maybe not *everything* . . .) But what does hydrogen power look like in action? Now is your chance to find out, by working with a model fuel cell car. Of course, most of the features of this car are very different from what you would find in an actual fuel cell car (for one thing, the driving distance between refuelings is pretty short), but it does include a real fuel cell that runs on hydrogen and oxygen.

With your Hydrogen Technology Research team, conduct the Model Fuel Cell Car Lab. Assemble and then operate the model car, collecting data about its **fuel efficiency**—the distance a car can travel on a given amount of fuel.

DID YOU KNOW?

The "car of the future" may not be that far away. In the 1990s, scientists and engineers at the Rocky Mountain Institute in Colorado developed the idea for the Hypercar®, a lightweight, aerodynamic, hybrid-electric automobile. The Hypercar would be 3–10 times more fuel-efficient than today's cars, without compromising performance, safety, or affordability. How is that possible?

The Rocky Mountain Institute says that rather than incrementally improving the design of today's automobiles, the key to success is to start designing from scratch and to use cutting-edge technologies. For example, using lightweight composite materials (such as the carbon fiber composite used to make some high-end race cars), the mass of a car can be reduced by 50–67 percent while preserving or even improving on impact safety.

In theory, the combination of reduced weight with other technologies could make it possible for Hypercars to get as many as 200 miles per gallon of fuel. Because an actual Hypercar has not been built, critics are skeptical of these extremely optimistic numbers. However, several design elements of the Hypercar have been incorporated into prototypes and "show cars" of major automobile manufacturers.

Notes:

TEACHER INFORMATION

For more information about running the fuel cell car, see **Model Fuel Cell Car Tips** on page T 64.

At the end of class, refer students to the **Lab Report Guidelines** on pages 90–91 in the Skill Appendix, and hand out the **Lab Report Assessment (RM 1.4)**. Remind students that you will assess their lab reports according to the criteria listed in the assessment.

HOMEWORK 1.2

Answer the Analysis questions from **Model Fuel Cell Car Lab** and then write up the lab report for the Model Fuel Cell Car Lab. Before you begin your report, look over the **Lab Report Guidelines** on pages 89–90 in the Skill Appendix and the **Lab Report Assessment** to see how your work will be assessed.

Notes:

SESSION 4

REALITY CHECK

[Whole Class]

Students reflect on their experience with the model fuel cell car, and use it as a starting point for identifying some of the challenges of using hydrogen and fuel cells.

Ask students to share their results from calculating the volume of hydrogen needed for the model fuel cell car to travel 300 miles. Engage students in a discussion of the following questions, recording their responses on chart paper.

TIP...

Your students don't need to know anything about real hydrogen cars to answer these questions. You may need to prompt them to compare the model fuel cell car to the gasoline-powered cars they're already familiar with: What would their model fuel cell car look like if scaled up to the size of cars on the road today? How big would the hydrogen tank be? How big would the fuel cell be? Where would the passengers sit?

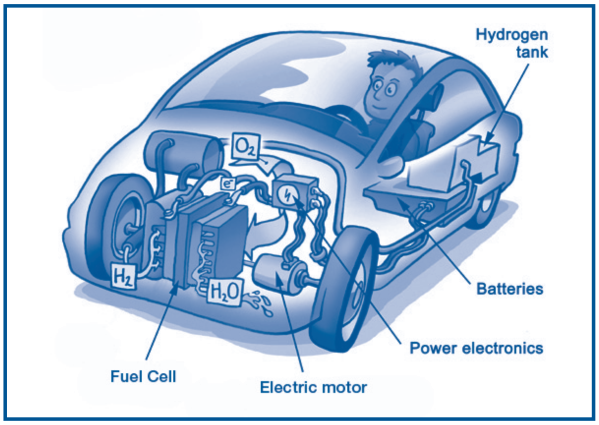
Ask students the following:

- In what ways is the car you built similar to a real hydrogen fuel cell vehicle? In what ways is it different?

  Possible Answers: One of the most important differences between real hydrogen fuel cell cars and the model car is the source of the hydrogen: The model car uses its own fuel cell, run in reverse as an electrolyzer, to produce the hydrogen, but a real vehicle would need a source of hydrogen. The model car has no space for passengers and no storage space. (This is not a trivial observation; one of the major challenges facing designers of hydrogen-powered cars is how to fit in all the features consumers expect from a car, such as trunk space, when hydrogen takes up so much room.)

REALITY CHECK

Building and running the model fuel cell car may have been fun, but how much did it tell you about the real challenges of building a fuel cell-powered vehicle? Consider the following and share your ideas with your classmates:



- In what ways is the car you built similar to a real hydrogen fuel cell vehicle? In what ways is it different?
- What are some of the challenges to developing hydrogen fuel cell-powered cars and to having these cars adopted on a widespread basis?
- Considering the challenges you have identified, are there other uses for hydrogen and fuel cells that might be more appropriate?

NUENERGY INVESTMENT POSSIBILITIES, PART 2

It's time to hear from two more companies who are hoping for an investment from NuEnergy. As you read, again, be sure to keep in mind the key questions on functionality, adoption, and environmental consequences.

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With your Hydrogen Technology Research team, make a list of questions you have about any of the four start-up companies or the **Hydrogen Technology Research Project Guidelines**.

HOMEWORK 1.3

All matter is made up of slightly more than 100 elements. Do you know what elements make up the matter that you are familiar with? Can you think of any types of matter that consist of only one element? For example, look around your house: Do you see anything that is made up of *just* carbon or *just* hydrogen? Make a list of any matter that consists of only one element.

Notes:

- What are some of the challenges to developing hydrogen fuel cell-powered cars and to having them adopted on a widespread basis?

  Possible Answers: Based on their calculations of the volume of hydrogen needed to travel 300 miles, students should recognize that on-board hydrogen storage is a challenge. In addition, students may recognize the need to develop a hydrogen fueling station infrastructure (for refueling) as well as challenges around the production and storage of hydrogen gas.

- Considering the challenges you have identified, are there other uses for hydrogen and fuel cells that might be more appropriate?

  Possible Answers: Students' answers will vary, but they may mention stationary applications, such as buildings, which would not face the same size limitations for hydrogen storage that cars do and which would not require the development of a fueling station infrastructure.

NUENERGY INVESTMENT POSSIBILITIES, PART 2

[Whole Class/Teams]

Use **NuEnergy Investment Opportunities 2** to introduce the class to the third and fourth start-up companies seeking funding from NuEnergy.

Have Hydrogen Technology Research teams meet briefly to discuss any questions or thoughts they have about the project. Bring the class together and discuss students' remaining questions.

TIP...

As students research hydrogen throughout the module, they may learn about another hydrogen technology that they believe has more potential than any that NuEnergy is considering. If a team wants to recommend another hydrogen-based technology, they still need to do the research required to support their decision and present their recommendation to NuEnergy.

EXTENSIONS

1.1

Continue to investigate the Hindenburg explosion. Conduct research to find out more about the role of hydrogen in the disaster.

1.2

With your teammates, come up with a few ideas for modifying your fuel cell car to increase its fuel efficiency. Decide on the option most likely to work, and test it on your car. How did the fuel efficiency of the modified car compare to that of the original model?

TEACHER INFORMATION:

MODEL FUEL CELL CAR TIPS

[For Session 3]

There are several points to keep in mind as students work with their fuel cells:

- The fuel tank of a real fuel cell car would be filled at a hydrogen fueling station. Because hydrogen fuel is not readily available, fuel cell car kits include a means of producing their own hydrogen.
- There are several kinds of fuel cell car kits. Some use solar cells to produce the electricity needed for hydrogen production by electrolysis, and some use batteries. A kit that uses solar cells is not recommended, because it may take too long to produce the hydrogen.
- Students should only use distilled water with the fuel cells. Any other water will include minerals or other substances that can contaminate the fuel cell and shorten its lifespan or cause it to stop working completely.
- For the car to work at maximum efficiency, the proton exchange membrane (part of the fuel cell) must be fully hydrated. Students should run the car three or four times before they start collecting data about efficiency or distance traveled.
- When you are putting away the kits for storage, place each fuel cell in an air-tight plastic bag.

The **Ford PAS Web site** offers troubleshooting tips for the recommended fuel cell car kit, which you can consult if needed.

ACTIVITY 2:

Putting Hydrogen to Work

Notes:

ACTIVITY OVERVIEW

Students learn about the two ways to make use of the energy in hydrogen: through combustion and in fuel cells. Students discover how atoms and compounds can be transformed through chemical reactions. They conduct scientific investigations in which they look at two different kinds of chemical reactions, exothermic and endothermic, and they learn how to write balanced equations that describe these reactions. Students learn more about the process by which fuel cells use the chemical reaction between hydrogen and oxygen to create electricity. They conduct a lab to find out more about reaction rates and catalysts, which are a crucial component of fuel cells. In their Hydrogen Technology Research teams, students look more closely at fuel cells by reading about how they work and looking at animations of fuel cells.

Sessions 5–9

Before You Teach

Session 5

- Decide whether to show the hydrogen and helium balloon videos or to conduct the balloon demonstrations yourself. If you decide to show the videos, preview the videos on the **Ford PAS Web site**.

If conducting the balloon demonstrations in class:

- Find a source for a hydrogen gas container or make the hydrogen yourself.
- Find a source for a helium canister. (A party supply store is a good possibility.)

Notes:

- For methane: you can use the gas in your lab's Bunsen burner, but ONLY if it uses natural gas (methane gas with additives that make the gas smell); buy a container of compressed natural gas (which may be purchased from recreational vehicle supply companies); or make it yourself by burning sodium hydroxide (NaOH) and sodium acetate ($C_2H_3NaO_2$).

Session 8

- Download and preview the Microsoft® PowerPoint® **Reaction Rates and Catalysts Slideshow** from the **Ford PAS Web site**.
- For the Catalysts Lab, if possible, obtain hydrogen peroxide with a concentration higher than the 3 percent typically found at drugstores. (For sources, go to the **Ford PAS Web site**.)

Materials Needed

Session 5

- Computer and projector OR one computer with access to the Internet for each team

If conducting any of the balloon demonstrations in class:

- Safety goggles (one pair for each student and the teacher)
- Four large latex rubber balloons (one for each balloon demonstration)
- String for each balloon
- Optional: Weight (for the string)
- Taper candle attached to meter stick from Session 1
- Matches or lighter

For the hydrogen-filled balloon demonstration:

- Ear plugs (one pair for each student and the teacher)
- Small canister of hydrogen gas

For the helium-filled balloon demonstration:

- Small canister of helium gas

For the air-filled balloon demonstration:

- Optional: A balloon pump

Notes:

For the methane-filled balloon demonstration:

- Small canister of methane gas

If not conducting the methane-filled balloon demonstration:

- Butane lighter

Session 6

- Copies of **RM 2.1 Chemical Reactions Lab 1** (one copy for each student in half the Hydrogen Technology Research teams)

For each Chemical Reactions Lab 1 team:

- Safety goggles (one pair for each student)
- Styrofoam coffee cup
- 250 mL beaker
- 25 mL citric acid solution ($H_3C_6H_5O_7$)
- Thermometer
- 15 g baking soda ($NaHCO_3$)
- Stirring rod
- Timer, stopwatch, or watch/clock with a second hand
- Sink with running water

- Copies of **RM 2.2 Chemical Reactions Lab 2** (one copy for each student in half the Hydrogen Technology Research teams)

For each Chemical Reactions Lab 2 team:

- Safety goggles (one pair for each student)
- Styrofoam coffee cup
- 250 mL beaker
- Optional (but highly recommended): Fume hood (one for the class)
- 100 mL 1.5–3 M hydrochloric acid (HCl)
- Thermometer
- 0.5 g granular zinc (Zn)
- Stirring rod
- Place to properly dispose of hydrochloric acid/zinc solution

Notes:

Session 7

- Copies of **RM 2.3 More Equations** (one for each team)

Session 8

- Computer and projector to show the **Reaction Rates and Catalysts Slideshow**
- Copies of **RM 2.4 Catalysts Lab** (one for each student)
- Safety goggles (one pair for each student)

For each Catalysts Lab team:

- 90 mL hydrogen peroxide (H_2O_2) ideally, with a concentration higher than 3 percent
- Three 50 mL beakers
- Liquid dish soap
- Stirring rod
- Small piece (approximately 1 cm^3) of potato
- Optional: Small piece of beef liver (instead of, or in addition to, the potato)
- Stopwatch, or watch/clock with a second hand
- Three wooden splints
- Matches
- Scoopula
- 0.5 g powdered manganese dioxide (MnO_2)

Session 9

- Optional: Computer with access to the Internet

Notes:

VOCABULARY

Activation energy

Aqueous

Bond dissociation energy

Catalyst

Chemical equation

Chemical reaction

Coefficient

Combination (synthesis) reactions

Combustion

Compounds

Decomposition reactions

Endothermic

Enthalpy

Enthalpy of reaction

Exothermic

Hydrocarbons

Ions

Law of conservation of matter

PEM fuel cell

Products

Reactants

Reaction rate

Student Guide, p. 25

ACTIVITY 2: Putting Hydrogen to Work

INTRODUCTION

To put hydrogen to work for us, we need to find a way to make use of its energy. In this activity you'll learn about two ways to use the energy in hydrogen: through combustion and in fuel cells. Since using the energy in hydrogen is really all about chemical reactions, you'll conduct investigations to explore different kinds of chemical reactions and learn how to describe these reactions like a scientist would. You'll also examine the important components of fuel cells and how they all work together to generate electricity.

Learning Goals

- Describe chemical reactions and what is taking place at the atomic level during those reactions.
- Write and interpret balanced chemical equations for different chemical reactions.
- Describe how different factors affect rates of chemical reaction, and the role that catalysts play in chemical reactions.
- Describe the components of a fuel cell and the process by which fuel cells produce electricity.

FOR YOUR GLOSSARY

Activation energy
Bond dissociation energy
Catalyst
Chemical equation
Chemical reaction
Combination (synthesis) reactions
Combustion
Compounds
Decomposition reactions
Endothermic
Enthalpy
Enthalpy of reaction
Exothermic
Hydrocarbons
Law of conservation of matter
PEM fuel cell
Products
Reactants
Reaction rate

Notes:

SESSION 5

IT'S ALL ABOUT BONDING

[Whole Class]

Revisit the demonstration of the chemistry of hydrogen from Session 1 and compare it to the chemistry of other substances in order to have students begin thinking about the energy of hydrogen.

Show students a demonstration of a flame being applied to hydrogen- and helium-filled balloons (or show video clips of each demonstration, available on the **Ford PAS Web site**).

Hydrogen-Filled Balloon Demonstration

1. Have students put on safety goggles and insert earplugs, and do so yourself.
2. Fill a balloon with hydrogen gas.
3. Connect a weighted string to the balloon or tie the balloon to a fixed location at the front of the classroom.
4. Light the candle that you have attached to the end of a meter stick, and touch the balloon with the candle flame. The balloon should explode into a cloud of flame.

Students should remain at least 3 meters from the balloon setup at all times.

Helium-Filled Balloon Demonstration

1. Have students put on safety goggles and do so yourself.
2. Fill a balloon with helium gas.
3. Connect a weighted string to the balloon or tie the balloon to a fixed location at the front of the classroom.
4. Light the candle that you have attached to the end of a meter stick, and touch the balloon with the candle flame. The balloon will burst with a familiar pop, due solely to the rubber bursting.

Although the helium balloon will not explode, be sure to practice standard safety procedures.

IT'S ALL ABOUT BONDING

You already know that hydrogen is an element, and in the form of hydrogen gas it is considered to be an energy carrier. But just how much energy is in hydrogen? What does it look like when the energy of hydrogen is released?

Watch the demonstration. What do you observe about the behavior of the different balloons? Why do you think a balloon containing hydrogen reacts differently from a balloon filled with helium?

The periodic table (see **Periodic Table of the Elements** on page 29) is a way of organizing all the elements—their names, symbols, and properties—and provides a quick guide to their chemical behavior and properties. You may recall that the periodic table arranges elements by their atomic number (number of protons), starting with the lowest. Each column (group) of the table corresponds to the "fullness" of the outer (or valence) electron shell of electrons—each of the noble gases (the elements in period VIIIa) has a full outer (valence) shell. Elements in the same columns (groups) tend to share similar chemical properties. The row (period) that an element is located in shows the number of energy levels in which the element's electrons reside. For some elements, the period indicates more similarities between elements than the group.

Locate hydrogen and helium on the periodic table. What are the relative locations of the two elements, and what do these locations indicate about the different properties of hydrogen and helium?

Notes:

Discuss the following questions with the class:

- What happened in each demonstration?

  Answer: The hydrogen-filled balloon explodes in a burst of light, while the helium-filled balloon does not explode, though the rubber pops like any balloon does.

TIP...

Although students may not recognize it, the explosion of the hydrogen-filled balloon indicates that the hydrogen inside is highly reactive. Students may suggest that the hydrogen-filled balloon has a lot of energy within it. The fact that the helium-filled balloon does not explode indicates that helium is not highly reactive or doesn't react to the amount of heat applied. Students may suggest that helium doesn't have a lot of energy.

- What do you think would have happened to the balloons if they had been popped with a pin instead of heated with a flame?

  Answer: Both balloons would have popped, but there would be no explosion for the hydrogen balloon.

- What did the flame do in each reaction?

  Answer: The flame added sufficient energy to cause a reaction in the hydrogen-filled balloon. However, while the flame popped the helium-filled balloon, it did not cause a reaction, so the flame did the same thing as popping the helium-filled balloon with a pin.

Have students look at **Periodic Table of the Elements** on page 29 in the Student Guide and locate hydrogen and helium on the table. Ask the following questions:

- What can the location of the two elements on the periodic table tell us about what happened during the demonstration?

  Answer: Helium (He) is part of a group of elements on the periodic table that have full valence electron shells, which means that they do not react with other elements. Hydrogen (H), on the other hand, is in a group of elements that have only one electron in their valence electron shells, which means that they are highly reactive.

Notes:

TIP... Students should be able to answer this question accurately. If they cannot, you may want to review the configuration of the periodic table and atomic structure.

TEACHER INFORMATION

Helium (He) belongs to group 2—the noble gases. (However, helium is different from the other elements in this group because it can have only two electrons in its valence shell—the others all have eight.) Because these elements have a completely full valence electron shell, they are stable and inert (unreactive). Therefore, when heat is applied, the balloon filled with helium simply pops like a normal party balloon that has been punctured.

Hydrogen (H) is located in group 1 of the periodic table (though hydrogen is a special case and actually has some properties of both groups 1 and 7). Since the elements in group 1 have only one electron in their outer shells, they are highly reactive. Hydrogen gas (made of two atoms of hydrogen in a covalent bond) is flammable at concentrations as low as 4 percent in air.

- What do you know about chemical reactions that helps to explain what happened in the hydrogen balloon demonstration?

  Possible Answer: Students may not know the correct answer to this question, but asking it will allow you to assess their knowledge of chemical reactions. Students may suggest that there is an attraction between hydrogen and other molecules in the air and that the reaction between hydrogen and these molecules is initiated by the heat of the flame.

TIP... Students *may not know* much about how chemical reactions occur at the molecular level and may not understand what is happening thermodynamically, but this is a chance to explore what they do or do not understand.

Students *may know* that energy must be added to the system in order to initiate the reaction between the reactants.

Students *should know* that elements react chemically to produce other substances that have different properties than the original substances, and that chemical reactions either consume or release energy.

Notes:

TEACHER INFORMATION

Thermodynamically, the reaction between hydrogen and oxygen is very favorable. There is a stronger bond between the hydrogen and oxygen atoms than between the two hydrogen atoms. However, energy must be added to the system in order to initiate a reaction between hydrogen and oxygen. When the balloon pops, the hydrogen is exposed to oxygen in the surrounding environment, and the heat of the candle provides the activation energy required for hydrogen and oxygen to combine to form water. This reaction is *exothermic* (it releases energy in the form of heat) and therefore produces an explosion. If the balloon were filled not just with hydrogen but with both hydrogen and oxygen, the size of the explosion would increase as the percentage of oxygen in the mixture increased. This does not mean that a balloon filled with hydrogen and oxygen will inevitably explode; the balloon will remain inert indefinitely at room temperature, until and unless activation energy (in the form of heat) is applied to it.

Notes:

CONSIDERING COMPOUNDS

[Whole Class]

Connect the previous discussion of elements to compounds by having students share examples from their homework of familiar substances that are made up of only one element.

Have the class look at the **Periodic Table of the Elements** again (page 29 in the Student Guide). Remind students that compounds are molecules made up of two or more elements. Ask students the following questions:

- What are some compounds that you are familiar with?
- What elements are they made from?

List and display students' responses.

> **Possible Answers: A simple compound that students are likely familiar with is water (H_2O), made of hydrogen and oxygen. Another is salt (sodium chloride, NaCl). If students have completed the module *We All Run on Energy*, they may also remember hydrocarbons, such as methane (CH_4) and butane (C_4H_{10}).**

Note any compounds that contain hydrogen, and remind students that hydrogen is a common component of compounds on Earth.

Air-Filled Balloon Demonstration

Fill a balloon with air and set up the balloon demonstration again as previously described on page T 72. Use the candle flame to ignite the balloon.

TIP...

If a balloon pump is available, use this to inflate the balloon instead—this way, the balloon will not contain the small amounts of carbon dioxide and water vapor that will be present if you blow up the balloon by mouth.

CONSIDERING COMPOUNDS

While all matter is made up of slightly more than 100 elements, in fact, *most* matter is really only made up of 19 elements. So how do we have so many different things on Earth—from the air we breathe to the multitudes of plants and animals? The answer is—compounds!

Fructose, a sugar found in fruits, such as this apple, and in some vegetables, is a *carbohydrate*, a hydrogen-containing compound.

As you know, hydrogen gas is rarely found on Earth. However, atoms of hydrogen are commonly found as part of **compounds**, the product of two or more elements combining chemically. These compounds have a wide range of properties, depending on what other elements are bonded with the hydrogen and how they are bonded together. Some of these compounds—those containing only hydrogen and carbon—are called **hydrocarbons** and are used as fuels (such as the gasoline we use to drive our cars). How do these compounds behave, and why do they act this way?

DID YOU KNOW?

Hydrogen is the simplest element in the universe, with just one proton in its nucleus and one electron orbiting it. Hydrogen is also the most abundant element in the universe. Stars, including our own sun, are made primarily of hydrogen.

Nearly all the hydrogen and much of the helium in the universe today are believed to have been created during the first several minutes after the Big Bang that created the universe. By best estimates, that could have been almost 14 billion years ago!

Most of the rest of the elements in the periodic table were made at some point during the life or death of a star. At the extremely hot temperatures in a star's core, hydrogen atoms can combine to form helium atoms, releasing a great deal of energy, in a process called fusion. At even higher temperatures, the star can fuse helium atoms together to form carbon. Progressively heavier elements up to iron can be formed inside stars. Naturally occurring elements heavier than iron are formed during supernovae—explosions of stars.

Notes:

Methane-Filled Balloon Demonstration

Using the same setup, show students the ignition of a methane-filled balloon.

> TIP... Note that the methane-filled balloon may be difficult to ignite because the flame must first rupture the balloon before the methane gas ignites. One recommended technique is to sweep the lit candle across the middle of the balloon.

> TIP... Alternatively, you can show students a butane lighter and explain that it is filled with butane, which is a hydrocarbon. Light the lighter, and explain that the lighter provides a spark that serves the same function as the candle flame did in the other demonstrations. Although the butane in the lighter does not explode, because the rate at which the butane is released is controlled, the reaction is the same—there is a flame and heat present, which causes the butane to combust.

Explain to students that methane is a *hydrocarbon*—a molecule made of atoms of hydrogen and carbon.

Ask students the following questions:

- How did the air-filled balloon and the methane-filled balloon (or the butane in the lighter) each react when the flame (or spark) was applied to them?

  Answers: The air-filled balloon popped but did not otherwise react to the flame. The methane-filled balloon exploded (and the butane combusted, as seen by the flame).

- How were these reactions similar to the hydrogen- and helium-filled balloon demonstrations?

  Answers: The air-filled balloon reacted similarly to the helium-filled balloon, in that they both popped, but the gases in the balloons did not react in any way. The methane- and hydrogen-filled balloons both exploded (and the butane in the lighter combusted, as seen by the flame).

HOMEWORK 2.1

Read **Chemical Reactions**. Using the information in the reading and your own observations, list the inputs and outputs that were involved in the hydrogen balloon demonstration you saw during class. Your list should include both matter and energy inputs and outputs.

Notes:

- Based on what you know about chemical bonding and the positions of the elements that make up these compounds in the periodic table, how would you describe the properties of these compounds?

  Answers: The exhaled air from your lungs in the first balloon is made primarily of a combination of oxygen, carbon dioxide, and nitrogen, all of which are stable gases that are nonreactive, because of the strength of the bonds between the molecules. Methane is a hydrocarbon (as is butane), consisting of atoms of carbon and hydrogen. As with hydrogen gas, the bonds in the molecule are weaker than the bond between hydrogen and oxygen. The products of the reaction between methane (or butane) and oxygen are water and carbon dioxide.

SKILL RESOURCE

If students have recently completed *We All Run on Energy* or similar material, they should be prepared for the content in the rest of this module. However, if you are unsure of students' understanding of the structure of atoms and molecules or want to give them a refresher, refer them to **Atoms and Molecules**.

Periodic Table of the Elements

GROUPS (Columns) · PERIODS (Rows)

	Iα	IIα	IIIb	IVb	Vb	VIb	VIIb	VIIIb	VIIIb	VIIIb	Ib	IIb	IIIα	IVα	Vα	VIα	VIIα	VIIIα
1	1 H Hydrogen																	2 He Helium
2	3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
3	11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
4	19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
5	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
6	55 Cs Cesium	56 Ba Barium	57 *La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
7	87 Fr Francium	88 Ra Radium	89 *Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadium	111 Rg Roentgenium	112 Uub Ununbium	113 Uut Ununtrium	114 Uuq Ununquadium	115 UUp Ununpentium	116 Uuh Ununhexium		118 Uuo Ununoctium

58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Nonmetals
- Other nonmetals
- Noble gases

Metalloids

Metals
- Metals
- Transitional metals
- Lanthanoids and Actinoids

Chemical Reactions

Chemical reactions are happening around us all the time. Whenever a match burns, a pipe rusts, or a plant undergoes photosynthesis, a chemical reaction is taking place. A **chemical reaction** is a change in which one or more substances are transformed into new substances by the breaking of chemical bonds, rearrangement of atoms, and formation of new bonds. All chemical reactions involve a chemical change (a change in substance) and a change in energy that results from the making and/or breaking of the chemical bonds.

Think about the hydrogen balloon demonstration. When the flame is applied to the hydrogen gas-filled balloon, a chemical reaction takes place in which the hydrogen and the oxygen in the air combine to form water. (To keep things simple, just consider the interaction of the hydrogen and oxygen, and ignore the other elements present in the air.)

The reaction in the hydrogen balloon demonstration is the combustion, or burning, of hydrogen. **Combustion** is the chemical reaction between a fuel (in this case, hydrogen) and oxygen that is accompanied by the production of heat and light in the form of either a glow or flames.

A candle burning is another kind of combustion reaction.

Now consider what happens to the hydrogen and oxygen molecules during the reaction. Before the flame is applied, the balloon contains molecules of hydrogen gas (H_2), and there is oxygen (O_2) in the air surrounding the balloon. When the flame is applied, the balloon pops, a reaction takes place, and water (H_2O) molecules (in gas form, as water vapor) are left behind. During this reaction, the bonds holding the hydrogen gas and oxygen molecules together have to be broken, and new bonds linking the hydrogen and oxygen together have to be created.

But why does the candle flame need to *touch* the balloon for the reaction to take place? Not just to pop the balloon. The spark ignites the hydrogen and oxygen, starting the chemical reaction. The addition of heat to the balloon causes the hydrogen gas and oxygen molecules close to the flame to move more rapidly, hitting each other with enough energy to break the bonds holding the molecules together. The individual hydrogen and oxygen atoms quickly reform into water molecules. This formation of water also releases additional energy, making other hydrogen gas and oxygen molecules hit each other harder and producing more water vapor. The amount of energy needed to get molecules of **reactants** (substances that exist before the reaction) to collide with enough energy to form **products** (substances that exist after the reaction) is called the **activation energy**.

Notes:

SESSION 6

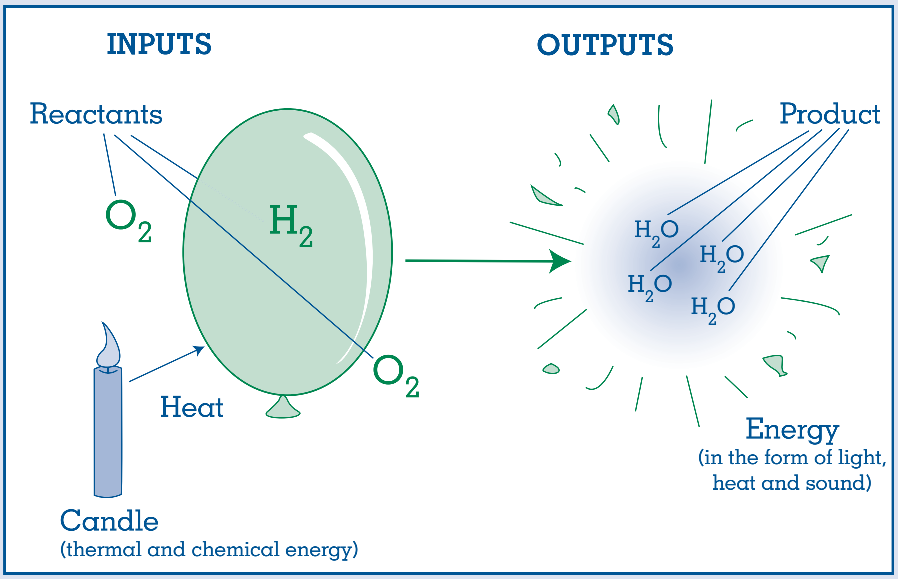
Creating a Chemical Reaction Diagram

[Whole Class]

Students look at chemical reactions in more detail in order to understand what happens at the molecular level. They begin by reviewing the reaction between hydrogen and oxygen.

Review the combustion of hydrogen from **Chemical Reactions**. Draw a diagram of the hydrogen balloon demonstration on the board, and ask students to help label the diagram with all the system inputs and outputs.

Sample Labeled Diagram



The diagram should include the reactants and products involved in the reaction (students will learn about balancing chemical equations later in the activity), and show where energy was moving into and out of the system.

> **Answer: System inputs include the hydrogen gas molecules (H_2) inside the balloon, the oxygen molecules (O_2) in the air outside the balloon, the thermal energy present in the candle flame, and the chemical energy in the candle that is the source of the candle flame. System outputs include the energy released during the chemical reaction (which took the form of an explosion) and water molecules (H_2O).**

Students should be aware that bringing a combustible substance such as hydrogen into the presence of oxygen will not necessarily result in combustion. Every combustible substance has an "ignition temperature," to which it must be raised before it will chemically combine with oxygen. The diagram should indicate that thermal energy (from a flame) was needed to trigger the combustion reaction they

Notes:

observed. The diagram should be representative of the following generalized reaction:

$$H_2 + O_2 + \text{Thermal Energy} \rightarrow H_2O + \text{Lots of Energy}$$

Once the diagram is complete, ask a student to explain what happened during the chemical reaction.

TIP...

Students should understand that during the chemical reaction, the bonds were broken between the atoms in the hydrogen gas and oxygen molecules, and that these atoms then formed new bonds to create new molecules (water molecules).

LOOKING AT REACTIONS

[Teams/Whole Class]

Working in teams, students carry out and observe a chemical reaction.

Give half the Hydrogen Technology Research teams **Chemical Reactions Lab 1 (RM 2.1)** and the materials they need for that lab. Give the remaining teams **Chemical Reactions Lab 2 (RM 2.2)** and the materials they need for that lab. Have teams carry out their lab.

Note that the reaction in Chemical Reactions Lab 2 produces hydrogen gas—students should conduct this lab under a fume hood if one is available. Make sure that there are no open flames in the room during the lab. Be sure to properly dispose of the hydrochloric acid/zinc mixtures after the lab. (The baking soda and citric acid from Chemical Reactions Lab 1 are nontoxic and can be poured down a drain without further dilution.)

TIP...

After completing their lab, students read about exothermic and endothermic reactions. In Chemical Reactions Lab 1, students observe an endothermic reaction by mixing baking soda and citric acid and measuring the temperature of the citric acid solution before and after the baking soda is added. In Chemical Reactions Lab 2, students observe an exothermic reaction by mixing together hydrochloric acid and zinc.

LOOKING AT REACTIONS

Chemical reactions are everywhere in our lives—when we move a muscle, turn on the stove, or drive somewhere in a vehicle, chemical reactions are taking place. We rely on them to turn the food that we eat into energy that we use in our body, and to turn stored energy, such as that in a candle, into usable energy, such as light and heat. Chemical reactions are important because, among other things, we use them to release energy from a substance so it can be used for various purposes—such as burning gasoline to drive the pistons in the motor of a car. You'll need to know about chemical reactions in order to understand how fuel cells work.

There are several different kinds of chemical reactions (including combustion, which you just learned about). In all of them, a change in energy is taking place as the bonds between atoms are broken and reformed. This change in energy is usually indicated by a change in temperature.

To learn more about chemical reactions and changes in energy and temperature, you'll conduct a Chemical Reactions Lab. Before you begin, make a hypothesis about what you think will happen. As you conduct the lab, be sure to take notes in your science notebook so that you can complete your lab report afterward.

Once you have completed the lab, read **Endothermic and Exothermic Reactions** and answer the **Questions for Reflection**.

HOMEWORK 2.2

Write up your lab report for the Chemical Reactions Lab.

Use what you've learned about chemical reactions to create a diagram that visually represents how the atoms in the molecules of hydrogen gas and oxygen gas break apart and reform as water molecules during a chemical reaction.

Notes:

TEACHER INFORMATION

For more information about the Chemical Reactions Labs, see **Chemical Reactions Labs Explained** on page T 116.

SKILL RESOURCE

The optional session **Reading Scientific Texts** can be helpful for both struggling and proficient readers. Consider taking an extra session and using the reading **Endothermic and Exothermic Reactions** to help students focus on specific ways to read complex text, share ideas and questions with one another, and summarize their thinking. Once students are introduced to these strategies, they can practice and apply them throughout the module.

When teams complete their labs, have them read **Endothermic and Exothermic Reactions** and determine whether the reaction they observed was endothermic or exothermic.

Bring the class together to discuss what teams observed during their Chemical Reaction Lab and what they learned about chemical reactions, using the **Questions for Reflection** on page 33 in the Student Guide (page T 91).

1. Was the reaction that you investigated exothermic or endothermic? How do you know?

   Answers: The chemical reaction between the citric acid and baking soda was endothermic, as shown by the temperature drop of the solution. The chemical reaction between the hydrochloric acid and zinc was exothermic, as shown by the temperature rise of the solution.

2. Was the chemical reaction between hydrogen and oxygen that you observed during the balloon demonstration endothermic or exothermic?

   Answer: The reaction between the hydrogen and oxygen was exothermic, as was apparent in the heat and light of the explosion that took place.

   More Information: The enthalpy of hydrogen combustion is –286 kJ/mol.

Endothermic and Exothermic Reactions

A complete outer shell of electrons is a very stable condition for an atom. This is why atoms with fewer than eight electrons in their valence shell bond with other atoms to form compounds. The stability of an atom or a compound is really a measure of energy. When atoms bond to form compounds, the total energy of the new molecule is typically lower than the total energy of the separate atoms. This means that energy is released when chemical bonds are formed. And since it is favorable for atoms to stay in the more stable condition of being bonded to other atoms, energy must be added to a system in order to break the bonds that hold the atoms in a molecule together. The amount of energy required to break a chemical bond is called the **bond dissociation energy**. The stronger the bond is between the atoms in a molecule, the more stable the molecule is and the more energy it takes to break the bond:

Stronger Bond = Higher Bond Dissociation Energy

Molecules have both *kinetic energy* (energy of motion) and *potential energy* (stored energy). The potential energy is stored both in the chemical bonds between the atoms in a molecule and in bonds with other molecules. The sum of the kinetic and potential energies of a molecule is called **enthalpy**. During a chemical reaction, bonds are broken in the reactants and new bonds are formed in the products, which results in an overall change in the energy of the system. This change in energy is called the **enthalpy of reaction**, and it is equal to the difference between the total energy needed to break bonds in the reactants and the total energy released by the formation of new bonds in the products.

Enthalpy of Reaction =

Energy Used to Break Bonds – Energy Released by Formation of New Bonds

If more energy is released when new bonds form in the products than is used to break bonds in the reactants, the enthalpy of reaction < 0, and the reaction is said to be **exothermic**. If it takes more energy to break bonds in the reactants than is released by the formation of new bonds in the products, the enthalpy of reaction > 0, and the reaction is **endothermic**. The energy exchange in reactions is often in the form of heat, so the products of exothermic reactions tend to be warm or hot to the touch, whereas the products of endothermic reactions may feel cold.

Notes:

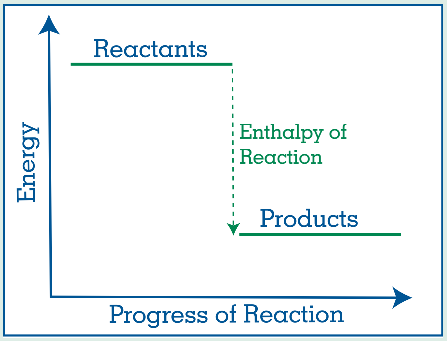
3. Why are exothermic reactions useful?

   Possible Answers: Exothermic reactions release energy. If the reactions take place in controlled settings (such as the combustion of gasoline in the engine of a car), the energy that is released can be harnessed to do useful work, such as move a car or heat a room.

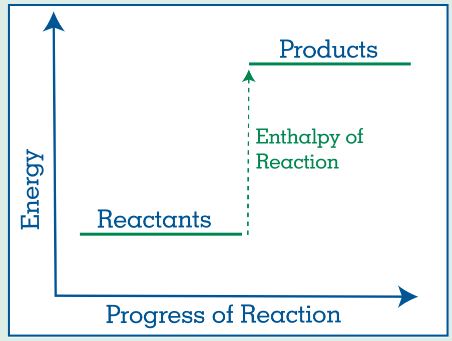
4. What situations can you think of in which we make use of the energy released in exothermic reactions?

   Possible Answers: Common exothermic reactions in which we make use of the energy released include burning wood, lighting a candle, burning gasoline in a vehicle, and burning coal in a coal-fired power plant to make steam that turns generators to make electricity.

Exothermic Reaction



Endothermic Reaction



In an exothermic reaction (left), the products are at a lower energy than the reactants because energy is released in the reaction. In an endothermic reaction (right), the products are at a higher energy level than the reactants because energy is absorbed in the reaction.

Questions for Reflection

1. Was the reaction that you investigated exothermic or endothermic? How do you know?
2. Was the chemical reaction between hydrogen and oxygen that you observed during the balloon demonstration endothermic or exothermic?
3. Why are exothermic reactions useful?
4. What situations can you think of in which we make use of the energy released in exothermic reactions?

Notes:

SESSION 7

CREATING EQUATIONS

[Whole Class/Teams]

Students learn about balancing chemical equations in order to better understand what happens at the molecular level during a chemical reaction.

Have a few students share the diagrams they created on their own. Complete diagrams will show two hydrogen gas molecules and one oxygen gas molecule breaking their bonds and reforming into two water molecules. If students have included only one hydrogen atom, one oxygen atom, and one water molecule in their diagram, encourage them to think more deeply about the reaction by asking them where the second oxygen atom from the oxygen gas molecule has gone. Remind students of the law of conservation of matter, which states that matter cannot be created or destroyed.

Show students how to create a balanced equation for this chemical reaction, having them follow along in **Balancing Act: Chemical Equations** on pages 36–38 in the Student Guide (pages T 97–T 99).

Step 1: Begin by asking students the products and reactants of the reaction, and writing the unbalanced equation on the board:

$$H_2\,(g) + O_2\,(g) \rightarrow H_2O\,(l)$$

Step 2: Ask students to list the number of each kind of atom on both sides of the equation:

Reactants:	Products:
2 H	2 H
2 O	1 O

Step 3: Ask students if the equation is balanced.

Answer: It is not, because there are two oxygen atoms on the reactants side of the equation but only one on the products side.

Step 4: Ask students how changing the coefficient of one or more of the molecules would make the equation balanced.

Answer: Adding a coefficient of 2 to the hydrogen and water molecules will balance the equation.

Once students have come up with the correct answer, change the equation on the board so that it is balanced:

$$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(l)$$

CREATING EQUATIONS

How would you describe the reactions you witnessed in the Chemical Reactions Lab to someone who wasn't there? In words? With a picture? A graph?

Chemists use **chemical equations** to describe chemical reactions. Although these equations may not seem like much, they contain a great deal of information about the chemical reactions they describe. So, why should this matter to you? Chemical equations are part of the language of science, and it's important for you to understand how to read and use that language as you continue to learn about the science behind fuel cells. As you conduct research on such issues as hydrogen production and storage, it is very likely that you will run into chemical equations that you'll need to be able to interpret.

A chemical equation (1) identifies the reactants and the products, (2) describes the states of the matter involved in the reaction (solid, liquid, gas, or aqueous solution), and (3) reflects the **law of conservation of matter** (which states that matter can't be created or destroyed) by including the same numbers and types of atoms on both sides of the equation.

Using the information in **Balancing Act: Chemical Equations** on page 36, you will create an equation for the reaction between hydrogen and oxygen that you witnessed during the hydrogen balloon demonstration. You'll then work with your team to create balanced equations for the reactions in the Chemical Reactions Lab.

Notes:

Step 5: To check the equation, again have students list the number of each kind of atom on both sides of the equation:

Reactants:	Products:
4 H	4 H
2 O	2 O

Divide the class into teams. Give each student **More Equations (RM 2.4)**, and have them work in teams to balance the equations for the Chemical Reactions Labs. When teams have finished writing their equations, meet as a class and have one or two teams share their equation for each reaction.

Answers:

The balanced equation for the citric acid and baking soda reaction is:

$$H_3C_6H_5O_7\ (aq) + 3NaHCO_3\ (s) \rightarrow 3CO_2\ (g) + 3H_2O\ (l) + Na_3C_6H_5O_7\ (aq)$$

The balanced equation for the hydrochloric acid and zinc reaction is:

$$2HCl\ (aq) + Zn\ (s) \rightarrow ZnCl_2\ (aq) + H_2\ (g)$$

TIP...

For more resources on balancing chemical equations, go to the **Ford PAS Web site**.

TIP...

Students will need calculators for homework. You can also give students the option of graphing the data by hand, or using Microsoft® Excel's chart tool (reaction rate on the *y*-axis, temperature on the *x*-axis).

WHEN BALANCING EQUATIONS, REMEMBER . . .

1. In order to abide by the law of conservation of matter, the same kind and number of atoms must appear on both sides of the arrow in a chemical equation. This means that atoms are not lost or gained, nor do they change their identity, because of a chemical reaction.
2. Changing subscripts changes the identity of a compound. A chemical equation therefore cannot be balanced by altering the number or placement of subscripts.
3. Changing a coefficient in front of a chemical formula changes the number of molecules participating in a reaction. This means that the coefficient multiplies everything in the formula by that number.
4. When balancing an equation, start by looking at the formula of the most complex compound (the one that contains the greatest number of atoms). Try changing the coefficients of the simpler molecules and compounds to match the number of atoms with those in the more complex formula.

HOMEWORK 2.3

Read **Reaction Rates and Temperature**, complete the **On Your Own**, and answer the **Questions for Reflection** on page 40.

Notes:

SKILL RESOURCE

For homework, students read **Reaction Rates and Temperature**. You may want to read aloud the beginning of the reading before students read it on their own. Another possibility is that at the beginning of the following session, you can ask students if there were any parts of the reading they would like to read again, and read those parts aloud. Regularly reading short excerpts aloud from science books, articles, and Web sites is one way to help students become accustomed to the structure and cadence of scientific texts. As you read, explain the meanings of words that you think may be unfamiliar. You don't have to spend a lot of time discussing these readings. You might just point out what you found interesting, such as why the reaction rate of a chemical reaction is much like the rate of speed of a car traveling to a destination. The purpose is to help students become familiar with the ways in which writers communicate about science. For more ideas about reading aloud to students, refer to **Model Thinking with Think-Alouds**.

Balancing Act: Chemical Equations

Parts of a Chemical Equation

Chemical equations all have the same general form:

Reactants → Products

The arrow, which is read as "yields," signifies the time elapsed between the beginning and the end of a chemical reaction.

Two common types of reactions described by chemical equations are combination (synthesis) reactions and decomposition reactions:

- **Combination (synthesis) reactions** are those in which simpler reactants combine to form more complex products (such as the combination of hydrogen and oxygen gases to form water). Combination reactions have this general form:

  $$X + Y \rightarrow XY$$

- **Decomposition reactions** are those in which more complex molecules are fragmented into simpler products (such as the formation of hydrogen through a decomposition of water back into hydrogen and oxygen). Decomposition reactions have this general form:

  $$XY \rightarrow X + Y$$

In addition to chemical formulas, chemical equations include other symbols that provide information about the reaction. The following symbols tell you the physical state of the reactants and products:

- (*s*) solid
- (*l*) liquid
- (*g*) gas
- (*aq*) aqueous solution (meaning that substances are dissolved in water).

An upward pointing arrow (↑) indicates an escaping gas, while a downward pointing arrow (↓) indicates that a solid precipitates or condenses out of a solution. Words or symbols can appear above or below the arrow to indicate that heat, electricity, or a catalyst is added to the reactants. A **catalyst** is a substance that speeds up a reaction by creating a different pathway—one with a lower activation energy—for the reaction to occur.

Writing and Balancing a Chemical Equation

So, how do you put the components together to write a chemical equation? Take the example of the hydrogen and oxygen synthesis reaction that you have been learning about. In words, the reactants and products for this reaction are:

hydrogen + oxygen → water

Substituting in the proper chemical symbols and formulas, this equation becomes:

$$H_2\ (g) + O_2\ (g) \rightarrow H_2O\ (l)$$

Simple, right? But take another look. This can't be correct, because you can't put in two molecules of oxygen and yield just one on the other side! That would violate the law of the conservation of matter.

How can this equation be made correct? It needs to be balanced. Balancing a chemical equation means establishing the correct relationship between the quantities of reactants and products. An equation is not properly balanced until the same number of each kind of atom appears on both sides of the arrow. Begin the balancing process by listing the number of each kind of atom on both sides of the unbalanced equation:

$$H_2\ (g) + O_2\ (g) \rightarrow H_2O\ (l)$$

Reactants:	Products:
2 H	2 H
2 O	1 O

As you attempt to balance this equation, your first instinct might be to simply change some of the subscripts on the molecules. However, subscripts tell you the number of atoms of a particular element that are in a compound, so changing subscripts would actually change the identity of the compounds. Instead, you want to change the amounts of substances (the number of molecules) participating in the reaction. To do this, you can place a number called a *coefficient* in front of the substance's formula. Keep it simple (that is, stick with whole numbers). For the hydrogen and oxygen reaction, try placing a coefficient of 2 in front of the hydrogen gas and water molecules:

$$2H_2\ (g) + O_2\ (g) \rightarrow 2H_2O\ (l)$$

To check that you have correctly balanced the equation, make a new list to ensure that the number of each type of atom is the same on both sides of the equation:

Reactants:	Products:
4 H	4 H
2 O	2 O

Congratulations! You have successfully created a balanced equation.

Note that this equation does not contain a component that you know is an important part of the reaction—energy. All reactions release or use energy (this reaction in particular releases energy, and is thus exothermic). However, this information (the amount of energy used or released during a chemical equation) is shown separately from balanced chemical equations, and that's why it's not used here.

Reaction Rates and Temperature

As you learned during the hydrogen balloon demonstration, for a chemical reaction to occur, molecules need a certain amount of energy, known as *activation energy*, to break or change the chemical bonds holding them together. The amount of time it takes for a reaction to occur depends on how quickly the activation energy is overcome. Some reactions, like burning hydrogen or wood, occur very quickly. Other reactions, like the rusting of iron, take much longer. The **reaction rate** of chemical reactions— the speed at which a reaction takes place—is affected by several factors, such as the concentration of the reactants or the temperature at which the reaction occurs.

There are many reasons that we should be concerned with reaction rates and the factors that affect them. For example, think about the process of cooking a meal. During cooking, different chemical reactions are taking place as the food is being cooked. Turning up the heat speeds up the chemical reactions that take place, cooking the food faster. Reaction rates are important for fuel cells, too—in order for fuel cells to work, we have to be able to control the reaction between hydrogen and oxygen. (You'll soon learn more about how this is done.)

So, how exactly do different factors affect chemical reactions? Let's take the example of temperature. Consider the reaction that takes place when a piece of solid magnesium (Mg) is dropped into a beaker of hydrochloric acid (HCl) solution:

WHAT'S A MOLE?

A *mole* is a standard unit in chemistry for measuring the amount of a substance. One mole (abbreviated as mol) is equal to 6.022×10^{23} particles of whatever is being counted. So, a mole of magnesium contains 6.022×10^{23} molecules of magnesium. This number, 6.022×10^{23}, is known as *Avogadro's constant*, named after the same man who discovered Avogadro's law, which you will learn about later.

While counting in moles is not very useful for most objects (6.022×10^{23} jellybeans is a lot of jellybeans!), it is very useful for extremely small substances, such as atoms and molecules. It is also used as a measurement in chemistry to talk about solutions—a 1 molar (1 M) solution is a solution with one mole of a substance per liter of solution. So, a 1 M solution of hydrochloric acid (HCl) is a solution with 6.022×10^{23} of HCl molecules in every liter.

$$\mathbf{Mg}\ (s) + \mathbf{2HCl}\ (aq) \rightarrow \mathbf{MgCl_2}\ (aq) + \mathbf{H_2}\ (g)$$

The following table shows data collected during an experiment to test the effect of temperature on the rate of this reaction. The times recorded in the table reflect how long it took (in seconds, or s) for 0.005 grams (g) of Mg to completely disappear in a 1 M HCl solution at each temperature.

Effect of Temperature on Rate of Reaction

Temperature (°C)	5.0	15.4	23.5	32.8	43.5
Time (s)	168	107	66	45	32
Reaction Rate (g/s)					

The reaction rate of a chemical reaction is much like the rate of speed of a car traveling to a particular destination. When determining a car's average rate of speed, you divide the distance the car traveled by the amount of time it took the car to reach its destination. For the chemical reaction in this experiment, the "destination" is the point at which the Mg has been completely consumed, so the reaction rate would be the mass of the magnesium divided by the time it took for the piece of metal to disappear:

$$\text{Rate of Reaction (g/s)} = \frac{\text{Mass of Mg (grams)}}{\text{Reaction Time (seconds)}}$$

On Your Own

1. Copy the data table onto a sheet of paper or into an electronic spreadsheet.
2. Calculate the reaction rate for each temperature, and fill in the empty cells in the table.

Questions for Reflection

1. How was the reaction rate affected by temperature? Based on your knowledge of energy and chemical bonds, explain why you think temperature had the observed effect on reaction rate.
2. How do you think the concentration of reactants affects the reaction rate? (Hint: Reactants need to collide with one another for a reaction to take place.)

Notes:

SESSION 8

Discuss Reaction Rates [Whole Class]

Students continue to learn about chemical reactions by looking at the rates of chemical reactions and thinking about factors that influence reaction rates.

To begin this session, project the first slide from the **Reaction Rates and Catalysts Slideshow**. This slide shows a graph of the reaction rate data that students looked at and calculated for homework (the reaction rates of magnesium and hydrochloric acid at different temperatures). Have students share the hypotheses about reaction rates that they developed, and discuss as a class the effect that temperature has on different chemical reactions.

> **Answer: Based on the homework, students should conclude that increasing temperature often speeds up a chemical reaction.**

TEACHER INFORMATION

It takes energy to break chemical bonds. Increasing the temperature increases the energy in a system, giving molecules more kinetic energy, which increases the frequency of collisions and speeds up the reaction rate. Reaction rates for many reactions double or triple for every temperature increase of 10 degrees Celsius, although some reaction rates are independent of temperature, or decrease with increasing temperature. There is also a cutoff point at which increasing the temperature will no longer increase the reaction rate. Once the temperature reaches a certain point, some of the substances involved in the reaction may be altered (for example, denaturing of proteins) and the chemical reaction will slow or stop.

Ask students to share the ideas they generated for homework about what other factors besides temperature might have an effect on reaction rates. As a class, make a list of these factors.

> **Possible Answers: Students might mention the following:**
>
> - **Concentration of reactants: As is the case with temperature, a higher concentration of reactants will result in higher rate of effective molecular collisions.**

Notes:

- **The medium in which the reaction occurs: The rate of reaction may be different if the reaction takes place in a liquid, solid, gaseous, or aqueous medium.**
- **Stirring: Mechanical mixing (stirring) can increase the rate of reaction by increasing the movement of the reactants.**
- **Catalysts: The presence of a catalyst increases the reaction rate by lowering the activation energy needed to initiate the reaction.**

CRUCIAL CATALYSTS

[Whole Class/Teams]

As part of learning about reaction rates, students learn about catalysts, which are an essential component of fuel cells.

Project the second slide from the **Reaction Rates and Catalysts Slideshow**: a labeled illustration of a PEM fuel cell. Point out the catalyst that makes up one component of the fuel cell. Ask if students have any ideas about what a catalyst does. If no students have learned about the role of the catalyst in fuel cells, explain that just as temperature can have an effect on chemical reaction rates, so too can certain materials, called *catalysts*.

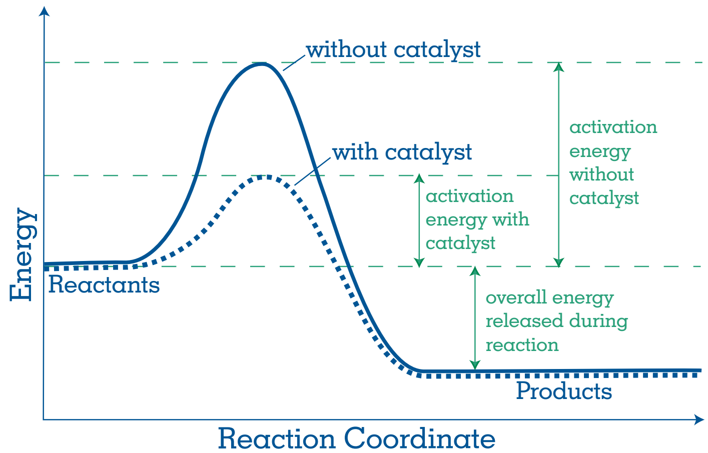
TIP...

It is important that students understand that catalysts cannot make energetically unfavorable reactions possible. A catalyst creates an alternate path for the reaction, and this path has a lower activation energy. You might use the analogy of getting to a destination on the other side of a mountain: Instead of climbing straight over the mountain, which would require a lot of energy, you could dig a tunnel through the mountain. This new, alternate path will get you to the same destination using less energy, but you haven't made the mountain any lower, or eliminated that path as a choice for reaching the destination. Students will learn more about how the platinum catalyst in a PEM fuel cell works during Session 9.

Have students work in their Hydrogen Technology Research teams to conduct the Catalysts Lab. Distribute **Catalysts Lab (RM 2.5)** and the materials needed for this lab.

CRUCIAL CATALYSTS

Temperature isn't the only thing that affects reaction rates. Other factors, such as the amount of surface area exposed during a reaction, can also play a role. Another factor that can affect reaction rates is the presence of catalysts, which increase the rate of chemical reactions, without being consumed themselves during the reaction. A catalyst creates an alternate path for a reaction, and this path has a lower activation energy.



Catalysts provide an important way to control reactions. For example, you may have heard of catalytic converters in cars. Catalytic converters reduce the amount of pollutants, such as carbon monoxide, from a car's exhaust system by using catalysts to facilitate chemical reactions through which the pollutants are turned into less harmful substances.

Catalysts also play a crucial role in the fuel cells that are most often used in vehicles. Think back to the hydrogen balloon demonstration. In that demonstration, the candle flame provided the initial activation energy, and each reaction provided energy that fueled the next reaction, until all the hydrogen was gone. But even though the desired reaction in fuel cells is the same as the one in the demonstration (combining the atoms from hydrogen and oxygen to make water), heat can't be added to the reactants—that would just make the hydrogen explode! In fuel cells, platinum acts as a catalyst instead, enabling the reaction to take place (you'll learn exactly how later).

Notes:

When teams have completed the lab, have one or two teams share their results with the class. Discuss the results of the lab, using the questions on page 42 in the Student Guide (page T 107).

Answers:

1. **The role of the catalyst was to speed up the rate of the chemical reaction (already taking place at a slow rate) in which hydrogen peroxide breaks down into water and oxygen. The catalyst was not consumed in either reaction.**

2. **The splint will glow more strongly or possibly reignite in the presence of oxygen.**

3. **The balanced equation for the chemical reaction is $2H_2O_2\ (aq) \rightarrow 2H_2O\ (l) + O_2\ (g)$.**

TEACHER INFORMATION

For more information about how the Catalysts Lab works, see **Catalysts Labs Explained** on page T 117.

To learn more about catalysts, conduct a Catalyst Lab with your Hydrogen Technology Research team. When you have completed the lab, consider the following questions:

1. What was the role of the catalyst in each trial of the lab? Was the catalyst consumed by the reaction?
2. What does the glowing splint test tell you about the chemical reaction that took place in each beaker?
3. What is the balanced chemical equation for each reaction you observed during the lab?

HOMEWORK 2.4

Write your lab report for the Catalyst Lab.

Notes:

SESSION 9

SEEING HOW FUEL CELLS WORK

[Teams]

Have students meet in their Hydrogen Technology Research teams. Have teams assign each member one or more sections of **All About Fuel Cells** to read and then synthesize for their team members. To facilitate this process, students can go to the **Ford PAS Web site** for resources that show how fuel cells work.

SKILL RESOURCE

Introduce or review **Questioning the Text**, a literacy strategy that categorizes comprehension questions into four types. This strategy gives students the *opportunity* to learn that different types of questions require different reading behaviors and thought processes. For example, in the reading **All About Fuel Cells**, Questions 1 and 2 are *Right there* questions, as the answers can be found directly in the text. Question 3 is an *On my own* question; each reader might answer it differently, depending on the his or her background knowledge or experience. As students do more research on hydrogen, encourage them to identify the types of questions they are trying to answer; this will help them ascertain how to go about answering each question.

SEEING HOW FUEL CELLS WORK

You've used a fuel cell to power a model car, and you know a lot about the *chemistry* of fuel cells—including the reaction that takes place between hydrogen and oxygen and how a catalyst works. Now, you'll get a chance to put together everything you've learned so far to understand how a fuel cell actually works.

To learn more about fuel cells, assign each member of your Hydrogen Technology Research team one or more of the sections in **All About Fuel Cells**. Each section describes one part of the fuel cell and how it works. Read the introductory paragraph and the section(s) that you have been assigned. To get a more thorough understanding, go to the **Ford PAS Web site** to look at animations of fuel cells, and take good notes on what you learn.

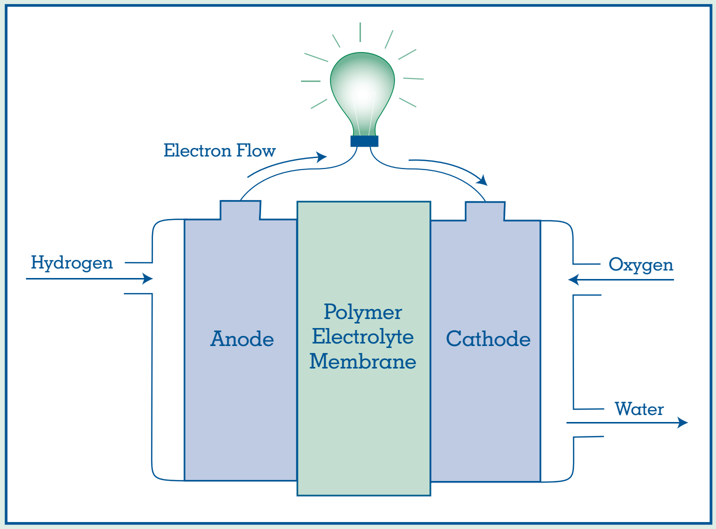
Once each team member has become the team's expert on one part of the fuel cell, meet to share what you've learned and discuss how the parts of the fuel cell work together.

HOMEWORK 2.5

Read **Redox Reactions and Electrochemistry**.

All About Fuel Cells

The fuel cell that you're going to focus on is called a **PEM fuel cell**—PEM stands for both Polymer Electrolyte Membrane and Proton Exchange Membrane. Although there are several different kinds of fuel cells available, PEM fuel cells are the ones most commonly used in vehicles, in part because they have a relatively low operating temperature and a fast start-up time.



Fuel cells are a lot like batteries: A chemical reaction inside the device produces an electric current that flows through an external circuit. But unlike batteries, fuel cells never run down, because they can be continuously resupplied with oxygen and hydrogen. One fuel cell by itself doesn't produce much electricity, so in a car many fuel cells are assembled together in what is called a *fuel cell stack*.

The following are the PEM fuel cell's most important components.

Catalyst

Catalysts, as you know, facilitate chemical reactions. In a PEM fuel cell, the catalyst is usually powdered platinum. The powdered platinum may be distributed throughout anodes and cathodes made of porous carbon, or it may be deposited in a thin layer on the inner surfaces of the anode and cathode. Reactions take place on the surface of the catalyst, so the catalyst is rough and porous to expose as much surface area as possible to the hydrogen and oxygen.

Because platinum is so expensive, many fuel cell researchers are trying to design fuel cells that use less of it or to find a less expensive material that works just as well.

Anode

Hydrogen gas is pumped into the fuel cell and channeled to the fuel cell's anode. Upon contact with the catalyst at the anode, the hydrogen gas splits into two positively charged hydrogen ions (H^+) and two negatively charged electrons (e^-). The electrons are attracted to the oxygen at the cathode, and flow from the anode through an external circuit to the cathode. This flow of electrons through the external circuit is called *electrical current*, and it can be used to do work, such as turn a car motor.

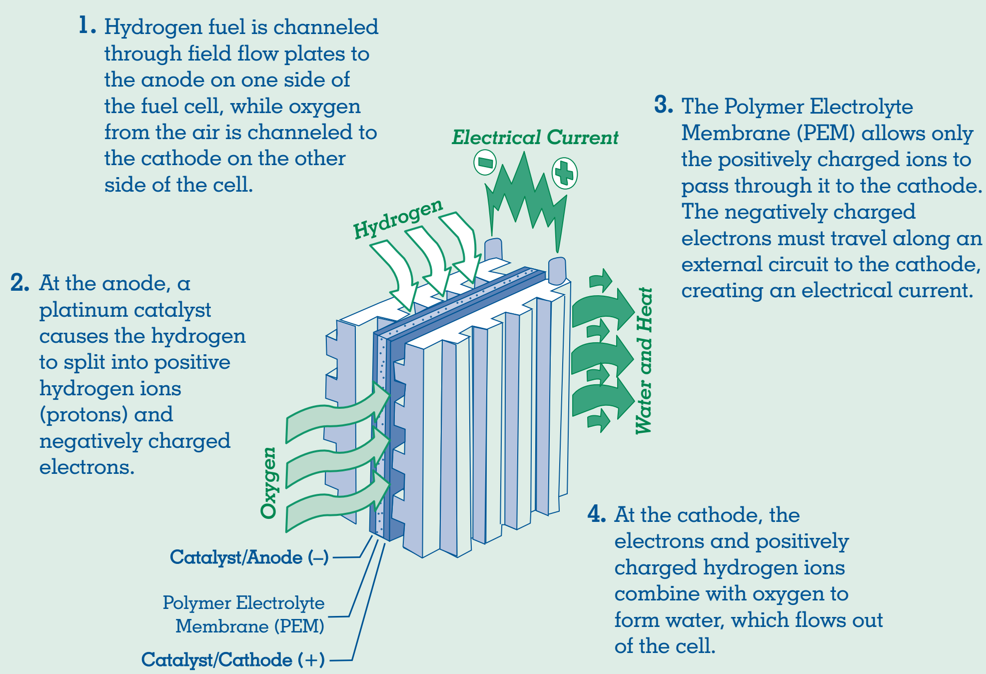
Polymer Electrolyte Membrane

At the center of the fuel cell is the polymer electrolyte membrane, which is thin and looks a little like plastic food wrap. The membrane allows hydrogen ions, which are attracted to the cathode, to pass through. However, the membrane *blocks* the passage of electrons, forcing them to travel through the external circuit to get to the cathode. This is essential for the functioning of the fuel cell: If the electrons flowed directly to the cathode rather than through the external circuit, there would be no useful electric current produced.

Cathode

Oxygen molecules from the air are pumped into the fuel cell and channeled to the fuel cell's cathode. Positively charged hydrogen ions come through the proton exchange membrane to the surface of the catalyst, and electrons flow to the cathode from the external circuit. On the surface of the platinum catalyst, the oxygen, hydrogen ions, and electrons combine to form water molecules, which flow out of the fuel cell.

Summary



Student Guide, p. 46

Questions for Reflection

1. What are the major components of a fuel cell?
2. Consider a single electron that starts out in a molecule of hydrogen gas that is used to power the fuel cell. What is the electron's path through the fuel cell and electrical circuit?
3. You looked at several different illustrations and animations of PEM fuel cells. Which one was the most helpful to you in understanding how fuel cells work? Why did you find this illustration or animation particularly helpful?

Redox Reactions and Electrochemistry

An **oxidation-reduction reaction** (known as a *redox reaction*) is any reaction in which electrons are transferred from one reactant to another. You're already familiar with one redox reaction—the reaction that takes place in a hydrogen fuel cell. But you've probably talked about or even initiated many other redox reactions without even knowing it:

- If you've ever made a comment about rusty metal, you were talking about a type of redox reaction called corrosion.
- When you turn on a battery-powered device, you are setting in motion a redox reaction—and if you recharge those batteries, you are making the same reaction go in reverse.
- Have you ever lit a fire? That starts a type of redox reaction known as combustion.

You even have redox reactions going on inside your own body; for example, when your cells "burn" glucose (a sugar molecule), a redox reaction takes place that produces water, carbon dioxide, and energy.

So why "oxidation reduction"? Oxidation is the loss of electrons, and reduction is the gain of electrons. So in a redox reaction, one reactant loses electrons and one reactant gains electrons.

Redox reactions can be put to a lot of practical uses. Often this is done using a device called an electrochemical cell. **Electrochemical cells** have the following parts:

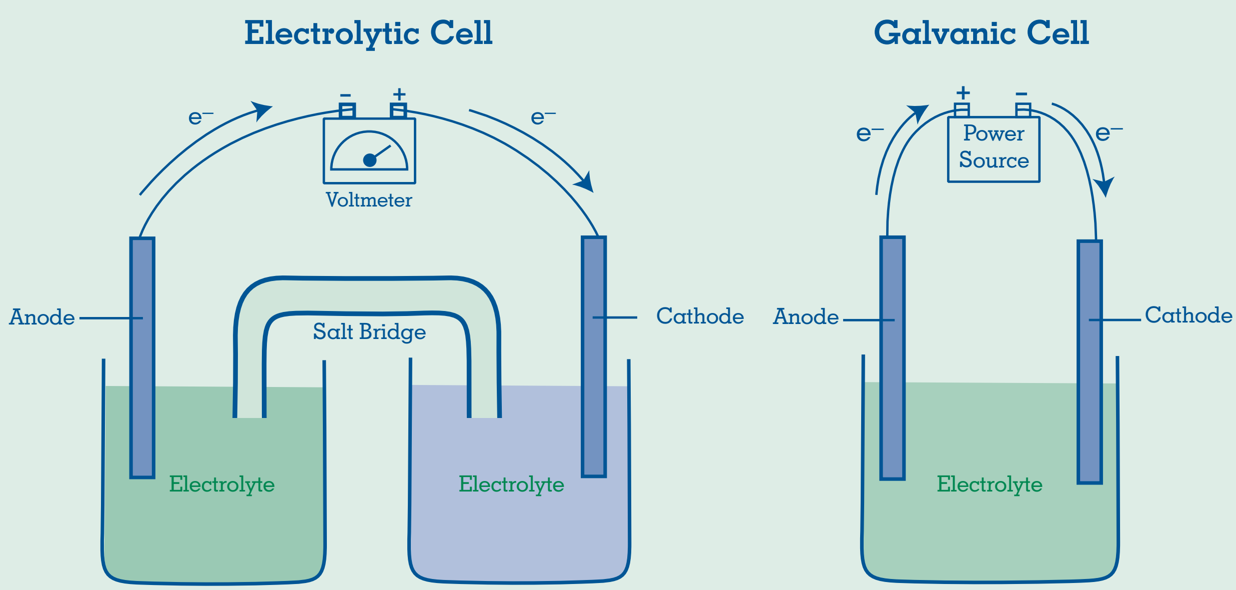
- Two electrodes, an anode and a cathode. An **electrode** is a solid substance on whose surface redox reactions take place. Oxidation (loss of electrons) takes place at the anode, and reduction (gain of electrons) takes place at the cathode.
- An **electrolyte**—a substance that contains ions and can conduct electricity.
- An electrical connection (such as a wire) from the anode to the cathode.

WHAT'S IN A NAME?

The word *oxidation* might give the impression that oxygen is always involved in a redox reaction. That's not quite true, but it's close. Oxygen is the most plentiful element on Earth and can take electrons away from many other elements. As a result, many of the first redox reactions understood by early chemists involved oxygen, and the process of taking electrons away from an atom or molecule became known as oxidation.

Do some of these words sound familiar? That's because fuel cells, which you learned about earlier, are a type of electrochemical cell. Batteries, both rechargeable and non-rechargeable, are also electrochemical cells. There are many other types of electrochemical cells, but they can all be divided into two main categories:

- In electrolytic cells, electricity is used to cause a non-spontaneous redox reaction to occur. A power source, such as a battery, pulls electrons from molecules at the anode, turning the molecules into positively charged ions. The power source pushes these electrons to the cathode, where they combine with positively charged ions in the electrolyte.
- In galvanic cells (also called voltaic cells, or sometimes just electrochemical cells), a spontaneous redox reaction occurs. The electrons at the anode are attracted to molecules at the cathode. Because free electrons cannot travel through the electrolyte, they get to the cathode by traveling through the external wire, producing an electrical current.



The reactions that take place in electrochemical cells are often reversible. This means that a reaction that proceeds spontaneously, producing electric current, can be made to run in reverse by applying an electric current.

As an example, consider the reaction that occurs in hydrogen fuel cells to generate electricity. Just as it's possible to form water and energy from oxygen and hydrogen through a chemical reaction, it's possible to separate the hydrogen and oxygen molecules from water through a decomposition reaction. (As you've learned, a decomposition reaction is one in which a more complex molecule is broken into simpler parts.)

On Your Own

Write a balanced chemical equation for the decomposition of water. The reactant is water (H_2O), and the products are oxygen gas (O_2) and hydrogen gas (H_2).

EXTENSIONS

2.1

While much of the interest in hydrogen as an energy carrier is for its potential use in fuel cells, there is also interest in using hydrogen in internal combustion engines. How are do-it-yourselfers converting traditional automobiles to accept hydrogen fuel?

2.2

Conduct research to find out about the possibility of using fuel cells to provide electricity for different types of buildings, such as offices, schools, or residential homes. What types of devices use electricity in these types of buildings? What are the typical power needs of these types of buildings? Are fuel cells a practical solution? Explain why or why not.

2.3

Besides vehicles and buildings, what other applications might be suitable for fuel cell use? Conduct research to find out what scientists and engineers have in mind for future uses of fuel cells on both small and large scales. Go to the **Ford PAS Web site** to locate sources for your research.

2.4

You learned about PEM hydrogen fuel cells, but there are many other types of fuel cells. Research other kinds of fuel cells, and compare and contrast them with the PEM hydrogen fuel cell. Go to the **Ford PAS Web site** to locate sources for your research.

TEACHER INFORMATION:

CHEMCIAL REACTIONS LABS EXPLAINED

[For Session 6]

Chemical Reactions Lab 1

Most endothermic reactions require toxic chemicals, but a baking soda (sodium bicarbonate)/citric acid reaction ($3NaHCO_3$ [*s*] + $H_3C_6H_5O_7$ [*aq*] → $Na_3C_6H_5O_7$ [*aq*] + $3H_2O$ [*l*] + $3CO_2$ [*g*]) is both simple and safe. The concentration of the citric acid solution and the quantity of baking soda can be varied to explore the effects on the reaction. Students should measure a decrease in temperature of the citric solution when the baking soda is added, indicating that this is an endothermic reaction.

Chemical Reactions Lab 2

Combining zinc (Zn) metal with dilute hydrochloric acid (HCl) produces heat as well as zinc chloride ($ZnCl_2$) and hydrogen gas (H_2). When students drop the zinc into the dilute hydrochloric acid, they will see bubbles of hydrogen being released. The temperature will increase as long as there is zinc left to react with the hydrochloric acid. Not only is this reaction exothermic, it also produces hydrogen—the focus of this module.

TEACHER INFORMATION:

CATALYSTS LAB EXPLAINED

[For Session 8]

The following information will help you understand what is happening in the Catalysts Lab.

The addition of a catalyst to the hydrogen peroxide/dish soap solution produces foam as the hydrogen peroxide breaks down into water and oxygen gas. The glowing splint tests will confirm the presence of oxygen in the bubbles—the splint will glow more strongly or possibly reignite in the presence of oxygen. For combustion to occur, there must be heat, fuel, and oxygen. The glowing splint provides the heat and fuel, and the reaction provides the excess oxygen needed to make the splint glow more strongly or reignite. The beaker containing only hydrogen peroxide and soap will not make the splint glow more strongly or reignite, because the reaction rate without a catalyst is too slow to produce enough oxygen during the time span of the lab.

The bubbles produced when manganese dioxide is used as a catalyst will have a grayish color because the powder is trapped inside the foam—it does not participate as a reactant. The manganese dioxide may be recovered and re-used because it is not consumed by the reaction. The potato contains an enzyme (a biological catalyst) called *catalase*, the same enzyme in human blood that causes hydrogen peroxide to foam when it comes into contact with a cut or scrape. Depending on the strength of the peroxide solution, the potato catalyst may not produce enough foam to reach the top of the beaker.

TIP...

Using hydrogen peroxide with a concentration higher than the 3 percent typically found at drugstores will produce more dramatic effervescence when the potato and manganese dioxide catalysts are added. You can also substitute beef liver for the potato or use it as an additional catalyst trial. Liver has the same enzyme, catalase, as the potato and will produce a slightly more dramatic reaction.

ACTIVITY 3:

Fuel from Water

Notes:

ACTIVITY OVERVIEW

Students learn about oxidation-reduction reactions, focusing on electrochemical reactions in particular. After learning how to predict in which direction electrochemical reactions will run spontaneously, each Hydrogen Technology Research team researches one process or device that involves an electrochemical reaction; teams then present their process or device to the rest of the class. After reflecting on and evaluating what they have learned about hydrogen so far, student teams conduct a lab to extract hydrogen from water through electrolysis, measuring the amount of gas they are able to produce, and then use their data to calculate the efficiency of electrolysis. Finally, students research other methods of hydrogen production, creating Background Memos to share what they learn with their Hydrogen Technology Research teams.

Sessions 10–17

Before You Teach

Session 10

- To display the steps to calculate cell potential, download the **Current Predictions Slideshow** on the **Ford PAS Web site**.

Session 12

- List the following questions on chart paper to debrief the team Electrochemistry Presentations:
  - What features or processes were the same for all the electrochemical cells?
  - What features or processes were different?

Notes:

- Like the lead-acid battery and the alkaline dry cell, fuel cells are a type of galvanic cell. What are the major differences between fuel cells and batteries?
- Based on what you learned about electrochemical reactions, what ideas do you have about the equipment and supplies you would need to carry out electrolysis of water?

Session 13

- If you wish to have students conduct a more step-by-step version of the Water Electrolysis Lab, download and preview **Decomposing Water** from the **Ford PAS Web site**.

Session 14

- Gather some additional materials, such as Burette clamps or utility clamps, that might be useful to have on hand for the Water Electrolysis Lab.

Session 15

- Decide whether to have students write their Hydrogen Production memos on the computer, rather than by hand.

Materials Needed

Sessions 10 and 11

- Copies of **RM 3.1 Electrochemistry Presentation Assessment** (one for each student)
- Computers with access to the Internet (one for each team)

Session 12

- Copies of **RM 3.2 Electrochemistry Presentation Peer Assessment** (one per student for each team's presentation)
- Optional: Computer with access to the Internet and/or a projector (if a team needs these for its presentation)
- Chart paper of students' knowledge and questions about hydrogen from Session 1
- Markers and chart paper
- Copies of **RM 3.3 Chemical Equations** (one for each student)

Session 13

- Copies of **RM 3.4 Module Quiz** (one for each student)
- Optional: If using the step-by-step version of the Water Electrolysis Lab, copies of **Decomposing Water** student pages (one for each student)

Notes:

Session 14

- Safety goggles (one pair for each student)
- Optional: Copies of **RM 3.5 Measuring Voltage** (one for each student)

For each Water Electrolysis Lab team:

- Water
- 1000 mL beaker
- 4 g washing soda (sodium carbonate, or Na_2CO_3)
- Two test tubes (20 mL) with stoppers
- Grease pencil
- Two carbon electrodes approximately 4 cm long
- Two 30-cm long pieces of coated copper wire, with the coating removed from 4 cm of wire on both ends
- Two insulated alligator clips
- 6 V lantern battery
- Ammeter (or multimeter) with appropriate wires and connectors
- Optional: Other materials to conduct the lab, which students may have identified during Session 13
- Optional: Voltmeter (or multimeter—students can use the one listed in this session if necessary) with appropriate wires and connectors

Session 15

- Copies of **RM 3.6 Calculating the Energy Efficiency of Electrolysis** (one for each student)
- Copies of **RM 3.7 Hydrogen Production Background Memo: Electrolysis** (one for each team member)
- Copies of **RM 3.8 Hydrogen Production Background Memo: Reforming** (one for each team member)
- Copies of **RM 3.9 Hydrogen Production Background Memo: Gasification** (one for each team member)
- Computers with access to the Internet (at least one for each team)

Sessions 16 and 17

- Computers with access to the Internet (at least one for each team)

Notes:

VOCABULARY

Efficiency

Electrochemical cell

Electrode

Electrolysis

Electrolyte

Gasification

Fuel reforming

Oxidation-reduction reaction

ACTIVITY 3:
Fuel from Water

INTRODUCTION

In order to use the energy in hydrogen, we need to have some hydrogen! One way that we can produce hydrogen gas is by splitting water into hydrogen gas and oxygen gas. You saw that energy was released when hydrogen and oxygen combined to form water. This process can also be reversed: You put some energy into a water molecule to make it come apart, forming hydrogen and oxygen. Could this really be the answer to our energy needs? In this activity, you'll learn more about how this process works and what its benefits and drawbacks are. You'll conduct a lab in which you make hydrogen gas yourself, and you'll research some other ways of producing hydrogen gas.

Learning Goals

- Describe the transfer of electrons in oxidation-reduction reactions.
- Analyze different methods of hydrogen gas production to identify the pros and cons of each method.

FOR YOUR GLOSSARY

Efficiency
Electrochemical cell
Electrode
Electrolysis
Electrolyte
Gasification
Fuel reforming
Oxidation-reduction reaction

Notes:

SESSIONS 10 AND 11

Water from Fuel AND Fuel from Water

[Whole Class]

In these sessions, students learn more about electrochemical reactions.

To begin, have one or two students share their balanced equation for the decomposition of water reaction.

Answer: The balanced equation for the reaction is:

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$$

Ask students if they'd expect to see this reaction occur spontaneously in a glass of water. (Students will likely say that they would not, based on their experience.)

Ask them what would be needed to make this reaction occur.

You may need to give students the hint that when hydrogen and oxygen react in a fuel cell, water and electricity are produced (the reaction running in the opposite direction).

Answer: You would need to add energy in the form of electric current.

Explain that there are a wide variety of chemical reactions that produce electricity in one direction but that can be driven to run in reverse by the application of electric current. Many of these reactions are of great practical use, for example, in building batteries or purifying metals.

CURRENT PREDICTIONS: CALCULATING ELECTRICAL POTENTIALS

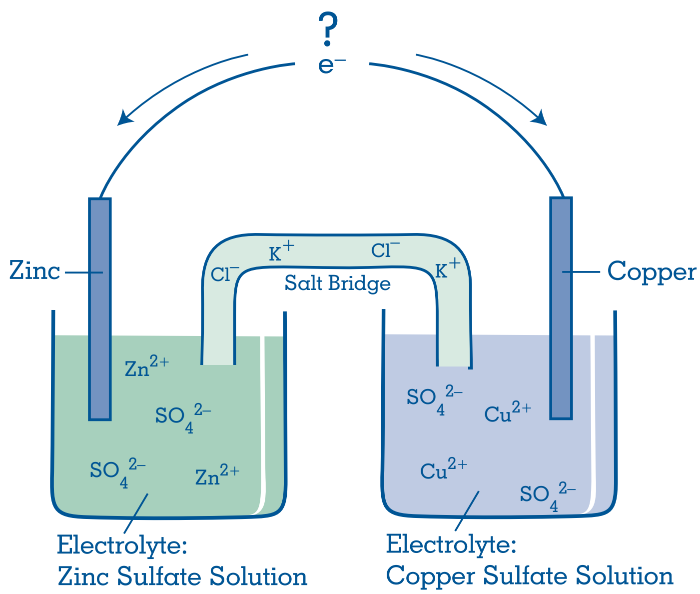
[Whole Class]

Students learn how to determine which electrochemical reactions are energetically favorable and will occur spontaneously.

Demonstrate the process of finding out the direction in which an electrochemical reaction will proceed spontaneously. Use the **Current Predictions Slideshow** to more easily display the steps.

CURRENT PREDICTIONS: CALCULATING ELECTRICAL POTENTIALS

How can you tell if an electrochemical reaction will occur spontaneously and generate a current? It depends on which of the reactants "pulls" more strongly on the electrons. This "pull" is called the *cell potential*, and it is measured in volts, just like battery strength. Basically, the cell potential gives an indication of how energetically favorable the electrochemical reaction is.



For an example of how to calculate the cell potential, consider this electrochemical cell, which is set up for the following reaction:

$$\text{Zn}\ (s) + \text{Cu SO}_4\ (aq) \overset{?}{\rightleftarrows} \text{Cu}\ (s) + \text{Zn SO}_4\ (aq)$$

Zinc (Zn) for the reaction is provided by the zinc electrode, copper (Cu) is provided by the copper electrode, and copper sulfate ($CuSO_4$) and zinc sulfate ($ZnSO_4$) are dissolved in water to create the electrolyte solution.

In one direction, this reaction occurs spontaneously and generates current. For the reaction to occur in the other direction, electric current must be applied. But which direction is which? The double arrow with the question mark indicates that we don't yet know.

Notes:

Students may also follow along on page 53 in the Student Guide.

TIP...

You may want to point out to students that they may also see this *pull* (cell potential) referred to as *electrochemical cell potential*, *cell voltage*, or *electromotive force*.

The electrochemical cell shown in the Student Guide is set up for the following reaction:

$$Zn\ (s) + CuSO_4\ (aq) \overset{?}{\rightleftarrows} Cu\ (s) + ZnSO_4\ (aq)$$

Step 1: Show the dissociation that occurs when the compounds are in an aqueous solution:

$$Zn\ (s) + Cu^{2+}(aq) + SO_4^{2-} \overset{?}{\rightleftarrows} Cu\ (s) + Zn^{2+}\ (aq) + SO_4^{2-}$$

Step 2: Eliminate the sulfate ions, because they are not involved in the transfer of electrons:

$$Zn\ (s) + Cu^{2+}\ (aq) \overset{?}{\rightleftarrows} Cu\ (s) + Zn^{2+}\ (aq)$$

Step 3: Break the reaction into two half-reactions:

$$Zn\ (s) \overset{?}{\rightleftarrows} Zn^{2+}(aq) + 2e^-$$

$$Cu^{2+}\ (aq) + 2e^- \overset{?}{\rightleftarrows} Cu(s)$$

Step 4: Look up the electrical potential of the *reduction* half-reactions:

$$Zn^{2+}\ (aq) + 2e^- \rightarrow Zn\ (s) \qquad -0.76\ V$$

$$Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s) \qquad 0.34\ V$$

To figure out which way the reaction occurs spontaneously, we need to break down the chemical equation until we're only looking at the molecules that get reduced (gain electrons) or oxidized (lose electrons).

In aqueous solution, $CuSO_4$ and $ZnSO_4$ dissolve, forming positively charged metal ions (Cu^{2+} and Zn^{2+}) and negatively charged sulfite ions (SO_4^{2-}):

$$Zn\ (s) + Cu^{2+}\ (aq) + SO_4^{2-} \overset{?}{\rightleftarrows} Cu\ (s) + Zn^{2+}\ (aq) + SO_4^{2-}$$

Since we are interested in the transfer of electrons, we can remove from the equation the sulfate ions (SO_4^{-}), which don't gain or lose electrons during this reaction:

$$Zn\ (s) + Cu^{2+}\ (aq) \overset{?}{\rightleftarrows} Cu\ (s) + Zn^{2+}\ (aq)$$

To see the transfer of electrons, we break down this reaction into two "half-reactions":

$$Zn\ (s) \overset{?}{\rightleftarrows} Zn^{2+}\ (aq) + 2e^{-}$$

$$Cu^{2+}\ (aq) + 2e^{-} \overset{?}{\rightleftarrows} Cu\ (s)$$

All we need to do now is find out the electrical potential of each half-reaction and add the potentials together. Fortunately, chemists have created data tables listing the electrical potentials of many half-reactions. An example of data you might find in one of these tables is shown here.

STANDARD REDUCTION POTENTIALS
in Aqueous Solution at 25°C

$BrO_4^{-} + 2H^{+} + 2e^{-} \longrightarrow BrO_3^{-} + H_2O$	+1.85 V
$Cu^{2} + 2e^{-} \longrightarrow Cu\ (s)$	+0.34 V
$Zn^{2+} + 2e^{-} \longrightarrow Zn\ (s)$	–0.76 V
$Ca^{2} + 2e^{-} \longrightarrow Ca\ (s)$	–2.87 V

Electrical potential tables usually list the potential of reduction half-reactions; to find out the cell potential of the reverse reaction (the oxidation reaction), take the negative of the voltage listed in the table.

Notes:

Step 5: Reverse the signs of the reduction half-reactions as needed to obtain the electrical potential of the oxidation half-reaction. Add the half-reaction potentials to find the overall cell potential

Reaction 1

	Reaction	Potential
	$Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$	0.76 V
+	$Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$	0.34 V
	$Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Cu\ (s) + Zn^{2+}\ (aq)$	1.10 V

Reaction 2

	Reaction	Potential
	$Zn^{2+}\ (aq) + 2e^- \rightarrow Zn\ (s)$	−0.76 V
+	$Cu\ (s) \rightarrow Cu^{2+}\ (aq) + 2e^-$	−0.34 V
	$Cu\ (s) + Zn^{2+}\ (aq) \rightarrow Zn\ (s) + Cu^{2+}\ (aq)$	−1.10 V

Reaction 1 occurs spontaneously, because the cell potential is positive.

We can use the data in the table to figure out which pair of half-reactions is more energetically favorable.

Reaction 1 and **Reaction 2** represent the two reactions that can occur in this electrochemical cell. Electrochemical reactions occur spontaneously if the cell potential is positive. To figure out the cell potential, we look up the potentials for the half-reactions in the table and then add them together.

Reaction 1

	$Zn\ (s) \longrightarrow Zn^{2+}\ (aq) + 2e^-$	0.76 V
+	$Cu^{2+}\ (aq) + 2e^- \longrightarrow Cu\ (s)$	0.34 V
	$Zn\ (s) + Cu^{2+}\ (aq) \longrightarrow Cu\ (s) + Zn^{2+}\ (aq)$	1.10 V

Reaction 2

	$Zn^{2+}\ (aq) + 2e^- \longrightarrow Zn\ (s)$	–0.76 V
+	$Cu\ (s) \longrightarrow Cu^{2+}\ (aq) + 2e^-$	–0.34 V
	$Cu\ (s) + Zn^{2+}\ (aq) \longrightarrow Zn\ (s) + Cu^{2+}\ (aq)$	–1.10 V

In this electrochemical cell, **Reaction 1** occurs spontaneously. To get **Reaction 2** to occur, a power source of at least 1.1 V must be connected to the cell.

Notes:

LIGHTS, CAMERA, REACTION!

[Whole Class/Teams]

To further their understanding of electrochemical reactions, each Hydrogen Technology Research team develops a presentation that shows and explains a process or device based on an electrochemical reaction.

Assign each Hydrogen Technology Research team one of the following:

- Lead-acid battery (also called a *lead storage battery*)
- Sodium and chlorine production from molten sodium chloride
- Alkaline dry cell (also called an *alkaline battery*)
- Electroplating with silver

Give each student the **Electrochemistry Presentation Assessment (RM 3.1)**. Have students work in their teams to brainstorm ideas for the presentation. Before making a final decision about the presentation format, teams need to check with you about the availability of the materials and equipment they'll need.

Have students work on their presentations, visiting the **Ford PAS Web site** to find resources to help them with their research. Depending on the format they choose, students may also need access to computers to create their presentations.

TIP...

Looking ahead to Session 12, decide how long each student presentation should be; tell students what the time limit is and that they will be held to this limit.

LIGHTS, CAMERA, REACTION!

NuEnergy
Investing in the Future

There are a wide variety of chemical reactions that produce electricity in one direction but can be driven to run in reverse by the application of electric current. Many of these reactions are of great practical use, for example, in building batteries or purifying metals.

To further your understanding of these important reactions, your Hydrogen Technology Research team will develop a creative presentation that shows and explains one of these reactions. Read the **Electrochemistry Presentation Assessment** to find out more about the requirements for the presentation.

Go to the **Ford PAS Web site** for resources you can use to learn about your assigned reaction. Think about how you might convey what you've learned about the reaction to someone who didn't know much about it. You could always create a diagram, or a slide show, or maybe a lecture—but what about something more visual and interactive?

With your team, come up with a creative way to explain to an audience the process by which your reaction occurs. Your presentation could take a number of forms:

- A live-action "play," in which you and your team members act out the process
- A short movie or animation about the process
- A Web page
- A comic or mini-graphic novel
- Something entirely different—the sky's the limit!

Brainstorm some ideas for what this presentation might look like. What kinds of props or equipment might you need? Come up with one or two ideas that you can work on, and check with your teacher about the availability of props and equipment. Then determine what work needs to be done, such as additional research, gathering materials, creating drawings or taking photographs, or writing text.

Work with your team to create your Electrochemistry Presentation, and be prepared to share your presentation with the class.

HOMEWORK 3.1

Work on your Electrochemistry Presentation.

HOMEWORK 3.2

Review the **Electrochemistry Presentation Product Assessment** to make sure that your presentation meets the requirements. If applicable, rehearse your role in your presentation.

Notes:

SESSIONS 12

LIGHTS, CAMERA, REACTION! THE FINALE

[Teams/Whole Class]

Allow teams time to make their final preparations. Give each student a copy of the **Electrochemistry Presentation Peer Assessment (RM 3.2)** for each team that's presenting.

Have each team share its presentation with the class.

Tying It All Together [Whole Class]

The class discusses similarities and differences among the reactions explained in the Electrochemistry Presentations and synthesizes what they've learned so far to come up with some general principles about electrochemical reactions.

Ask students the questions that are posted on the chart paper:

- What features or processes were the same for all the electrochemical cells?

  Possible Answers:

  All the reactions take place in an electrochemical cell that has an anode, a cathode, and an electrolyte. A reactant is oxidized at the anode, and another reactant is reduced at the cathode. Electrons travel through a circuit external to the device. Positive ions move through the electrolyte, preventing accumulation of charge. These are characteristics of all electrochemical cells.

- What features or processes were different?

  Possible Answers:

  The lead-acid battery and the alkaline dry cell are both galvanic cells, in which a spontaneous reaction is used to generate current. As in all galvanic cells, the electrons are separated from a reactant at the anode and travel through the external circuit because they are attracted to a reactant at the cathode.

  Both electrolysis of molten sodium chloride and electroplating with silver take place in electrolytic cells in which electric current is used to drive a non-spontaneous reaction. As in all electrolytic cells, electrons are "pumped" from the anode to the cathode by an external power source, such as a battery.

LIGHTS, CAMERA, REACTION! THE FINALE

Complete any final work that needs to be done on your Electrochemistry Presentation, and then share your presentation with the class.

HOMEWORK 3.3

Complete **Chemical Equations.**

Notes:

- Like the lead-acid battery and the alkaline dry cell, fuel cells are a type of galvanic cell. What are the major differences between fuel cells and batteries?

  Possible Answers:

  In fuel cells, the reactants come from outside the cell, while in batteries, the reactants are inside the cell. In most galvanic cells, the anode is consumed during the reaction, and material is deposited on the cathode. In fuel cells, the anode and cathode are inert, meaning, they are not part of the chemical equation that describes the cell.

- Based on what you learned about electrochemical reactions, what ideas do you have about the equipment and supplies you would need to carry out electrolysis of water?

  Possible Answers: Anode, cathode, electrolyte, and power source

TEACHER INFORMATION

Refer to **Electrochemistry Reactions** on pages T 159–T 160 for detailed information about the four electrochemical reactions assigned to students.

What Do We Know Now? [Whole Class]

Draw students' attention to the chart paper from Session 1, where their knowledge and questions about hydrogen were recorded. Discuss answers to questions on topics from the module up to this point. Ask students if they see anything incorrect, and, if so, how to correct it. If there is incorrect information but students are not able to identify it, draw their attention to it and help them connect the incorrect information to what they have learned so far. Record any changes to the list that the class makes and any additional questions students have.

At the end of the session, give each student **Chemical Equations (RM 3.3)** to complete for homework.

Notes:

SESSION 13

Module Quiz [Individual]

Use the first half of this session to have students complete the **Module Quiz (RM 3.4)**.

TEACHER INFORMATION

Before the quiz, you may want to review the chemical equations that students worked on for homework. Refer to **Answers to Chemical Equations** on page T 161.

TEACHER INFORMATION

The **Module Quiz Answer Key** is located on pages T 162–T 163.

Notes:

WATER, WATER EVERYWHERE, BUT NOT A DROP OF HYDROGEN

[Teams/Whole Class]

Students develop a procedure for a Water Electrolysis Lab, in which they use electrical energy to split water into hydrogen and oxygen gases (that is, the electrolysis of water).

TIP...

A version of this lab with more defined procedures, **Decomposing Water**, is available on the **Ford PAS Web site**. If you are using the alternate lab, students do NOT need to read Water, Water Everywhere, But Not a Drop of Hydrogen on pages 58–59 in the Student Guide. Hand out the student pages of **Decomposing Water** instead.

Have students meet in their Hydrogen Technology Research teams and examine the diagram on page 58 in the Student Guide. Have teams answer the **Questions for Reflection**.

Based on the diagram, each team works to create a procedure for the electrolysis of water, using the materials listed and any other materials they think they'll need. Review each team's procedure to be sure that it is safe. If a procedure calls for materials that cannot be obtained for the next day, when the electrolysis will be carried out, help the team think of substitutes.

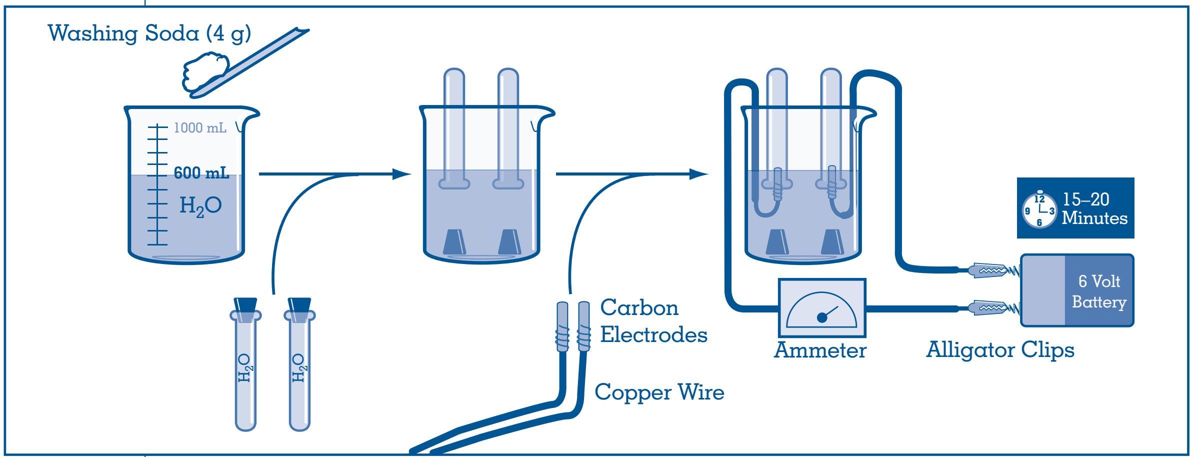
TIP...

In Session 15, Efficiency of Electrolysis, students calculate the efficiency of their water electrolysis reaction. Students use **Calculating the Efficiency of Electrolysis (RM 3.6)**, which instructs them to use the nominal voltage of the battery, 6 V, as the value for V in the equation $P = V \times I$. However, the nominal voltage of the battery is only an approximation of the voltage being applied to the reaction. If you prefer that students use a more accurate value of the voltage, they can measure the actual voltage during Session 14, using the procedure described in **Measuring Voltage (RM 3.5)**. If you choose to have students measure the voltage, you may want to discuss the efficiency of electrolysis at the end of this session or at the start of Session 14 so that students understand why they are collecting these data.

WATER, WATER EVERYWHERE, BUT NOT A DROP OF HYDROGEN

Seventy percent of Earth's surface is covered by water, and every molecule of water contains two hydrogen atoms. That's *a lot* of hydrogen—so what's the big deal about obtaining it?

The problem is that hydrogen and oxygen stick together pretty tightly, so energy needs to be added to break them apart. However, the decomposition of water can be done fairly simply through **electrolysis**, the process of using electricity to split water molecules into hydrogen gas and oxygen gas (the electricity provides the energy needed to break the bonds). See this for yourself by conducting a Water Electrolysis Lab. Examine the following diagram and answer the **Questions for Reflection**. Then create a procedure for making hydrogen from water, using the diagram and your answers to the **Questions for Reflection**. You may use the materials listed—and any other materials that you think are necessary—to carry out your procedure.



Questions for Reflection

1. What safety precautions will you take when you carry out this lab?
2. How will you keep the test tubes from falling over?
3. How will you know which test tube contains which electrode?
4. How will you measure the amount of gas formed in each test tube?
5. Based on the fact that the chemical formula for water is H_2O, how much hydrogen do you think you should produce relative to the amount of oxygen?
6. If you wanted to confirm which tube contained which gas, what test could you perform? (Hint: Remember the first balloon demonstration.)

Notes:

If students need to use the same multimeter to measure voltage and current, they should stop the electrolysis reaction immediately once they measure the voltage by disconnecting one electrode from the battery. They will then need to set the multimeter to measure current (which should be labeled A for amperes or mA for milliamperes) and connect the multimeter in place of the ammeter, as shown in the diagram in Water, Water Everywhere, But Not a Drop of Hydrogen on page 58 in the Student Guide (page T 139). Remind students that once they begin the electrolysis reaction again, they need to record the current and the length of time the electrolysis reaction is running.

Alternatively, one voltmeter (or multimeter) can be used by the whole class to measure voltage: teams should set up and start their electrolysis. Then they can use the voltmeter to measure the voltage at any time during the 15–20 minutes that the electrolysis is running.

7. The ammeter measures the electrical current flowing through the electrolysis circuit. How could you use this information to calculate the efficiency of electrolysis?

Caution: **In this lab, you will run an electric current through water. Be sure to take appropriate safety precautions, and do not touch any part of the electrolysis apparatus while the battery is connected to the system!**

Materials

- Safety goggles
- Water
- 1000 mL beaker
- 4 g washing soda (sodium carbonate)
- Two test tubes (20 mL) with stoppers
- Grease pencil
- Two carbon electrodes approximately 4 cm long
- Two 30-cm long pieces of coated copper wire, with the coating removed from 4 cm of wire on both ends
- Two insulated alligator clips
- 6 V lantern battery
- Multimeter or ammeter

Notes:

SESSION 14
TURNING WATER INTO FUEL

[Teams/Whole Class]

Teams carry out the Water Electrolysis Labs they designed.

Have teams meet to review their procedure and gather their materials. As teams conduct their electrolysis procedures, they will measure the amount of each gas produced, the amount of current applied, and the length of the time they allowed the reaction to proceed. Each student should take notes and record the data in his or her science notebook.

TIP...

Be sure that teams time their reactions, as this information is crucial to calculating the efficiency of the reaction, which they will do in Session 15. If you want students to measure the actual voltage supplied by the battery, have them follow the directions in **Measuring Voltage (RM 3.5)**.

TIP...

If students have difficulty figuring out how much of each gas they produced, show them the balanced equation for electrolysis ($2H_2O \rightarrow 2H_2 + O_2$) and help them think through the fifth **Question for Reflection** on page 58—students should understand that they will obtain approximately twice as many molecules of hydrogen gas as they do oxygen gas. Therefore, the tube with more gas contains the hydrogen. Alternately, you might provide students with Steps 10–12 of the **Decomposing Water** procedure on the **Ford PAS Web site**.

If there is time after the labs are completed, bring the class together to do the following:

- Share what they observed during the lab.
- Compare the ratios of the volumes of hydrogen and oxygen the teams produced. Did all teams produce approximately two times the volume of hydrogen as they did oxygen? What possible sources of error in the lab might have contributed to teams not obtaining these results?

If there is not time to discuss these topics, discuss them at the start of the next session.

TURNING WATER INTO FUEL

With your Hydrogen Technology Research team, carry out the procedure you developed for the Water Electrolysis Lab. Be sure to record the length of time that you run the reaction, the current being applied, and the volume of hydrogen produced.

While the reaction is running, think about electrolysis as an *energy transformation*: The electrical energy produced by the battery is transformed into the chemical bond energy of the hydrogen and oxygen produced. In an energy transformation, the **efficiency** of the process is the ratio between the *energy out* (in this case, the chemical bond energy in the hydrogen gas) and the *energy in* (in this case, the electricity). As a team, discuss any ideas you have about how you might calculate the efficiency of the electrolysis reaction.

DID YOU KNOW?

Generating electricity for hydrogen production could be a breeze! Wind turbines turn the kinetic (motion) energy of the wind into electrical energy. A wind turbine works like a fan in reverse—wind turns the rotor blades, which spin a shaft connected to a generator that produces electricity. Large wind turbines can generate up to several megawatts of electricity, and when grouped together on "wind farms" (wind power plants), they can produce an enormous amount of power. If the electricity generated by wind turbines were used for electrolysis, turbines could also be used to produce hydrogen.

Using wind turbines to produce hydrogen has both benefits and drawbacks. Wind is a clean and abundant, domestically available resource. Wind power plants can boost rural economies while using only a fraction of farm or ranch land. Hydrogen production by electrolysis might be a great use for wind turbines because the electricity generated by the wind turbines would not have to be transported. However, first and foremost, the current wind technologies would require *very* large numbers of wind turbines to produce enough hydrogen to be of use. In addition, many of

Notes:

TEACHER INFORMATION

Electrolysis of Water on pages T 164–T 165 provides a detailed explanation of what occurs at the molecular level when electricity is used to drive the decomposition of water.

the best wind sites are in rural or low-population locations, far from where hydrogen fuel will be most needed, so the hydrogen would still need to be stored and transported, or converted back into electricity that feeds into the electrical grid. Wind turbines have also been criticized for being unpleasant to look at and for posing danger to birds that may be killed if they fly into the rotors. Another consideration is cost: Building wind farms is expensive (though the costs are decreasing as time goes by), and wind farms may not generate enough electricity to compete with conventional sources.

HOMEWORK 3.4

Create a list of questions you still have about the process of separating water into hydrogen and oxygen.

Notes:

SESSION 15
EFFICIENCY OF ELECTROLYSIS

[Whole Class/Teams]

If there was not time to do so at the end of the previous session, bring the class together to do the following:

- Share what they observed during the Water Electrolysis Lab.
- Compare the ratios of the volumes of hydrogen and oxygen they produced. Did all teams produce approximately two times the volume of hydrogen as they did oxygen?
- Discuss possible sources of error for this lab.

Introduce students to the idea of *energy efficiency*. Explain that any time energy is transformed from one form to another, some of the energy is "lost," meaning that it does no useful work. For example, when a car burns gasoline, some of the energy in the gasoline is converted into mechanical energy for moving the car, but some of the energy is lost as heat. The energy efficiency is the ratio between the energy input and the usable or useful energy output. Display this equation:

$$\text{Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}}$$

Ask students the following questions:

1. Where did the energy input for the electrolysis reaction come from?

   Possible Answers: The energy came from the battery. The energy input was electrical energy.

2. Where is the useful energy produced by the electrolysis reaction?

   Possible Answers: In the hydrogen; within the chemical bonds in the hydrogen gas.

Show students this equation for the efficiency of electrolysis:

$$\text{\% Efficiency of Electrolysis} = \frac{\text{Energy Content of } H_2 \text{ Produced}}{\text{Electrical Energy Supplied}} \times 100$$

Connect this equation to the students' responses to questions 1 and 2: The electrical energy from the battery is the denominator of this equation, and the energy stored in the chemical bonds in the hydrogen gas is the numerator.

EFFICIENCY OF ELECTROLYSIS

You've probably heard quite a bit about *energy efficiency*. Many advertisements promote products based on their energy efficiency. The energy company that supplies your home with electricity probably offers home energy audits to help homeowners figure out how to make their homes more energy-efficient, perhaps by adding insulation or replacing the windows with more energy-efficient ones. When people talk about something being energy-efficient, they usually mean that it uses less energy to perform the same task.

In science, energy efficiency means something a little different. Any time that energy is transformed from one form to another, some of the energy is "lost," meaning that it's not available to do useful work. For example, when a car burns gasoline, only 15–25 percent of the energy in the gasoline is converted into mechanical energy for moving the car; the rest is lost, much of it as heat. This form of energy efficiency is sometimes referred to as *energy conversion efficiency*.

Notes:

Distribute **Calculating the Efficiency of Electrolysis (RM 3.6)** and have students work in their Hydrogen Technology Research teams to complete the calculations.

Discuss the teams' results with the whole class using the following questions:

- What was the range of efficiencies obtained by the teams?
- What are some possible sources of inefficiency?

  Possible Answers: Some electrical energy was converted to heat; not all the hydrogen gas produced was captured.

In their research about hydrogen, students may come across another type of efficiency that can be calculated, called the *conversion efficiency*. It is based on the volume of *hydrogen* rather than the energy input and output.

$$\%\text{ Conversion Efficiency} = \frac{\text{Volume of } H_2 \text{ Produced}}{\text{Theoretical Maximum Volume of } H_2 \text{ Produced}} \times 100$$

Conversion efficiencies may be useful for comparing different electrolyzers to each other, but they are not useful for comparing electrolysis to other hydrogen production methods or comparing hydrogen production to the production of other energy carriers.

Questions About Electrolysis [Whole Class]

Ask students to share any questions about electrolysis that they came up with for homework. Have other students help answer these questions, when possible. You can also use the information in **Teacher Information: Electrolysis of Water**. If there are any questions that you and the class can't answer, record and display them to use as additional research questions.

SEARCHING FOR HYDROGEN

[Whole Class/Teams]

For the rest of this session, students begin to research and write a Hydrogen Production Memo, which they will continue to work on in Sessions 16 and 17.

Ask students to share what they think the implications are of this fact:

When decomposing water to produce hydrogen gas, energy is required.

Explain that this energy has to come from somewhere, and that, depending on the source, it may result in the release of carbon dioxide into the atmosphere (as is the case with coal-fired power

SEARCHING FOR HYDROGEN

You've learned about the process of forming hydrogen gas by electrolysis. But in order to help your company decide whether hydrogen and fuel cells are a good bet for the future of energy, it's not just electrolysis that you have to think about.

The hydrogen used in commercial fuels today is *not* produced by electrolysis. Most of it (95 percent) is made from natural gas (methane) through **fuel reforming**, a process in which a hydrocarbon reacts with steam at high temperatures to form hydrogen gas and carbon monoxide. But there are two big problems with this process: It produces greenhouse gases, and natural gas is a non-renewable resource.

Another method that can be used to produce hydrogen is **gasification**, a process in which carbon-rich material, such as coal or biomass, reacts with oxygen and steam at high heat to create a synthesis gas—a gas mixture that contains varying amounts of carbon monoxide and hydrogen. This gas is further processed to extract the hydrogen gas. But gasification of coal presents the same problems as natural gas reforming: It produces greenhouse gases, and coal is a non-renewable resource.

To make matters more complicated, you'll need to know more than just the science behind hydrogen production methods (although that's important!). For example, how much do these methods cost? Are they practical on a commercial scale? And, maybe most importantly, where will all the necessary energy come from?

To learn more about the issues and questions associated with hydrogen production, work with your team to research your assigned production method. As a team, discuss and then decide how you will conduct your research.

Write a Hydrogen Production Background Memo, using the resources on the **Ford PAS Web site**. Once you complete your memo, each team member should have a copy of the team's completed Background Memo, because you'll need to bring this information to your Hydrogen Technology Research team. As you conduct your research, make a note of any scientific terms that you are unfamiliar with.

Notes:

plants). Energy used for electrolysis is also energy that can't be used for other things, such as providing electricity to homes.

Divide the class into Hydrogen Production teams, making sure that each member of a Hydrogen Technology Research team is on a different Hydrogen Production team. Assign teams to research one of the following methods of hydrogen production:

- Electrolysis
- Reforming
- Gasification

TIP...

Depending on the size of the class, you may have more than one team researching each method. Each Hydrogen Technology Research team should have members researching each of the three methods.

Give each team the appropriate **Hydrogen Production Background Memo (RM 3.7–3.9)**, and give them time to look it over. Advise students to go to the **Ford PAS Web site** to locate resources to help them with their research. Each team needs to answer all of the questions on its **Background Memo**. If there is time, each team should also try to answer the posted questions (if any) about electrolysis.

TIP...

Each of the **Hydrogen Production Background Memos (RM 3.7–3.9)** is available on the **Ford PAS Web site**. Teams may use a computer to complete their work and make copies for each team member.

TIP...

Students begin Homework 3.6 in Session 15 and continue their research through Session 16. Note that students do not complete their Hydrogen Production Memos until Session 17.

TEACHER INFORMATION

Refer to **Hydrogen Production** on pages T 166–T 173 for answers to the questions in the Hydrogen Production Background Memos.

HOMEWORK 3.5

Complete your lab report on the Water Electrolysis Lab.

HOMEWORK 3.6

Look over the research that you have collected for your Hydrogen Production Background Memo. Identify any additional information you'll need to complete the memo.

Notes:

SKILL RESOURCE

Some students may find doing research on hydrogen production challenging. If students are having difficulty reading the scientific text, take time to discuss some strategies they may find helpful. Use **Preview the Text** and **Reading Strategies to Use on Your Own** (located in the Skill Appendix) to help students focus on finding the information they need.

Notes:

SESSIONS 16 AND 17

Questions About Hydrogen Production Terms

[Whole Class]

To begin Session 16, ask students to share any scientific terms that they had difficulty understanding during Session 15. Go over these terms with the class, asking other students to help if they are familiar with them.

TEACHER INFORMATION

For a list and definitions of terms students might encounter during their research, see **Hydrogen Production Terms** on page T 174.

TIP...

Make sure that students note words they encounter in their research that they are not sure about, and share them with the class. You may decide to add them to the class Word Wall. If any of the words are glossary words, point out that students can look up the words in the glossary in the Student Guide on pages 95–97. Try to use these words frequently in future class discussions, and point them out on the Word Wall when they come up.

The Search for Hydrogen Continues [Teams]

Have Hydrogen Production teams continue to conduct research on their assigned method of hydrogen production. In Session 17, teams should finalize their Hydrogen Production Background Memos. Remind students that all team members need copies of the completed memos to share with their Hydrogen Technology Research teams.

Notes:

REFLECT ON HYDROGEN PRODUCTION

[Teams]

Have students meet in their Hydrogen Technology Research teams to share what they've learned about different methods of producing hydrogen. Ask them to discuss how this information relates to each of the start-ups being considered. Do they need any additional information about hydrogen production? If so, how might they find it?

SKILL RESOURCE

If students need guidance about communicating and coming to a consensus as a team, refer to **Team Communication Techniques**, which offers information about persuasive speaking, active listening, and giving and receiving feedback.

REFLECT ON HYDROGEN PRODUCTION

NuEnergy
Investing in the Future

Share with your teammates what you've learned about the hydrogen production process you researched. Together, discuss the pros and cons of the various production methods. What hydrogen production process is the most feasible and the most environmentally sustainable? Do any of them hold the promise of producing enough hydrogen, at a low enough price, to make fuel cell vehicles practical? Consider how what you've learned will affect your recommendation to the company.

HOMEWORK 3.7

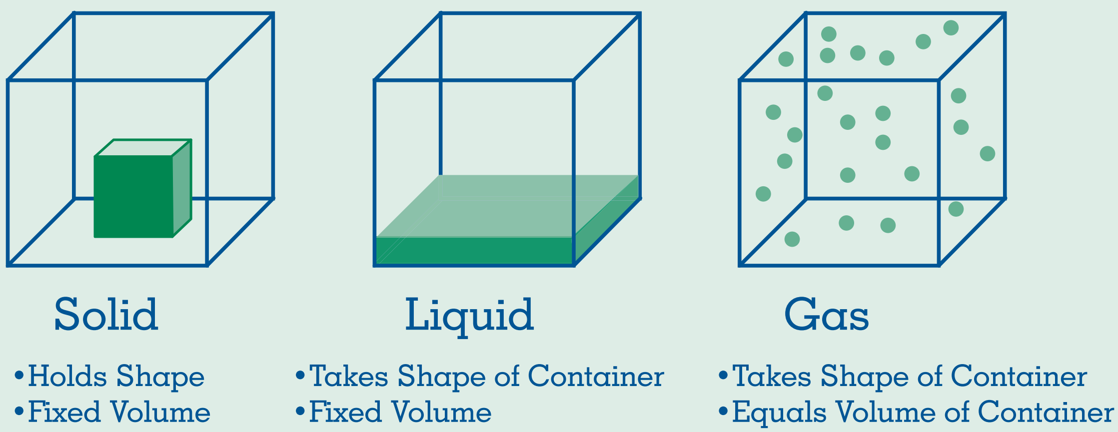
Read **State Your Matter** and answer the **Questions for Reflection.**

State Your Matter

Hydrogen, unlike gasoline, is usually found as a gas, which has implications for its use as a fuel. As you know, the matter you encounter in everyday life is in one of three states or phases: solid, liquid, or gas. These macroscopic (visible to the naked eye) states of matter are determined by microscopic properties, such as the spacing and mobility of the atoms or molecules that make up the substance.

The Kinetic Theory of Matter

The kinetic theory of matter is an explanation of how matter behaves—or, more specifically, of how the particles that make up matter behave. It says (in part) that all matter is made up of particles—atoms and molecules—and that these particles are in constant random motion. The energy possessed by matter as a result of its motion is *kinetic energy*. The kinetic theory also states that depending on the state of matter, the distances between the particles that make up the substance vary.



Solids

The particles that make up a solid are tightly packed, usually in an orderly pattern. These atoms or molecules vibrate but typically do not move from their fixed positions. The volume and shape of a solid are fixed (meaning, solids are rigid) unless a sufficiently strong force is applied.

Liquids

In a liquid, particles are close together but without a fixed arrangement or rigid structure. The atoms or molecules are able to move around and slide easily past one another. Due to the limited amount of space between particles, liquids have fixed volumes, but the shape of a liquid is flexible.

Gases

The atoms or molecules of a gas are widely separated (with lots of empty space between them), with no set arrangement or structure, and move about freely at high speeds. They are also highly disorganized.

Questions for Reflection

1. Name three substances that you know of that can be found in more than one state on Earth. What causes each of these substances to exist in more than one state? (In other words, what conditions affect the state?)
2. How do the particles of matter interact with one another? Come up with an analogy for how the particles interact, or create a drawing that shows what the particles look like inside a container in each of the three states.

EXTENSIONS

3.1

Although hydrogen is a clean-burning fuel, several hydrogen production methods use fossil fuels and emit harmful greenhouse gases. Many scientists believe that the impact of fossil fuel burning can be substantially decreased if we capture the emitted carbon dioxide and store it instead of allowing it to be released into the atmosphere. Conduct research to find out more about carbon capture and storage (also called *carbon sequestration*). As you gather information, look for answers to the following questions: How does carbon capture and storage work? How much will it cost? Is anyone currently using this technique? Once you have completed your research, summarize your findings and explain your own opinion as to whether you think carbon capture and storage is something that should be pursued by scientists.

3.2

Conduct research to find out more about electricity production from renewable energy sources other than wind power (for example, biomass, hydropower, or geothermal power), and the potential for using these energy sources to power large-scale hydrogen production by electrolysis.

TEACHER INFORMATION:

ELECTROCHEMISTRY REACTIONS

[For Session 12]

Lead-Acid Battery

Every time your students drive a car or ride in one, they are relying on lead-acid batteries, which power the starter motors in automobiles.

When in use (discharging), the lead-acid battery is an example of a galvanic cell: The spontaneous chemical reaction taking place inside the battery produces a current. The battery can be recharged by applying electric current. In automobiles, this current comes from the alternator, which converts mechanical energy from the engine into electrical energy.

Anode:	Lead (Pb)
Cathode:	Lead dioxide (PbO_2)
Electrolyte:	Sulfuric acid (H_2SO_4)
Oxidation reaction at the anode:	$Pb\ (s) + HSO_4^-\ (aq) \rightarrow PbSO_4\ (s) + H^+ + 2e^-$
Reduction reaction at the cathode:	$PbO_2\ (s) + HSO_4^-\ (aq) + 3H^+ + 2e^- \rightarrow PbSO_4\ (s) + 2H_2O\ (l)$
Overall reaction:	$Pb\ (s) + PbO_2\ (s) + 2H_2SO_4\ (aq) \rightarrow 2PbSO_4\ (s) + 2H_2O\ (l)$
The overall reaction can also be written as:	$Pb\ (s) + PbO_2\ (s) + 4H^+\ (aq) + 2SO_4^{2-}\ (aq) \rightarrow 2PbSO_4\ (s) + 2H_2O\ (l)$

Sodium and Chlorine Production from Molten Sodium Chloride

Sodium, a metal that does not occur naturally on Earth in its elemental form, is used in a wide variety of applications, such as the refining or purification of other metals. Chlorine is widely used in water purification. It is also used in the production of many organic compounds, such as vinyl chloride, an intermediate compound in the production of the plastic known as PVC.

Sodium and chlorine can be produced from molten sodium chloride in an electrolytic cell.

Anode:	Carbon (C)
Cathode:	Iron (Fe)
Electrolyte:	Molten sodium chloride (NaCl)
Oxidation reaction at the anode:	$2Cl^-\ (l) \rightarrow Cl_2\ (g) + 2e^-$
Reduction reaction at the cathode:	$2Na^+\ (l) + 2e^- \rightarrow 2Na\ (l)$
Overall reaction:	$2NaCl\ (l) \rightarrow 2Na\ (l) + Cl_2\ (g)$

Alkaline Dry Cell

Alkaline dry cells are in widespread use. If your students have some batteries stored in the freezer at home or have ever grabbed a pack in the check-out line at a convenience store, chances are that these are alkaline dry cells. These batteries can be found in clock radios, battery-powered toys, and remote controls for televisions and video game systems.

The alkaline dry cell is a galvanic cell in which the spontaneous reaction between zinc and manganese dioxide produces an electrical current. Most alkaline dry cells are not considered to be rechargeable. Attempting to recharge one can produce gases within the canister, which can result in an explosion.

Anode:	Paste containing powdered zinc (Zn), potassium hydroxide (KOH), and water (H_2O)
Cathode:	Paste containing manganese dioxide (MnO_2), graphite (C), and water (H_2O)
Electrolyte:	Potassium hydroxide (KOH)
Oxidation reaction at the anode:	$Zn\ (s) + 2OH^-\ (aq) \rightarrow ZnO\ (s) + H_2O\ (l) + 2e^-$
Reduction reaction at the cathode:	$2MnO_2\ (s) + H_2O\ (l) + 2e^- \rightarrow Mn_2O_3\ (s) + 2OH^-\ (aq)$
Overall reaction:	$2Zn\ (s) + 3MnO_2\ (s) \rightarrow 2ZnO\ (s) + MN_3O_4\ (s)$

Electroplating with Silver

Metal objects are frequently coated with a thin layer of another metal, sometimes for aesthetic purposes and sometimes to protect the object from corrosion or other damage. Table utensils and jewelry are often plated with silver.

An electrolytic cell can be used to deposit a thin coating of metal on an object. This process is called *electroplating*.

Anode:	Silver (Ag)
Cathode:	Object that is to be electroplated
Electrolyte:	Silver cyanide (AgCN) or silver nitrate (AgNO3)
Oxidation reaction at the anode:	$Ag\ (s) \rightarrow Ag^+ + e^-$
Reduction reaction at the cathode:	$Ag^+\ (aq) + e^- \rightarrow Ag\ (s)$
Overall reaction:	None

TEACHER INFORMATION:

ANSWERS TO CHEMICAL EQUATIONS

[For Session 13]

1. Combustion of liquid propane

   Answer: $C_3H_8\ (l) + 5O_2\ (g) \rightarrow 3CO_2\ (g) + 4H_2O\ (l)$

2. Rusting (oxidation) of iron

   Answer: $4Fe\ (s) + 3O_2\ (g) \rightarrow 2Fe_2O_3\ (s)$

3. Tarnishing of silver

   Answer: $2Ag\ (s) + S\ (g) \rightarrow Ag_2S\ (s)$

4. Haber Process (formation of ammonia)

   Answer: $3H_2\ (g) + N_2\ (g) \rightarrow 2NH_3\ (g)$

5. Production of the pollutant nitrogen dioxide from nitric oxide

   Answer: $2NO\ (g) + O_2\ (g) \rightarrow 2NO_2\ (g)$

TEACHER INFORMATION:

MODULE QUIZ ANSWER KEY

[For Session 13]

1. **[25 points]** Describe how the atomic structure of the element *hydrogen* affects the way that this element behaves in relation to other atoms and molecules.

   Answer: Hydrogen has only one valence electron in its valence shell. Because of this, the atom is extremely unstable, and it readily bonds with other elements. It is not found on Earth as a single atom, but rather in the form H_2 (hydrogen gas).

2. **[25 points]** Describe three properties of hydrogen gas.

   Possible Answers: Hydrogen gas . . .

   - **Is flammable and highly reactive**
   - **Is an excellent energy carrier**
   - **Is lighter than air**
   - **Takes up a large amount of space, unless it is compressed or cooled**
   - **Is not commonly found on Earth and must be extracted from another substance**

3. **(30 points]** Read the following chemical equation:

$$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(l)$$

   This equation describes both the combustion of hydrogen gas and the reaction of hydrogen with oxygen that occurs in fuel cells—but you know from observation that the two processes are very different. Explain why they are so different in terms of the role of catalysts and activation energy.

   Answer: When hydrogen combusts, hydrogen molecules react with oxygen molecules after enough energy has been applied to overcome the activation energy for the reaction. The reaction releases energy, and the product is water in the form of vapor.

   The reaction that occurs in a fuel cell can be represented by the same equation, but there are two main differences:

   - **For a combustion reaction to occur between hydrogen and oxygen, heat must be added to the reactants. Heat is not needed for the reaction in the fuel cell, but a catalyst is required.**
   - **The combustion reaction releases energy in the form of heat and light. The fuel cell reaction releases energy in the form of electricity.**

4. Imagine that you have just gotten a grass stain on your favorite pair of jeans. Unfortunately for you, grass stains can be really difficult to get out of natural fabrics such as cotton because the pigmented compounds in grass react with the fabric fibers, forming tight chemical bonds. The longer the stain is left untreated, the more likely it is the stain will become permanently "set."

a. **[10 points]** Experienced launderers use cold water to remove stains such as these. Why might cold water work better than hot water in this situation? Explain your reasoning.

Answer: High temperatures associated with hot water may increase the rate of reaction between the grass pigments and the cotton fibers, making the stain more likely to set. Using cold water, the agitation of the washing machine has a better chance of removing the stain.

b. **[10 points]** Some laundry detergents include an enzyme, which is a biological catalyst. What is the purpose of adding enzymes to laundry detergent?

Answer: An enzyme is a catalyst, so adding it to a laundry detergent would speed up the rate of the stain removal reaction, giving the stain even less time to set.

TEACHER INFORMATION:
ELECTROLYSIS OF WATER
[For Session 14]

Water decomposes into hydrogen and oxygen according to the following equation:

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$$

This overall reaction actually consists of two half-reactions: an oxidation reaction at the anode and a reduction reaction at the cathode. When the battery is connected to the electrolysis setup, the oxidation reaction produces oxygen gas, hydrogen ions (H^+), and electrons:

$$2H_2O\ (l) \rightarrow O_2\ (g) + 4H^+\ (aq) + 4e^-$$

Electrons flow from the anode to the battery, and then from the battery to the cathode of the electrolysis setup. The reduction reaction takes place in the water at the cathode (which is negatively charged), producing hydrogen gas and hydroxide ions (with the molecular formula OH^-):

$$4H_2O\ (l) + 4e^- \rightarrow 2H_2\ (g) + 4OH^-\ (aq)$$

To complete the circuit and prevent the build-up of charge at the anode and cathode, electrical current must flow through the aqueous solution in the beaker. *Electric current* is the movement of electrons or ions. Since free electrons cannot flow through water, the current must be carried through the water in the beaker by the flow of negatively charged ions from the cathode to the anode *and/or* the flow of positively charged ions from the anode to the cathode.

Pure water has only a slight conductivity due to self-ionization, during which two water molecules react to form hydronium (H_3O^+) and a hydroxide ion. However, most water contains impurities, such as salts, which help to increase conductivity. (*Salts* are ionic compounds that dissociate into positively charged and negatively charged ions in water.) Adding the washing soda (Na_2CO_3) electrolyte to the water further enhances the conductivity of the solution, as the washing soda dissociates into sodium ions (Na^+) and carbonate ions (CO_3^{-2}). The increased concentration of ions increases the conductivity of the solution and speeds up the electrolysis.

The negative side of the battery provides electrons to the hydrogen cations, producing hydrogen gas that collects in the "–" tube. The positive side of the battery strips the hydroxide anions of electrons, producing oxygen gas that collects in the "+" tube. This can be confirmed by splint tests (used in the step-by-step procedure provided in **Decomposing Water** on the **Ford PAS Web site**). For oxygen, a glowing splint should glow more strongly or burst back into flame, since oxygen supports combustion. The hydrogen gas should create a barking or squeaking sound when a burning splint is inserted into the test tube, because hydrogen explodes when ignited.

As shown in the overall decomposition reaction, twice as many hydrogen molecules as oxygen molecules are produced by electrolysis. If equal temperature and pressure are assumed for the two gases, then the volume ratio of hydrogen to oxygen collected should also be 2:1. Although individual teams may not get this exact ratio, averaging their results together should produce a ratio very close to 2:1.

TEACHER INFORMATION:

HYDROGEN PRODUCTION

[For Session 15]

A great deal of research is being done to find improved methods of hydrogen production and storage. The following information provides an overview of some hydrogen production methods currently in use or under development.

Comparing Methods

It is important to have standard measures that can be used to compare hydrogen production methods to each other and to conventional fuels. One of these standard measures is the price per gasoline gallon equivalent (gge). A gge is the amount of hydrogen that has the same energy content as a gallon of gasoline. (Equal volumes or equal masses of hydrogen and gasoline don't have the same energy content, so comparing hydrogen and gasoline by price per gallon or price per pound would not be useful.) Since a primary interest in hydrogen is as a transportation fuel, one overarching goal of hydrogen research programs is for the price of hydrogen to be competitive with gasoline. The actual price of gasoline varies on a weekly or even daily basis, so rather than having researchers aim for this moving target, the U.S. Department of Energy has set a target cost for hydrogen of $2–3/gge.

Different methods of producing hydrogen for use as a transportation fuel are also sometimes compared on a "well to wheels" basis; this means looking at not only the costs, but also the energy use and emissions from extracting/producing, refining, transporting, and using a fuel.

Electrolysis of Water

In the production of hydrogen by electrolysis, electricity is used to split water as follows:

$$2H_2O\ (l) \rightarrow 2H_2\ (g) + O_2\ (g)$$

This reaction takes place in two parts, called *half-reactions*—one at the electrolyzer's anode and one at the cathode. The exact equations of these half-reactions depend on the type of electrolyzer. Here are the half-reactions for a polymer electrolyte membrane (PEM) electrolyzer:

1. When the electrical power source is connected to the electrolyzer, electrons flow from this source to the cathode of the electrolyzer. A reduction reaction takes place at the negatively charged cathode:

$$4H_2O\ (l) + 4e^- \rightarrow 2H_2\ (g) + 4OH^-\ (aq)$$

The reaction at the cathode is also sometimes written without showing the hydroxide ions:

$$4H^+\ (aq) + 4e^- \rightarrow 2H_2\ (g)$$

2. An oxidation reaction occurs at the positively charged anode:

$$2H_2O\ (l) \rightarrow O_2\ (g) + 4H^+\ (aq) + 4e^-$$

The electrons produced at the anode flow back through the electrical circuit to the cathode. The hydrogen ions move from the cathode through the electrolyte to the anode.

Electrolysis takes place in an *electrolyzer*, a piece of equipment very similar to a fuel cell. In a fuel cell, the inputs are hydrogen and oxygen gases, and the outputs are electricity and water. Electrolyzers do the same in reverse: Electricity and water are the inputs, and hydrogen and oxygen gases are the outputs. (In fact, some fuel cells can be run in reverse and used as electrolyzers. This is what students did with their fuel cell car kits.) There are a variety of types of electrolyzers, but the basic unit of operation is a cell consisting of an anode and a cathode separated by an electrolyte. A large electrolyzer would combine many of these cells in a stack.

Sources of Electricity

Any power source that can be used to generate electricity can be used to power the production of hydrogen from water. This includes electricity from the power grid (which, in the United States, mostly comes from burning coal) as well as electricity directly from solar, wind, hydro, biomass, and nuclear power plants. Thus, one benefit of using electrolysis as a hydrogen production method is that it increases diversity of the energy supply, particularly the transportation energy supply; through electrolysis, any energy source that can be used to produce electricity can become, indirectly, a transportation fuel.

If solar, nuclear, or wind power are used to generate the hydrogen, the hydrogen can be produced with close to zero greenhouse gas emissions. However, if the power source used in the production of the hydrogen causes pollution, then pollution from car exhaust is just being traded for pollution at the hydrogen production plant. (These amounts of pollution are not necessarily equal, so this trade could be for the better or for the worse.) Currently about half the electricity produced in the United States is generated using coal, and about 20 percent is generated using other fossil fuels. Thus, if the electricity used to produce H_2 is generated using the fuels typically used to generate electricity, a lot of greenhouse gases and other pollutants will be released into the atmosphere.

Commercial Electrolysis

Commercial production of hydrogen through electrolysis currently occurs on a small scale, for applications where very pure hydrogen is needed, such as in the pharmaceutical, electronics, and food industries. However, according to the National Renewable Energy Laboratory (NREL), electrolysis is used to produce hydrogen only on a small scale simply because of the low demand for hydrogen. Should the demand increase, NREL says that it will become feasible to build low-cost wind- and nuclear-powered electrolyzers that are 10–100 times the size of today's electrolyzers.

The primary cost of producing hydrogen by electrolysis is the electricity required. Thus, the cost can be reduced by developing cheaper sources of electricity and by developing electrolyzers that are more efficient (meaning that they can produce more hydrogen from a given amount of electricity). Currently, the cost of hydrogen fuel is substantially higher than the cost of an equivalent amount of gasoline. However, because cheap renewable energy and energy-efficient electrolyzers are active areas of research, the cost of hydrogen produced by electrolysis is always changing.

Reforming

Reforming can be used to produce hydrogen from a variety of hydrocarbons. Of greatest interest are natural gas, because it is currently the dominant source of hydrogen gas, and liquid biofuels, because they offer the possibility of a carbon-neutral energy source. Natural gas consists mostly of methane. It may be found in underground deposits called *natural gas fields* or in deposits associated with oil fields or coal beds. Liquid biofuels, also called *renewable liquid fuels*, are derived from biomass—recently living organisms or their metabolic by-products. Examples include bioethanol, which is usually produced by fermenting sugars from sugar and starch crops; and biodiesel, which is made from vegetable oils and animal fats, including recycled grease.

Natural Gas Reforming

Hydrogen can be produced from natural gas through steam methane reforming, which generates about 95 percent of the hydrogen used in the United States, or through partial oxidation. (Note that the term *reforming* is sometimes used to refer specifically to steam reforming and is sometimes used to refer to both partial oxidation and steam reforming.)

Steam methane reforming: In this process (sometimes called *steam reforming*), the methane in natural gas reacts with high-temperature steam in the presence of a catalyst forming carbon monoxide (CO) and hydrogen gas, as shown in the following chemical equation:

$$CH_4 + H_2O \text{ (+ heat)} \rightarrow CO + 3H_2$$

The carbon monoxide is then reacted with water in the presence of a catalyst to produce carbon dioxide and more hydrogen gas:

$$CO + H_2O \rightarrow CO_2 + H_2 \text{ (+ heat)}$$

The above reaction is called the *water-gas shift reaction*; the oxygen is shifted from the water to the carbon monoxide gas.

Partial oxidation: In this process, the methane and other hydrocarbons in natural gas react with oxygen, but not enough oxygen to completely oxidize the hydrocarbons. Unlike steam methane reforming, partial oxidation doesn't require heat to be added for the reaction to occur; the reaction actually gives off heat:

$$CH_4 + ½O_2 \rightarrow CO + 2H_2 \text{ (+ heat)}$$

The gas mixture produced is called *synthesis gas* or *syngas*, and hydrogen can be separated from it. As with steam methane reforming, additional hydrogen gas is usually produced using the water-gas shift reaction.

Liquid Biofuel Reforming

There are a variety of hydrocarbons found in liquid biofuels. This equation shows the reformation of one of these hydrocarbons, ethanol (C_2H_3OH). The ethanol reacts with high temperature steam to produce carbon monoxide and hydrogen gas:

$$C_2H_3OH + H_2O \text{ (+ heat)} \rightarrow 2CO + 4H_2$$

The carbon monoxide can be reacted with steam in the water-gas shift reaction (the same reaction used in steam methane reforming) to produce carbon dioxide and additional hydrogen gas:

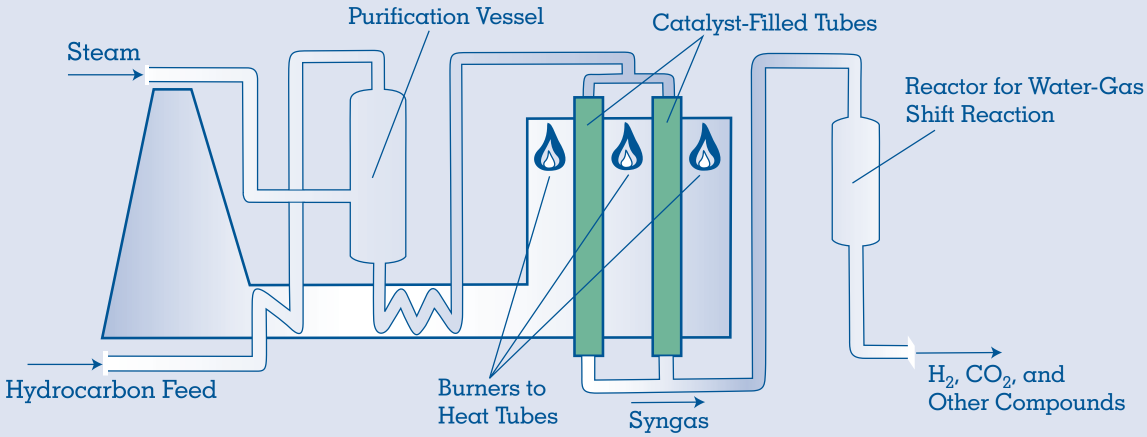
$$CO + H_2O \rightarrow CO_2 + H_2 \text{ (+ heat)}$$

Steam reforming or partial oxidation of other fuels, including propane and gasoline, is also possible, but natural gas reforming produces less carbon dioxide per unit of hydrogen produced than does reforming of these other fuels.

Reforming Plants

Currently, most natural gas reforming plants are large central facilities similar to oil refineries. A plant for large-scale reforming of liquid biofuels would be similar in design.

Natural Gas Reforming Plant



In a typical reforming plant, the hydrocarbon feed is purified and then mixed with steam. The hydrocarbon-steam mixture passes through catalyst-filled tubes that are heated (by combustion of other fuels), producing a synthesis gas (syngas), a mixture primarily made up of hyrodgen gas and carbon monoxide. The syngas then passes through one or more reactor tanks where the water-gas shift reaction takes place, producing additional hydrogen gas as well as carbon dioxide. The resulting gas mixture needs to be treated to separate the hydrogen gas from the other compounds.

Natural gas reforming at central facilities is currently the least expensive method of producing H_2 on a large scale, at a cost of $2–3/gge. The costs associated with natural gas reforming include the drilling for and refining of the natural gas, the capital equipment, and the operation and maintenance. Though natural gas reforming at centralized facilities is a mature technology, further research advances may reduce the cost. The cost of natural gas reforming on a smaller scale, which is currently higher than production at centralized facilities, is likely to decrease as a result of current research.

The Future of Reforming

Natural gas reforming is expected to be an important source of hydrogen in the near future; it is less expensive than other methods of hydrogen production currently available, and the infrastructure—reforming plants and a system for distributing the natural gas to them—already exists.

However, natural gas reforming is not expected to be a long-term source of hydrogen for transportation fuel. The United States already consumes more natural gas than it produces; in 2007, net imports of natural gas were more than 100 billion cubic meters. Relying on natural gas reforming to produce hydrogen would merely trade dependence on foreign oil for dependence on foreign natural gas. Also, as the chemical reactions above demonstrate, natural gas reforming produces greenhouse gases. (Refining of raw natural gas also produces other atmospheric pollutants.) Because of these factors, funding from the U.S. Department of Energy for research on natural gas reforming is directed only toward research on distributed natural gas reforming on a smaller scale, for use at hydrogen fueling stations during the period of transition to a hydrogen economy.

Liquid biofuels are of more interest as a possible long-term source for hydrogen production, but improvements to currently available technology are needed to make reforming of biofuels more efficient and cost-effective.

Gasification

Gasification is a process in which carbon-rich materials, such as coal or biomass, react with oxygen and steam at high temperatures to produce syngas—a mixture of carbon monoxide, carbon dioxide, hydrogen gas, and solid residue.

The chemical reaction for gasification of coal is as follows:

$$CH_{0.8} + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{other compounds}$$

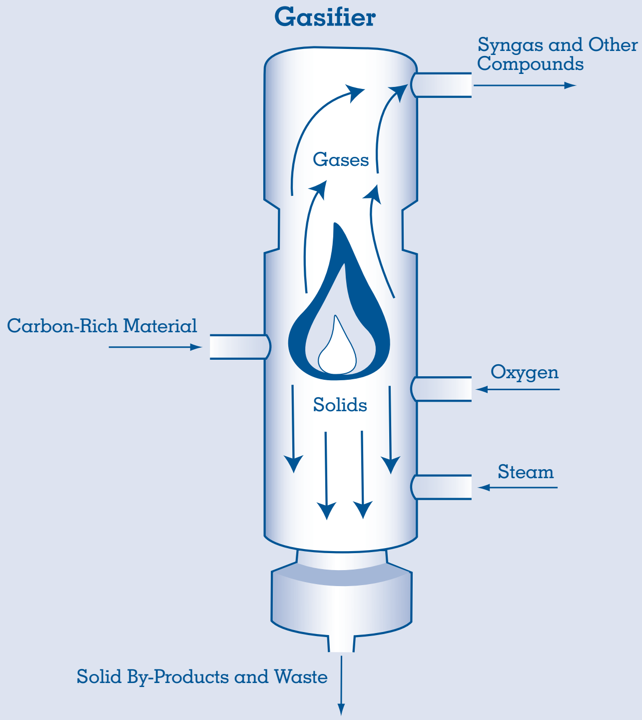
The fractional subscript on the CH indicates that coal is a mixture of hydrocarbons with an average of 0.8 hydrogen atoms per carbon atom.

Biomass contains a wide variety of hydrocarbons and other chemicals. One hydrocarbon that is common in biomass is cellulose. Cellulose is a *polysaccharide*—a long chain of sugars. In a chemical equation, cellulose can be represented as a single sugar, such as glucose. Multiplied many times over, this reaction represents the gasification of cellulose:

$$C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{other compounds}$$

Gasifiers

Gasification reactions take place in a unit called a *gasifier*. Water, oxygen, and fuel (such as coal or biomass) are fed into the gasifier. The outputs from the gasifier include high-pressure steam, syngas, and solid by-products. Hydrogen is already produced by gasification on an industrial scale. A common application is burning the syngas (containing the hydrogen) in a turbine to produce electricity. To use the hydrogen gas for other applications, it must be separated from the other chemicals in the syngas.



Sources of Carbon-Rich Materials

Coal, petroleum, biomass, and biofuels can all be used as a source of carbon-rich material for gasification. In the United States, the main interest is in using coal, biomass, and biofuels. (Because so much of the petroleum is imported, using it in gasification would not help the country progress toward energy independence.) It is estimated that the United States has enough coal reserves to produce a 200-year supply of hydrogen. Thus, gasification of coal could reduce U.S. dependency on foreign oil. There are disadvantages, however. The process of mining coal can be very harmful to the environment. Also, as the chemical equations above show, gasification produces carbon monoxide and carbon dioxide, both of which are greenhouse gases. For gasification of coal to be an environmentally sustainable means of producing hydrogen, effective ways to capture and sequester carbon must be developed.

Gasification of biomass also produces carbon dioxide. However, the carbon dioxide produced will be no greater than the amount of carbon dioxide absorbed from the atmosphere when the biomass was growing. Because of this fact, biomass gasification is sometimes described as being “carbon neutral”—resulting in a net-zero release of carbon dioxide.

Costs of gasification include mining the coal or growing and harvesting the biomass, the capital cost of equipment, and carbon sequestration. For gasification to be a viable means of producing hydrogen for widespread use, the cost of the gasifier and the cost of the separation equipment must be reduced. If biomass is to be used as the fuel, agricultural improvements that reduce the cost of the biomass are needed. If coal is to be used as the fuel, a safe and cost-effective means of sequestering the greenhouse gases produced is needed.

TEACHER INFORMATION:

HYDROGEN PRODUCTION TERMS

[For Session 16]

The following are terms that students might encounter as they conduct their research on methods of hydrogen production.

Adsorption: The binding of molecules or particles to a surface.

Alkaline: Having a pH greater than 7; a base.

BTU (British thermal unit): The amount of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

Carbon sequestration: The capture and removal of carbon dioxide from the atmosphere.

Compressor: The part of a cooling unit or heat pump that compresses refrigerant gas to help it absorb heat.

Fermentation: A process in which an organic substance breaks down into simpler substances, particularly under anaerobic (no-oxygen) conditions.

Particulate matter: Tiny particles of solid or liquid suspended in a gas.

Polymer: A large molecule made up of chains or rings of linked simpler molecules. Examples of common polymers include PVC (polyvinyl chloride) and polystyrene (plastic foam).

Recuperator: A device used to recover heat from the products of combustion.

Reformate: A product of hydrocarbon reforming.

Sieve: A device used to separate larger objects from smaller objects or to separate solids from a liquid; a strainer.

Synergy: Two things working together.

Types of Hydrogen Production

Chloralkali electrolysis: Electrolysis of common salt or sodium chloride.

Naphtha reforming: A process that converts low-octane hydrocarbons into higher-octane products.

Photobiological hydrogen production: A hydrogen production process that uses algae.

Photocatalytic decomposition of water: The process of using light to split water into hydrogen and oxygen in the presence of a catalyst.

Photoelectrochemical decomposition of water: The process of shining sunlight on a semiconductor immersed in an electrolyte solution to split water into hydrogen and oxygen.

ACTIVITY 4:

Under Pressure

Notes:

ACTIVITY OVERVIEW

Students learn about the relationship between the microscopic and macroscopic properties of different states of matter, and the impact of temperature and pressure on the state of matter. They explore the properties of gases and consider how these properties might impact hydrogen gas storage, especially for personal vehicles. Students conduct research and create Background Memos on different methods of hydrogen storage—liquefaction, compression, metal hydrides, and emerging technologies—and then share what they've learned with their Hydrogen Technology Research teams.

Sessions 18–21

Before You Teach

Session 18

- Make sure that the **States of Matter Simulation** on the **Ford PAS Web site** can be accessed and run on student computers.

Session 19

- Set up the Behavior of Gases Stations. Provide a box at each station for student teams to cast their ballots. Also, post a copy of the appropriate **Behavior of Gases Station RM (RM 4.5–4.10)** at each station.
- Make a large-size copy of **RM 4.3 Gas Laws at a Glance**, and post it at a central location between the six stations.

Session 20

- Decide whether to have students write their Hydrogen Storage Background memos on the computer, rather than by hand.

Notes:

Materials Needed

Session 18

- Copies of **RM 4.1 Exploring States of Matter** (one for each pair or team of students)
- Computers with access to the Internet (one for each pair of students)
- Copies of **RM 4.2 Physical Properties of Matter Table** (one for each pair or team of students)

Session 19

- Students' copies of **RM 4.1 Exploring States of Matter**
- Large-size copy of **RM 4.3 Gas Laws at a Glance**
- Copies of **RM 4.4 Analyze the Behavior of Gases** (one for each student)
- Copy of **RM 4.7 Behavior of Gases Station 3**
- Copy of **RM 4.8 Behavior of Gases Station 4**
- Copy of **RM 4.10 Behavior of Gases Station 6**
- Six ballot boxes (one for each station)
- Small notecards or pieces of paper for balloting (small stack for each station)

For each Behavior of Gases Station 1:

- Copy of **RM 4.5 Behavior of Gases Station 1**
- Safety goggles (one pair for each student in a team)
- Two 1 L beakers
- Ice
- Water
- Hot plate
- Two round balloons (for each team)
- String
- Tongs

For each Behavior of Gases Station 2:

- Copy of **RM 4.6 Behavior of Gases Station 2**
- 1 or 2 L plastic soda bottle with cap, label removed

Notes:

- Water
- Eyedropper

For each Behavior of Gases Station 5:

- Copy of **RM 4.9 Behavior of Gases Station 5**
- Safety goggles (one pair for each student in a team)
- Five large marshmallows (for each team)
- Vacuum pumper

Session 20

- Copies of **RM 4.11 Hydrogen Storage Background Memo: Compression** (one for each member of the hydrogen compression team)
- Copies of **RM 4.12 Hydrogen Storage Background Memo: Liquid Hydrogen** (one for each member of the hydrogen liquefaction team)
- Copies of **RM 4.13 Hydrogen Storage Background Memo: Metal Hydrides** (one for each member of the metal hydrides team)
- Copies of **RM 4.14 Hydrogen Storage Background Memo: New Technologies** (one for each member of the new technologies team)
- Computers with access to the Internet (at least one for each team)

VOCABULARY

Avogadro's law

Boyle's law

Charles's law

Energy density

Gas laws

Gas pressure

Metal hydrides

ACTIVITY 4:
Under Pressure

INTRODUCTION

At room temperature and pressure, hydrogen is a gas. This fact has important consequences for hydrogen's use—particularly as a transportation fuel—because hydrogen has a low energy content by *volume* (so you need a lot of it) and because gases behave differently from liquids, such as gasoline. In this activity, you'll learn more about the different states of matter, and you'll explore the scientific laws that describe the behavior of gases, which will help you better understand the challenges of using hydrogen as an energy solution—especially for personal vehicles. You'll also research the different methods that are currently being considered for storing hydrogen.

Learning Goals

- Describe the behavior of matter in different states and under different conditions.
- Analyze different methods of hydrogen storage to determine the pros and cons of each method.

FOR YOUR GLOSSARY

Avogadro's law
Boyle's law
Charles's law
Energy density
Gas laws
Gas pressure
Metal hydrides

Notes:

SESSION 18
WHAT STATE?

[Whole Class/Teams]

In the Model Fuel Cell Car Lab in Activity 1, students estimated the volume of hydrogen gas needed to fuel their model car for 300 miles. Of course, a real car would need a lot more hydrogen gas than the model car. And, since hydrogen is a gas at room temperature and pressure—and because storing hydrogen gas is a challenge—it's important for students to understand a bit more about the properties of the different states of matter as well as the characteristics of gases in particular.

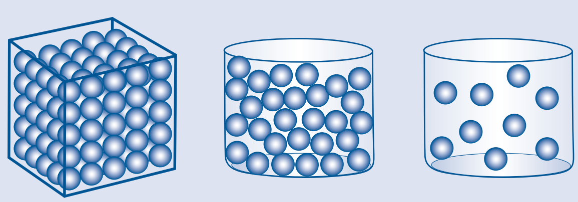
Begin by going over the **Questions for Reflection** from **State Your Matter** on page 67 (page T 157):

1. Name three substances that you know of that can be found in more than one state on Earth. What causes each of these substances to exist in more than one state? (In other words, what conditions affect the state?)

   Possible Answers: Water is the most obvious answer—it exists as a liquid, steam (a gas, once you can't see it any more), and ice (a solid), depending on the temperature. Students may also mention a variety of foods that they have seen in both solid and liquid states (for example, butter or chocolate), metals that can be found in liquid and solid forms, and rocks and magma found in volcanoes.

2. How do the particles of matter interact with one another? Come up with an analogy for how the particles interact, or create a drawing that shows what the particles look like inside a container in each of the three states.

   Possible Answers: One analogy might be marbles packed tightly in a jar (to represent a solid), rolling around loosely in a flat container (to represent a liquid), and falling off of a table (to represent a gas). Or, students may draw a representation similar to the one shown here:



Solid Liquid Gas

Have students work in pairs or small teams to explore the **States of Matter Simulation** on the **Ford PAS Web site**, using **Exploring States of Matter (RM 4.1)**. (Students will complete the Analysis questions for homework.) Bring the class back together and have student pairs/teams share their results.

WHAT STATE?

Under typical conditions, hydrogen is a gas and gasoline is a liquid. Why does the state of matter of a substance *matter*? It matters because the state of matter determines lots of things about a substance, which affects how we can use it.

Begin by exploring how matter changes from one state to another, using the **States of Matter Simulation** on the **Ford PAS Web site**.

Once you know a bit more about how matter changes from one state to another, it's time to think about how the microscopic properties of matter affect the macroscopic properties of a substance. Each state of matter has its own distinct macroscopic properties. You can easily distinguish between the phases of water, for example, by looking at them but also by the different properties of each—ice floats in water, while steam disperses in the air above a pot of boiling water. Think about the particles of matter in different states—their motion, the distances between them, and their organization. How would the particles themselves—and their interactions with one another—account for the physical properties of substances in different states?

DID YOU KNOW?

More than 99 percent of matter in the universe exists in a fourth state—the plasma state. Although they share a name, the plasma state of matter and blood plasma are unrelated. *Plasma* as a state of matter is ionized gas, made up of free electrons and positive ions (atoms or molecules that have been stripped of electrons). Overall, plasmas are electrically neutral, but the presence of charged particles within them makes plasmas good conductors of electricity.

Plasmas are typically associated with very high temperatures. Stars are made of plasma heated by nuclear fusion, and portions of comets' tails are plasma that is heated and ionized by sunlight. Even the space between stars is filled with plasma. Though relatively rare, plasma can also be found here on Earth. Lightning is a massive electrical discharge in the atmosphere that creates a jagged column of plasma. The northern and southern lights, or aurorae, are created by plasma in the solar wind interacting with Earth's magnetic field. Fluorescent light bulbs, neon signs, and plasma screen televisions also contain plasma, but it is artificially produced.

HOMEWORK 4.1

Answer the Analysis questions from **Exploring States of Matter**.

Notes:

TEACHER INFORMATION

For answers to **Exploring States of Matter (RM 4.1)**, see **States of Matter Explained** on pages T 199–T 200.

Have student pairs/teams fill out **Physical Properties of Matter Table (RM 4.2)**. Students should make their best guesses about the physical properties of each state, based on the information given about the behavior of the particles in each state of matter. Bring the class back together, and fill out the table as a class (or have individuals volunteer their answers for a state or a property).

Answers:

Physical Property	Solids	Liquids	Gases
Compressibility	**Slightly compressible**	**Slightly compressible**	**Highly compressible**
Density	**High**	**High**	**Low**
Volume (that is, what happens to the volume when matter is put into a container)	**Retains volume**	**Has definite volume—doesn't fill container**	**Volume expands to fill container completely**
Shape (that is, what happens to the shape when matter is put into a container)	**Retains shape**	**Assumes shape of container**	**Assumes shape of container**
Diffusion	**Diffusion at surfaces only**	**Slow diffusion**	**Rapid diffusion**
Expansion with heating	**Little**	**Little**	**High**

Ask students what they think the *attractive forces*—the forces between particles—are like for each state of matter, based on what they know about how the particles interact.

Answers: The attractive forces between particles in a solid are very strong, which is why the particles remain in fixed positions and packed together. The attractive forces between the particles in a liquid are strong enough to keep the particles together but not in a rigid structure. The attractive forces between particles in a gas are weak, which is why the particles do not remain together at all.

Notes:

SESSION 19
LAW-ABIDING GASES

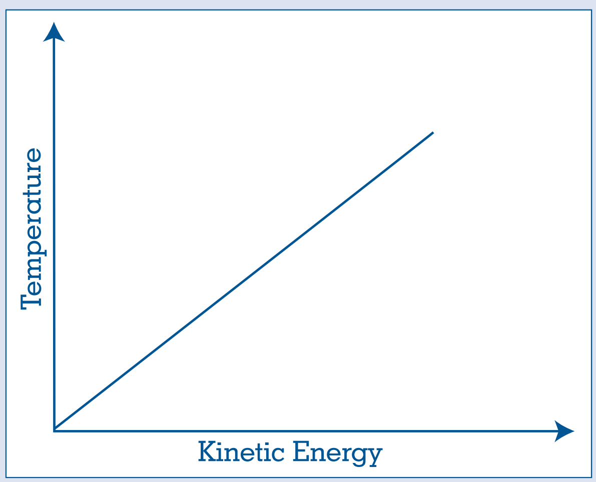
[Teams/Whole Class]

Explain that in the Model Fuel Cell Car Lab in Activity 1, students considered the hydrogen gas needed to fuel their model car. Now they are going to look in more depth at the behavior of gases, since this is the state of hydrogen that hydrogen fuel cells use. Students visit different Behavior of Gases Stations and are challenged to determine which gas law each station's demonstration or real-life example exemplifies.

Begin by discussing students' responses to the Analysis questions from **Exploring States of Matter (RM 4.1)**.

1. How does temperature relate to the kinetic energy of molecules? Briefly summarize or draw a graph to describe this relationship.

   Answer: As the kinetic energy of molecules increases, the temperature in the container rises.



Some students may mistakenly respond that as the temperature inside the container rises, the kinetic energy of the molecules increases. In fact, temperature is actually just a measure of the kinetic energy of molecules. So, as heat is added to the container, the kinetic energy of the molecules increases, measured externally as the temperature increasing inside the container.

LAW-ABIDING GASES

You already have learned about some ways that hydrogen gas can be produced for eventual use in fuel cell vehicles. But once the hydrogen is made, it doesn't get used right away—it needs to be stored. And hydrogen gas is not easy to store: It's highly flammable, and, at regular temperature and pressure, it takes up a lot of space.

One of the most important things to understand about hydrogen gas storage is that gases—which are very disorganized—do follow a certain set of "rules" that allow us to understand how they will behave under different conditions. Gases abide by a set of scientific laws known as the **gas laws**, which describe the relationships among the pressure, volume, and temperature of gases. Understanding these relationships will help prepare you to weigh the pros and cons of different methods of hydrogen storage and to decide whether hydrogen is feasible as a fuel for personal vehicles.

Visit each of the Behavior of Gases Stations to explore the different gas laws and find out what they tell you about the relationships among gas pressure, volume, and temperature.

HOMEWORK 4.2

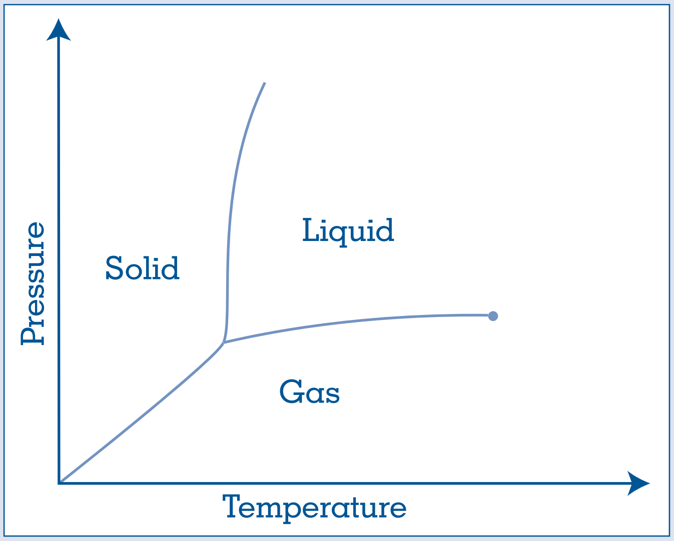
Read **Gas Laws Expanded** and answer the **Questions for Reflection**.

Notes:

2. How and why does a change in temperature affect the pressure inside a container?

   Answer: As the temperature increases, the particles move around the container more and faster, which leads to more collisions with the container and thus an increase in the pressure inside the container. As temperature decreases, the particles move around the container less and more slowly, which leads to fewer collisions with the container and thus a decrease in the pressure inside the container.

3. Explain the following phase diagram by relating what you know about states of matter, temperature, and pressure.



   Answer: Changes in temperature and pressure both cause changes in the state of matter. The diagram shows that temperature and pressure affect the state in which matter exists. Students may also describe specifically how temperature and pressure affect the state; for example, students may say that at high pressure and low temperature, matter is solid, and so on.

Distribute **Analyze the Behavior of Gases (RM 4.4)**. Divide the class into teams, having students from different Hydrogen Technology Research teams work together. Have teams cycle through the six stations, filling in the table on **Analyze the Behavior of Gases (RM 4.4)** to record their analysis for each station.

After teams complete the table for the station, they should vote on which gas law they think is represented and then place their ballot in the voting box.

After teams have visited all six stations, bring the class together and look at the ballots in each station's voting box. If all the ballots are the same, ask for a volunteer to discuss why that station

Notes:

represents the gas law selected, including sharing his or her team's analysis for that station. If there is any disagreement, ask volunteers who voted for different gas laws to explain their reasoning, and challenge the class to come to a consensus.

Answer: The following table shows the gas laws represented at each station:

Station	Boyle's	Charles's	Avogadro's
1		√	
2	√		
3			√
4	√		
5	√		
6		√	

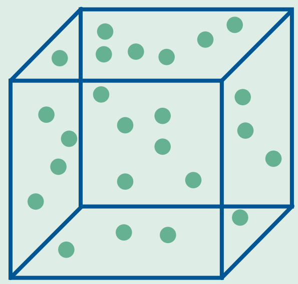
TEACHER INFORMATION

Refer to **Behavior of Gases Stations Explained** on pages T 201–T 204 for more detailed information about each demonstration and scenario and for answers to the questions from **Analyze the Behavior of Gases (RM 4.4)**.

Gas Laws Expanded

Stored gases are used for a variety of applications, such as providing SCUBA divers with air or filling party balloons with helium. As you begin to think about how hydrogen gas might be safely and conveniently stored for use in fuel cell vehicles, consider the general properties and behaviors of gases.

Gases are characterized by three directly measurable physical properties: pressure, volume, and temperature. Imagine a sample of gas inside a closed box or container.



Gas

- Takes Shape of Container
- Equals Volume of Container

Gas pressure is the force per unit area exerted on the walls of the container, generated by the collisions of gas particles with the walls. A gas has no definite shape or volume, so it will assume the shape and volume of its container. This means that the volume of the gas is equal to the volume of the container. When a substance is at a higher temperature, its particles are moving faster. So, temperature is actually a measure of the average kinetic energy of the particles, while pressure is a measure of the force of the particles striking a surface. The relationships among these physical properties of gases are described by a set of fundamental gas laws. Four of these laws, are described here.

Boyle's Law

In 1662, Irish scientist Robert Boyle published results from his experiments to determine the relationship between the pressure and volume of a gas at a constant temperature. **Boyle's law** states that the product of the pressure and the volume of any size gas sample is a constant for any constant temperature. In other words, if the pressure on a sample of gas decreases while the temperature stays the same, the volume of gas will increase.

The equation for Boyle's law is:

$$PV = k_1$$

where:

P = pressure
V = volume
k_1 is a constant

Charles's Law

Charles's law was discovered in the late 1700s by the French chemist Jacques Charles. This law states that when pressure is held constant, the volume and temperature of a gas are directly proportional to one another: The volume of a gas sample increases or decreases by the same factor that its absolute temperature increases or decreases. In other words, when the temperature of a gas at constant pressure rises, its volume increases, and when the temperature of a gas at constant pressure decreases, its volume decreases. Therefore, the product of the volume and the absolute temperature for any gas always has the same value. The value of that product is called the *proportionality constant*.

The equation for Charles's law is:

$$V = k_2T$$

where:

V = volume
k_2 is a proportionality constant
T = temperature

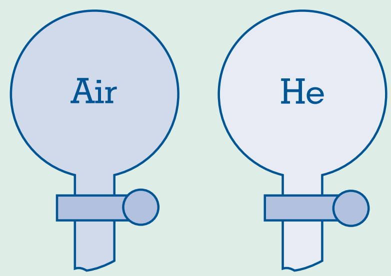
ABSOLUTE TEMPERATURE SCALE

The Kelvin temperature scale (the SI temperature scale) is the absolute temperature scale widely used in chemistry, physics, and astronomy. The Kelvin scale is named for the British scientist and inventor William Thompson, a.k.a. Lord Kelvin. The zero point of the Kelvin scale, known as *absolute zero*, is a hypothetical temperature at which all molecular motion ceases. (Absolute zero is a hypothetical temperature because it is impossible to actually reach such a temperature.) On the Kelvin scale, water freezes at 273 K (0°C; 32°F) and boils at 373 K (100°C; 212°F). Temperatures in Kelvin can easily be converted from Celsius using the following simple equation:

$$K = {}^{\circ}C + 273$$

Avogadro's Law

Avogadro's law states that equal volumes of gases at the same temperature and pressure contain the same number of particles. This means that the number of atoms or molecules in a given volume of gas is independent of the size or mass of the individual particles (because two identical volumes of different gases will contain the same number of particles). In other words, despite having the same volume and number of particles, a gas with higher mass will weigh more. So, while the number of particles in an air balloon and a helium balloon at the same temperature and pressure are the same, the helium atoms weigh less than the molecules of the gases that make up air (mostly nitrogen and oxygen, with a little carbon dioxide, water vapor, and argon).



	Air	He
Volume:	22.4 L	22.4 L
Mass:	~29 g	~4 g
Quantity:	1 mol	1 mol
Pressure:	1 atm	1 atm
Temperature:	273 K	273 K

The equation for Avogadro's law is:

$$V = k_3 n$$

where:

V = volume
k_3 is a proportionality constant
n = the number of moles

The Ideal Gas Law

Once all of these relationships were discovered, the three laws were combined to form a single general law known as the Ideal Gas Law. The name of this law indicates that it describes the behavior of an ideal gas. While no real gas behaves in an ideal fashion all of the time, under most conditions they do, and so the Ideal Gas Law can be used. The relationships defined by the Ideal Gas Law are least accurate when a gas is at low temperatures and high pressures (these are the conditions where a gas would be close to becoming a liquid or solid).

The ideal gas equation is often expressed as:

$$PV = nRT$$

where:

P = pressure
V = volume
n = the number of moles
R is a proportionality constant
T = temperature

Questions for Reflection

1. Based on what you've learned about the behavior of gases at different temperatures and pressures, what do you think are some challenges of storing hydrogen gas for use as an energy carrier?
2. Based on the storage issues you identified, what do you think of the potential of hydrogen as an energy carrier in different applications—such as personal vehicles or stationary power-generation?

Notes:

SESSION 20

Discuss Hydrogen Storage [Whole Class]

Have a few students share their answers to the **Questions for Reflection** from **Gas Laws Expanded**, and use these questions to discuss the difficulties posed by storing hydrogen gas.

1. Based on what you've learned about the behavior of gases at different temperatures and pressures, what do you think are some challenges of storing hydrogen gas for use as an energy carrier?

   Possible Answers: Gas takes up a lot of space at typical temperatures and pressures, and therefore must be stored at low temperatures and/or high pressure in order to make it reasonable for use in applications such as personal vehicles.

2. Based on the storage issues you identified, what do you think of the potential of hydrogen as an energy carrier in different applications—such as personal vehicles or stationary power-generation?

   Possible Answers: Answers will vary, but students may note that with stationary applications, the tanks that hold the hydrogen could be much larger and therefore provide a reasonable amount of energy before refueling was needed.

THE STORAGE CONUNDRUM

[Teams]

Divide the class into teams. Make sure that each member of a Hydrogen Technology Research team is on a different team. Assign each team to research one of the following methods of hydrogen storage:

- Hydrogen compression
- Hydrogen liquefaction
- Metal hydrides
- New technologies

Depending on the size of the class, you may have more than one team assigned to each method. Each Hydrogen Technology Research team should have members researching each of the four storage methods.

THE STORAGE CONUNDRUM

One of the greatest difficulties facing commercial production of fuel cell vehicles is how to store the hydrogen on board the vehicle. (For stationary applications of hydrogen fuel cells, the storage issue is not as much of a problem; if the storage tanks don't need to be moved, they can be larger and heavier.) The properties of gases that you've just learned about make hydrogen much more challenging to store than gasoline. Room-temperature hydrogen gas has a very low energy density when measured by volume. (**Energy density** is the amount of energy contained in a given volume or mass of a substance.) In fact, hydrogen takes up around 3,000 times as much space as gasoline containing the same amount of energy.

Currently, hydrogen is stored in a couple of different ways, and several new technologies are under development. One method currently used is compressing the hydrogen in high-pressure tanks. Of course, as you have learned, the smaller the volume the gas is contained in, the greater the pressure exerted on the tanks. The tanks thus have to be made of special materials, and great care has to be taken to design them so they don't burst.

Another storage method currently used is liquefying the hydrogen. However, hydrogen doesn't become a liquid until it is cooled to –253°C, so it has to be stored in special tanks. The process of liquefying the hydrogen also requires a lot of energy—as much as 30–40 percent of the energy contained in the hydrogen.

A promising technology under development involves using **metal hydrides**, which are formed when metal alloys are combined with hydrogen. Metal hydrides can absorb hydrogen and then, in certain conditions, release it again. Challenges in using hydrides include their heavy weight and the need for high temperatures to release the hydrogen. Scientists are also working on other new hydrogen storage technologies, such as *carbon nanotubes*—microscopically tiny tubes of carbon that have lots of surface area that hydrogen atoms can bond to. However, these technologies are still in the early stages of development, and many challenges remain.

To learn more about the different ways that hydrogen is currently stored or might be stored in the future, work with your team to research your assigned storage method. Complete your Hydrogen Storage Background Memo, using the resources on the **Ford PAS Web site**. As you conduct your research, make a note of any scientific terms that you are unfamiliar with.

Notes:

Give each team the appropriate **Hydrogen Storage Background Memo (RM 4.11–4.14)**. Have teams read over their **Background Memo** and then go to the **Ford PAS Web site** to find resources to help them with their research.

TIP...

Each of the **Hydrogen Storage Background Memos (RM 4.11–4.14)** is available on the **Ford PAS Web site**. Teams may use a computer to write their memos and make copies for each team member.

TEACHER INFORMATION

Answers to the questions in the Hydrogen Storage Background Memos can be found in **Hydrogen Storage** on pages T 205–T 207.

HOMEWORK 4.3

Look through the notes that you took during your research on hydrogen storage methods, and list any scientific or technical terms that you had difficulty understanding.

Notes:

SESSION 21

Questions About Hydrogen Storage Terms

[Whole Class]

Ask students to share any scientific terms that they had difficulty understanding during yesterday's session. Go over these terms with the class, asking other students to help define them if they can.

TIP...

One strategy for figuring out the meaning of unfamiliar words is to break them apart into smaller words that students may already know. For example, if students can't figure out the meaning of the word *conformability* from the context, students may recognize the words *conform* and *ability*. This strategy and others are described in **Reading Strategies to Use On Your Own** in the Skill Appendix on page 93 (page T 231).

TEACHER INFORMATION

For a list and definitions of terms that students might encounter during their research, see **Hydrogen Storage Terms** on page T 208.

TIP...

If you have already set up a Word Wall, consider setting up a Hydrogen Storage section, using words that students identify from their research.

REFLECT ON HYDROGEN STORAGE

[Teams]

Have students meet in their teams to continue to research hydrogen storage methods. Toward the end of the session, have students meet in their Hydrogen Technology Research teams to share what they have learned about hydrogen storage and discuss the implications that their findings might have for the recommendations they make to their company.

REFLECT ON HYDROGEN STORAGE

Meet with your Hydrogen Technology Research team to share what you've learned about the hydrogen storage methods you researched. Together, discuss the pros and cons of the various storage methods. Are any of them suitable for on-board vehicle storage? What methods would work best for stationary applications of hydrogen fuel cells? Discuss how what you've learned will affect your recommendation to NuEnergy.

HOMEWORK 4.4

Think about what you have learned about hydrogen and fuel cells. For each of the four start-up companies, draft short answers to the key questions:

1. How will the technology being developed work? What's the science behind it?
2. What are the challenges to widespread adoption of this technology?
3. What environmental consequences, positive or negative, are likely to result from widespread adoption of this technology?

EXTENSIONS

4.1

Conduct research to get an idea of what a hydrogen fueling system for cars would mean for the country's infrastructure. What are some major obstacles to establishing a hydrogen infrastructure? What measures are already in place for a hydrogen infrastructure in the United States?

4.2

Learn about SCUBA diving and how the gas laws relate to this sport. Use what you learn to create an informational packet for potential students of the sport, explaining what SCUBA divers need to know about the gas laws and why. Go to the **Ford PAS Web site** for resources to help you get started.

TEACHER INFORMATION:

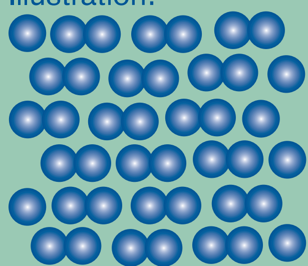
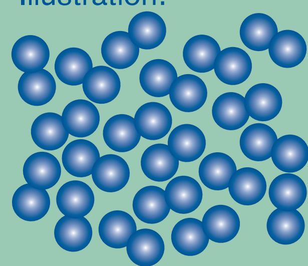
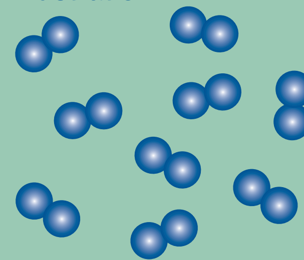
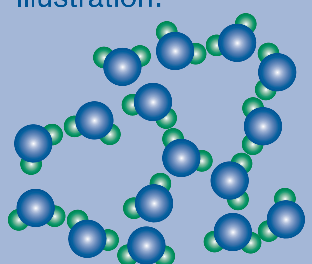
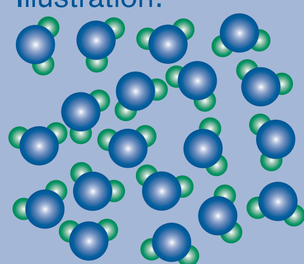
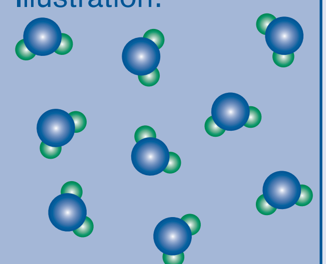
STATES OF MATTER EXPLAINED

[For Session 18]

The following are the answers to **Exploring States of Matter (RM 4.1)**.

Solids, Liquids, and Gases

Answers:

Substance	Solid	Liquid	Gas
Oxygen	Temperature: 20 K Illustration: 	Temperature: 59 K Illustration: 	Temperature: 194 K Illustration: 
Water	Temperature: 102 K Illustration: 	Temperature: 292 K Illustration: 	Temperature: 809 K Illustration: 

Phase Changes

Possible Answers: Students' answers may vary quite significantly. The following table provides answers or describes trends (underlined text) that should be exhibited in students' answers.

Substance	OBSERVATIONS: Initial Sample	Heat Added	Lid Pushed Down	After 10 Pumps
Oxygen	• Temperature: 20 K • Pressure: 0 ATM • Movement of molecules: Limited (in speed and distance) • Distance between molecules: Small	• Temperature: Temperature should rise by 100 K or more • Pressure: Pressure will rise • Movement of molecules: Lots • Distance between molecules: Increases	• Temperature: Temperature will rise • Pressure: Pressure will rise • Movement of molecules: Lots; fast • Distance between molecules: Decreases	• Temperature: Temperature will remain constant • Pressure: Pressure will rise • Movement of molecules: Lots; fast • Distance between molecules: Decreases
Water	• Temperature: 102 K • Pressure: 0 ATM • Movement of molecules: Small • Distance between molecules: Arranged in lattice pattern	• Temperature: Temperature will rise by approximately 400 K or more • Pressure: Pressure will rise • Movement of molecules: Lots, including spinning • Distance between molecules: Increases	• Temperature: Temperature will rise • Pressure: Pressure will rise • Movement of molecules: Lots; fast and spinning • Distance between molecules: Decreases	• Temperature: Temperature will remain constant • Pressure: Pressure will rise • Movement of molecules: Lots; fast and spinning • Distance between molecules: Decreases

Answers to the **States of Matter Simulation** Analysis questions are on pages T 184 and T 186.

TEACHER INFORMATION:
BEHAVIOR OF GASES STATIONS EXPLAINED
[For Session 19]

Behavior of Gases Station 1: Charles's Law

Charles's law states that at constant mass and pressure, the volume of a gas increases in a linear fashion as temperature rises.

In the late 1700s, French scientist Jacques Charles conducted experiments to determine how temperature affects the volume of a gas. Charles designed his experiment such that all properties of the gas were kept constant except for temperature and volume. He used a J-shaped glass tube containing mercury (similar to the one used by Boyle—see *Boyle's law*, below), such that a fixed amount of gas was trapped in the sealed end of the tube. He immersed the tube in a water bath so that he could change the temperature of the gas in the tube by changing the temperature of the water. He kept the pressure constant by adjusting the amount of mercury in the tube. (As long as the height of the mercury column on either side of the bend was kept the same, the pressure on the gas was constant.) Charles's experiment showed that the volume of the air in the tube was directly proportional to the temperature of the air: $\frac{V}{T} = \text{constant}$.

In this demonstration, students place one filled balloon in an ice bath and hold a similarly sized filled balloon over a beaker of boiling water, and then observe what happens to the balloons. The demonstration shows that the volume of gas in the balloon gets larger as the temperature rises and shrinks when the temperature drops. It illustrates Charles's law because the volume of the gas in the balloon increases as the temperature increases, and vice versa.

Behavior of Gases Station 2: Boyle's Law

Boyle's law states that the product of the pressure and the volume of any size gas sample is a constant for any constant temperature. In other words, if the pressure on a sample of gas decreases while the temperature stays the same, the volume of gas will increase.

Boyle's original 17th century investigation of the relationship between gas pressure (P) and volume (V) at constant temperature was done with a J-shaped glass tube (similar to Charles's—see above) that was sealed on the short end and open on the long end. Boyle added mercury to the tube, trapping a measurable volume of air in the sealed end of the tube. The pressure on the trapped air was proportional to the height of the mercury column. This setup allowed Boyle to measure how the volume occupied by a fixed amount of air changed as pressure was increased by the addition of more mercury to the tube. Taking careful measurements, Boyle discovered that the product of P and V was constant for a fixed amount of gas at a constant temperature ($PV = \text{constant}$).

In this demonstration, students fill a bottle with water and insert a partially filled eyedropper in the bottle. They then seal the bottle and put pressure on it by squeezing it. When they squeeze the bottle, the pressure on the air in the eyedropper causes the volume of air to decrease and more water to be drawn into the eyedropper. With a smaller volume of air and a greater volume of water, the eyedropper sinks. This demonstration illustrates Boyle's law because the increase in pressure (caused by squeezing the sides of the bottle) with no change in temperature causes the volume of the gas to decrease.

Behavior of Gases Station 3: Avogadro's Law

Avogadro's law states that equal volumes of different gases at the same temperature and pressure contain the same number of particles. In other words, the number of atoms or molecules in a given volume of gas is independent of the size or mass of the individual particles.

Hypothesized by the Italian scientist Amedeo Avogadro in the early 1800s, this law explained some of the behaviors of gases that confused scientists at the time, but it wasn't actually accepted by the scientific community until after Avogadro's death.

In this scenario, there are two balloons—one filled with helium and the other filled with an equal volume of air. Both balloons—according to Avogadro's law—are filled with the same number of particles of gas. However, helium weighs less than air, and so the balloon filled with helium floats, while the balloon filled with air sinks to the floor.

Behavior of Gases Station 4: Boyle's Law

In this scenario, a SCUBA diver notices that as a fellow diver breathes out gas bubbles, the bubbles rise toward the surface of the water. As the bubbles approach the surface, they expand in volume. This scenario demonstrates Boyle's law—as the pressure exerted by the water on the exhaled gas decreases (water pressure increases as you go deeper into the water), with no change in temperature, the volume of the gas increases, making the bubbles expand.

Behavior of Gases Station 5: Boyle's Law

In this demonstration, students observe marshmallows in a low-pressure environment. When they evacuate some of the air from the vacuum chamber, the marshmallows expand (because the air trapped inside them expands). This demonstration illustrates Boyle's law because the decrease in pressure from the vacuum, with no change in temperature, causes the volume of the gas to increase.

Behavior of Gases Station 6: Charles's Law

In this scenario, a syringe thermometer is used to see whether a turkey is done cooking. The syringe thermometer contains air. As the turkey heats up, the temperature of the air trapped in the syringe increases. As the temperature rises, the volume of the air increases. Eventually, the air expands so much that it breaks the seal on the syringe's plunger and the indicator pops up. This scenario demonstrates Charles's law because as the temperature of the air increases, the volume of the gas increases.

Answers to Analyze the Behavior of Gases

Table TI 4.1 shows the table in **Behavior of Gases (RM 4.4)** as students should complete it.

Table TI 4.1: Behavior of Gases Table Answers

		Station Number					
		1	2	3	4	5	6
What condition(s) changes *first* in this demonstration or scenario?	Pressure		X		X	X	
	Volume						
	Temperature	X					X
What changes as a result of the *first* change?	Pressure						
	Volume	X	X		X	X	X
	Temperature						
What stays the same throughout this demonstration or scenario?	Pressure	X		X			X
	Volume			X			
	Temperature		X	X	X	X	
Describe what happens to the gas in this demonstration or scenario.		As the temperature rises, the volume of the gas in the balloon increases. As the temperature drops, the volume of the gas in the balloon decreases.	As the pressure increases (by squeezing the bottle), the volume of gas inside the eyedropper decreases.	Since pressure, temperature, and volume remain constant, something else must differ between the two balloons.	As the gas bubbles rise, less pressure is exerted on the gas by the water, and the volume of the bubbles increases.	As the pressure on the gas in the marshmallow decreases, the volume of the gas increases.	As the temperature of the gases within the syringe increases, the volume of the gas increases and causes the plunger to pop.

TEACHER INFORMATION:

HYDROGEN STORAGE

[For Session 20]

One of the greatest challenges in the development of hydrogen fuel cell-powered vehicles is the need for compact, lightweight on-board storage systems. (For stationary applications of hydrogen fuel cells, the storage issue is not as important; if the storage tanks don't need to be moved, they can be larger and heavier.)

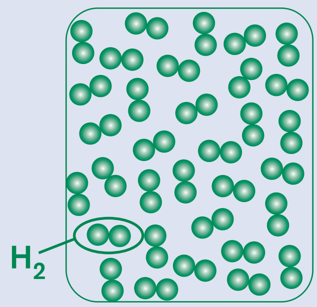
It is widely agreed that for hydrogen fuel cell cars to be acceptable to drivers, the cars must be able to travel 300 miles between refuelings. Given the expected fuel efficiency of hydrogen fuel cell vehicles, the on-board storage method must therefore have a capacity of 5–13 kg. (The exact amount of hydrogen needed depends on the size and type of vehicle.)

There are a number of characteristics required for a successful on-board hydrogen storage system, and the U.S. Department of Energy (DoE) has set target values for some of these characteristics. For example, the target value for gravimetric capacity is 2.5 kWh/kg. *Gravimetric capacity* is the usable energy from the stored hydrogen (measured in kWh), divided by the mass of the entire storage system (measured in kg).

A number of storage methods are under development, including hydrogen compression, hydrogen liquefactions, metal hydrides, and other solid materials, but as of 2010, none of these storage methods meet the DoE targets.

Hydrogen Compression

Compressed Hydrogen



To compress hydrogen for on-board storage, the gas is pumped into containers that can withstand anywhere from 5,000 to 10,000 psi (pounds per square inch). At these high pressures, the volume occupied by the hydrogen is much less than it would be at standard pressure.

For industrial use, hydrogen is stored in steel cylinders or tubes, but these containers are too large and too heavy to be used on fuel cell vehicles. For storage on vehicles, tanks made of lighter-weight composite materials are being developed. The process of refueling a vehicle with compressed hydrogen looks much like refueling with gasoline. The main difference is that when the fuel nozzle is inserted into the tank, an airtight seal keeps the hydrogen from leaking out.

Tanks for storing compressed hydrogen must be strong enough to withstand very high pressures.

AN ANALOGY

Filling a fuel tank with hydrogen is similar in many ways to filling a car's tires with air: The nozzle of an air hose fits onto the tire valve in such a way that air cannot escape. The air pump forces air into the tire, and the air pressure in the tire reaches a value much higher than the surrounding air pressure. A hydrogen fueling system works in a similar way, but instead of pumping in air to a pressure of 30 psi or so, the hydrogen refueling system pumps in hydrogen at pressures hundreds of times higher.

Tanks for storing compressed hydrogen must be strong enough to withstand very high pressures. This can result in the tanks being large and heavy. A number of possible solutions to this problem are being investigated:

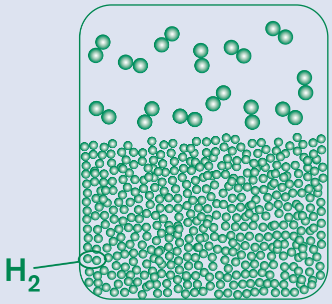
- New materials from which to make the storage tanks—however, such materials are likely to be expensive.
- Hybrid tanks that store hydrogen that has been compressed and cooled.
- New materials and new geometries for conformable tanks rather than cylindrical tanks. (Gasoline tanks in today's vehicles are *conformable*, meaning, they are shaped to take advantage of the available space, even when the space is irregularly shaped. With current technology, the walls of high-pressure hydrogen tanks have to be even thicker for a non-cylindrical tank than for a cylindrical tank.)

There are hydrogen fuel cell demonstration vehicles that store compressed hydrogen, and this method of on-board storage will be an important method in near-term efforts to create hydrogen fuel cell vehicles. However, it's difficult to predict whether this method might be a long-term solution to the storage problem.

Hydrogen Liquefaction

To store hydrogen as a liquid, the hydrogen must be cooled to -253°C and kept in insulated tanks. (Gases that have been cooled until they become liquid are sometimes referred to as *cryogenic*.) As a liquid, hydrogen takes up much less space than it does as a gas.

Liquid Hydrogen

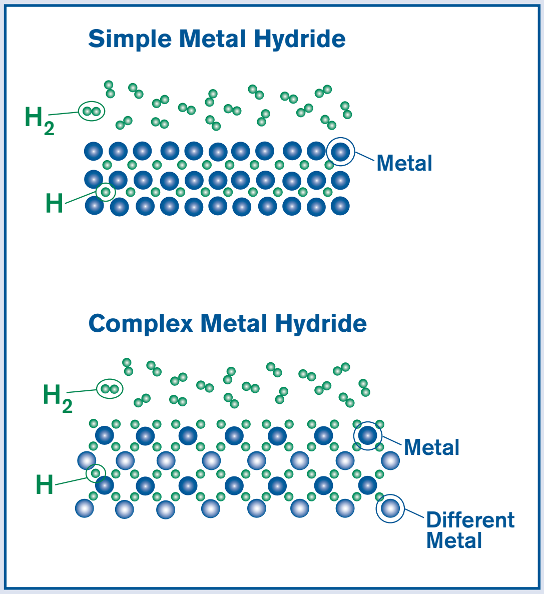


The on-board storage system for liquid hydrogen consists of an insulated tank. Refueling the tank would be very similar to filling up a fuel tank with gasoline. The primary difference is that a tight seal is needed between the nozzle and the fuel tank, to control the evaporation of hydrogen.

Compared to compressed hydrogen, more liquid hydrogen can be stored in a given volume. Also, the insulated tanks can more easily be made conformable. However, a lot of energy is required to cool the hydrogen. Another problem is that hydrogen may be lost through evaporation (sometimes referred to as *boil-off*.)

As with hydrogen compression, there are hydrogen fuel cell demonstration vehicles that store liquid hydrogen, and this method of on-board storage will also be important in near-term efforts to create hydrogen fuel cell vehicles. However, again, it's difficult to predict whether this method might be a long-term solution to the storage problem.

Metal Hydrides



A metal hydride is a chemical compound consisting of hydrogen and at least one metallic element. Simple metal hydrides form when hydrogen ions are absorbed into a metal with a simple crystal structure. The hydrogen ions fit in the gaps between the metal atoms. For example, lanthanum nickel ($LaNi_5$) absorbs hydrogen and becomes lanthanum nickel hydride ($LaNi_5H_6$). Heat is released when the hydrogen ions are absorbed; the ions can be released by heating the metal hydride. In complex metal hydrides, hydrogen bonds to a metal or metalloid to form an anion, and this anion bonds ionically to positively charged ions of another metallic element. Sodium alanate (also known as *sodium aluminum hydride*, with the molecular formula $NaAlH_4$) is an example of a complex metal hydride being investigated as a possible hydrogen storage material. Heat is released when a complex metal hydride forms. The process can be reversed, releasing the hydrogen ions, by adding heat.

Metal hydride storage materials are typically used in powdered form. The increased surface area of a powder improves absorption of hydrogen. On-board storage for metal hydrides would consist of a tank filled with powdered metal.

Metal hydrides have the potential to store large quantities of hydrogen at or near room temperature and pressure. However, today's metal hydrides have low capacities, are too expensive and too heavy, and are too slow to absorb and release the hydrogen.

TEACHER INFORMATION:

HYDROGEN STORAGE TERMS

[For Session 21]

Students might encounter the following terms as they conduct their research on methods of hydrogen storage.

Aerogel: Silicon-based solid with a porous, sponge-like structure that is 99.8% empty space by volume.

Carbon fiber: Incredibly strong material made from extremely thin fibers (0.005–0.010 mm) in diameter and composed mostly of carbon atoms bonded together in microscopic crystals.

Carbon nanotubes: Incredibly strong molecular-scale tubes made of graphite carbon.

Chemisorption: A type of adsorption in which a molecule sticks to a surface by forming a chemical bond.

Clathrates: Chemical substances made up of a lattice of one type of molecule with a second type of molecule trapped and contained inside.

Conformability: The ability to fit into a given size or shape.

Cryogenic: Having to do with very low temperatures.

Gravimetric: Related to measurement by weight.

Hydrogen boil-off: The vapor loss from liquid hydrogen stored at extremely low temperatures.

Interstitial: The condition of being between things, especially things that are normally closely spaced.

Mesoporous: Having pores between 2 and 50 nanometers in diameter.

Pa (Pascal): The SI unit of pressure; 1 Pa = 1 Newton/meter^2.

Physisorption: A type of adsorption in which the forces involved are intermolecular (van der Waals) forces.

Slurry: A watery mixture of insoluble matter, such as mud or concrete.

Stakeholders: People or organizations that are involved in or affected by a course of action.

Volumetric: Related to measurement by volume.

ACTIVITY 5:

Investing in the Future

Notes:

ACTIVITY OVERVIEW

Hydrogen Technology Research teams make their final decisions about which hydrogen technologies show promise as an investment for NuEnergy. During a company meeting, each team shares its recommendation and the reasoning behind its decision with the class. The class discusses the viability of the various hydrogen-related technologies and votes on which start-ups NuEnergy should invest in.

Sessions 22–25

Before You Teach

There is no preparation necessary for this activity.

Materials Needed

Session 22
- Chart paper from Session 12
- Optional: Computers with access to the Internet

Session 23
- Copies of **RM 5.1 NuEnergy Meeting Presentation Assessment** (one for each student)

Session 25
- Copies of **RM 5.2 Module Test** (one for each student)

Vocabulary

There are no new vocabulary words for this activity.

ACTIVITY 5:
Investing in the Future

INTRODUCTION

The time has come for you to make a recommendation to NuEnergy! Your Hydrogen Technology Research team needs to decide which start-up companies NuEnergy should invest in, and develop a list of reasons supporting your decision. You'll share your recommendation with the other NuEnergy employees, and then vote as a group on what the company should do next regarding hydrogen technologies.

Learning Goals

- Apply scientific knowledge to decision-making about hydrogen energy technologies.
- Weigh the trade-offs among positive and negative consequences when making a decision about developing a technology.

FOR YOUR GLOSSARY

There are no glossary words for this activity.

Notes:

SESSION 22

Hydrogen Savvy [Whole Class]

Revisit the chart paper that was last updated in Session 12, when students considered their knowledge of and questions about hydrogen from Session 1. Ask students to review the information to assess, revise anything that is incorrect, and answer any remaining questions.

Draw their attention to any questions that are still not answered or incorrect information that students have not picked up on. When possible, have students answer these questions and correct any misinformation themselves.

ANSWERING THE KEY QUESTIONS

[Teams]

Have students meet in their Hydrogen Technology Research teams to write a NuEnergy Investment report answering the key questions for each start-up company.

If necessary, teams can conduct any remaining research that they need to answer the questions.

ANSWERING THE KEY QUESTIONS

NuEnergy
Investing in the Future

Meet with your Hydrogen Technology Research team to share your responses to the following questions for each start-up company:

1. How will the technology being developed work? What's the science behind it?
2. What are the challenges to widespread adoption of this technology?
3. What environmental consequences, positive or negative, are likely to result from widespread adoption of this technology?

If you don't have good answers to some of the questions, use the Internet to complete your research. Finally, try to come to a team consensus, and write a Hydrogen Technology Report that answers these questions for each start-up.

HOMEWORK 5.1

Write an article aimed at students in your school explaining what "the hydrogen economy" is and why there's such disagreement about whether a hydrogen economy is the solution to our energy problems. (You'll need to conduct additional research to write this article; you can use the resources on the **Ford PAS Web site** to get started.)

Notes:

SESSION 23
MAKING A DECISION

[Teams]

Have students meet in their Hydrogen Technology Research teams to make their final decisions about which companies NuEnergy should invest in and to plan their presentations. Teams should prepare a presentation of no longer than five minutes, in which they state their recommendations and explain how their recommendations are based on the answers to the questions about functionality, adoption, and environmental consequences. Inform teams that if they ultimately decide that NuEnergy should not choose to fund any of the start-ups, they must explain why and suggest other hydrogen technologies to consider investing in.

Give students the **NuEnergy Meeting Presentation Assessment (RM 5.1)** to help them plan their presentations.

MAKING A DECISION

NuEnergy is counting on your research and advice as it makes its decision about investing in hydrogen technologies. After all, the company wants to invest in projects that are likely to make money as well as to improve the quality of the environment over the long term. So, what's your recommendation? Meet with your team to decide, based on the information in your Hydrogen Technology Report, which companies NuEnergy should invest in.

NuEnergy
Investing in the Future

You are going to share your recommendation with other NuEnergy employees during a company meeting. Plan a five-minute presentation in which you state your recommendations and explain how these recommendations relate to the answers in your report. Be prepared to explain your reasoning to the other employees at the company—particularly those who disagree with you!—and to answer their questions.

DID YOU KNOW?

A career in chemistry can be rewarding . . . and delicious! Food and flavor chemists apply the principles of chemistry to developing, analyzing, and improving the quality and taste of food and beverages. Their jobs focus on a variety of food-related issues, such as processing and packaging, ensuring freshness, testing products to determine if they meet laws and standards, experimenting with additives and preservatives, identifying flavor components, improving existing flavor technologies, and even developing brand-new products. In an increasingly health-conscious society, food and flavor chemists are becoming more important than ever, helping to make fat-free and sugar-free foods and beverages that don't compromise taste or texture.

Since food and flavor chemists are responsible for making our food and beverages taste as good as possible, keen senses of taste and smell are a must for any potential food scientist. It is also important for food and flavor chemists to have sharp memories for identifying subtle flavors and smells, the ability to clearly and precisely communicate flavors and aromas in great detail, and a lot of creativity. Food or flavor chemists typically get an undergraduate degree in chemistry or chemical engineering and a master's degree in food science. For those interested in teaching or research, a Ph.D. may also be required. Most food and flavor chemists work in industry, for food processing or ingredient supply companies, but may also be employed in higher education institutes or government agencies, such as the Food and Drug Administration or the Department of Agriculture. Salaries for food and flavor chemists can be as high as six figures for the most talented and experienced scientists, and the future job market is always promising—everyone has to eat!

HOMEWORK 5.2

Prepare for your role in your team's presentation. Review the **NuEnergy Meeting Presentation Assessment**, and double-check that your presentation meets all the requirements. Rehearse anything you will say during the presentation. Try to think of questions you might be asked. How would you answer these questions?

Notes:

SESSION 24
SHARE YOUR RECOMMENDATIONS

[Whole Class]

Students participate in a NuEnergy company meeting to share and discuss their recommendations.

Give each Hydrogen Technology Research team about five minutes to present its recommendations and reasoning to the other teams. Allow time for questions and answers after each team presents.

Tell the class that NuEnergy has two options:

- Invest in one or more of the start-ups
- Conduct further research on other applications of hydrogen as an energy carrier

Record and display these two options.

Ask the class to vote for or against funding each start-up, and record the number of votes. Then have the class take a vote as to whether the company should instead look at different hydrogen technologies to invest in.

Finally, discuss the future of hydrogen as an energy carrier with the class. Ask students the following questions:

- Do you think you'll see the hydrogen economy become a reality within your lifetime? Why or why not?

SHARE YOUR RECOMMENDATIONS

Now is the time for you to share your thoughts about the hydrogen start-ups with your company. Meet with other employees from NuEnergy, and share your team's recommendations and reasoning. Listen carefully to other researchers' recommendations, and think about whether their arguments are strong enough for you to change your position.

NuEnergy
Investing in the Future

Finally, consider these questions: Do you think you'll see the hydrogen economy become a reality within your lifetime? Why or why not?

HOMEWORK 5.3

Prepare for the **Module Test**.

Notes:

SESSION 25

Module Test [Individual]

Have students complete the **Module Test (RM 5.2)**.

TEACHER INFORMATION

The **Module Test Answer Key** is located on pages T 222–T 224.

EXTENSIONS

5.1

The CEO of NuEnergy is particularly interested in the potential of hydrogen as a fuel source for personal vehicles—not just for urban or commuter cars, but for full-size cars capable of travelling long distances. Write a short forecasting report for the CEO on whether you think hydrogen will play a role as a fuel source for full-size cars in the future, and why.

5.2

If a wind-powered hydrogen fueling station were going to be built in your community, where should it be located and why?

5.3

Identify a real start-up company working on hydrogen technologies. Research the company and write a report for the management of NuEnergy about whether this company would be a good investment opportunity.

For more extensions go to the **Ford PAS Web site**. 

TEACHER INFORMATION:
MODULE TEST ANSWER KEY
[For Session 25]

1. **[15 points]** Using your knowledge of how pressure, volume, and temperature are related for gases, explain why a properly inflated football might feel like it needs more air when you take it outside to have a catch on a chilly autumn day.

   Possible Answer:

   For most gases, $PV = \text{constant} \times T$. As long as the air valve on the football is sealed, the pressure on the air inside the football remains constant when the ball is taken outside. This leaves you with $V = \text{constant} \times T$ (Charles's law). As the temperature of the air in the football decreases, the volume will decrease accordingly and the football may feel underinflated.

2. Use this information about photosynthesis to do the following:

   a. **[15 points]** Write a balanced equation for the photosynthesis reaction.

      Answer:

      Sunlight + $6CO_2\ (g) + 6H_2O\ (l) \rightarrow C_6H_{12}O_6\ (aq) + 6O_2\ (g)$

   b. **[20 points]** Describe what happens to the molecules and energy during the photosynthesis reaction. What is the role of sunlight, and how does it affect the molecules? Be sure to identify whether the reaction is endothermic or exothermic.

      Answer:

      Photosynthesis is an endothermic reaction, meaning that it has to absorb energy from the environment in order to occur. Sunlight provides this energy for the photosynthesis reaction, helping to break the bonds holding together the CO_2 and H_2O so that they can reconfigure into glucose and oxygen.

3. **[20 points]** Describe the similarities and differences between batteries and fuel cells. Identify the different components of batteries and fuel cells and explain their functions. Describe the chemical reactions that take place within and the flow of electrons through each device.

   Answer: Batteries and fuel cells are both examples of galvanic cells and have the same basic components:

   - **An anode, where oxidation (the loss of electrons) takes place**
   - **A cathode, where reduction (the gain of electrons) takes place**
   - **An electrolyte, which permits the transfer of positive ions but not electrons**

In both batteries and fuel cells, reactants at the anode lose electrons. These electrons travel through an external circuit to get to the cathode. At the cathode, the electrons combine with positively charged ions and, in some types of batteries and fuel cells, other reactants as well. The flow of electrons through the external circuit is the electric current.

The primary difference between batteries and fuel cells has to do with the reactants. For a fuel cell, the reactants (a fuel, such as hydrogen gas, and an oxidizing agent, such as oxygen) come from outside the device. As long as these reactants continue to be supplied, the fuel cell can continue generating current indefinitely. For a battery, the reactants are all inside the battery. When these reactants have been consumed, the battery no longer produces current.

4. **[20 points]** Describe the pros and cons of using hydrogen fuel cells to power vehicles. How do these compare to the pros and cons of using hydrogen-powered fuel cells for non-transportation energy needs?

Answer:

Pros of using hydrogen fuel cells for transportation:

- **Hydrogen fuel cells emit virtually no greenhouse gases or other pollutants. This is important, because vehicle emissions are a major source of greenhouse gases.**
- **Because hydrogen can be produced from a wide variety of energy sources, a shift to hydrogen fuel cell-powered vehicles would diversify the U.S.'s energy portfolio.**

Cons of using hydrogen fuel cells for transportation:

- **Hydrogen is currently far more expensive than gasoline, because of the cost of producing and transporting it.**
- **In its natural state, hydrogen gas takes up a lot of space. Storing enough hydrogen on board a vehicle for it to travel typical driving distances is a major challenge.**

Stationary applications of hydrogen fuel cells have the same pros as transportation applications, as well as two potential advantages:

- **If the hydrogen is produced and used at the same location, then it does not need to be transported.**
- **Space is not the issue in stationary applications that it is in transportation applications.**

5. **[15 points]** If you were deciding on your own which companies, if any, NuEnergy should invest in, would you make the same recommendation that your team did? Why or why not? (A thorough answer to this question will incorporate some information from the three key questions you answered in your Hydrogen Technology Report.)

   Answers will vary.

Skill Appendix

The following pages include skill resources related to *Is Hydrogen a Solution?*

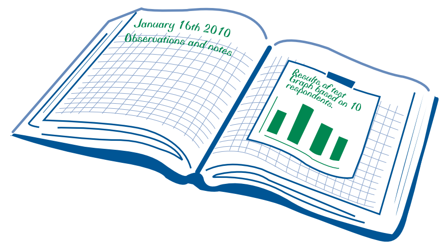
Science Notebook Guidelines 88
Lab Report Guidelines 90
Preview the Text 92
Reading Strategies to Use on Your Own 93

Student Guide, p. 88

Science Notebook Guidelines

Guidelines

Keeping track of ideas and experiment results is essential for inventors who hope to receive patents, for scientists who hope to publish their findings, and for engineers or anyone who must document a sequence of actions and results and communicate them to others. Similarly, you will keep your own science notebook to document your work. Your science notebook will contain:



- Notes from scientific investigations, including calculations and sketches
- Research notes and ideas for the Hydrogen Technology Research project

Requirements

Your science notebook will differ from other class notebooks in a few specific ways:

- Use a composition notebook with sewn bindings and numbered pages—this proves that findings haven't been altered by the removal of pages. (You may have to number the pages.)
- Use a notebook with graph paper to make sketching easier.
- Write each entry in blue or black ink, not pencil, and date every entry. This provides a record of when ideas were conceived or experiments were performed.
- Draw a single line through errors and note any corrections you make. A science notebook provides information about predictions, results, and incorrect entries, which may be useful later.

Organization

Your science notebook will contain three sections:

- **Table of Contents:** This makes it easy to find information. It's very important that you put in accurate titles and page numbers.
- **Lab Notes:** This section is for notes on the scientific investigations you conduct.
- **Hydrogen Technology Research Project Notes:** Here you'll keep all the planning and research information for your team's Hydrogen Technology Research project.

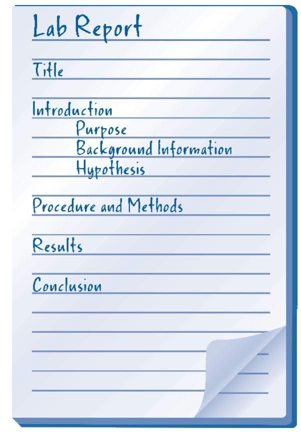
Follow these steps to set up your notebook.

1 Label the cover.	• Include your name, teacher's name, class period, and the school year.
2 Create a *Table of Contents* (TOC).	• Number the first four pages. • Make three columns on each of these four pages, titled "Page Number," "Title," and "Date." Use a ruler! • Title the first two pages "Table of Contents: Lab Notes." • Title pages 3 and 4 "Table of Contents: Hydrogen Technology Research Project."
3 Number all the pages.	• Number every page in your notebook. Yes, it takes time! Do it now, to avoid numbering mistakes and to save time later.
4 Create a *Hydrogen Technology Research Project* section.	• Open to the *middle* of the notebook. Title the page "Hydrogen Technology Research Project Notes." Notice the page number. • Turn back to the third page of the TOC, where you see "Hydrogen Technology Research Project Notes," and enter that page number.
5 Enter the first two items in the TOC.	• Make the first entry in the Lab Notes section of the TOC. Include the page number (5) and the title of the first lab (Model Fuel Cell Car Lab). • Make the first entry in your Project Notes TOC. Include the page number and the title (Ideas and Questions).

Table of Contents: Lab Notes

Page Number	Title	Date

Lab Report Guidelines



Lab reports are an essential part of the scientific process. Scientists need to create an organized, written document that helps other people (who may or may not be scientists) understand the purpose of the experiment, how it was conducted, the results, and what conclusions the scientists drew. You will create a lab report for each lab that you conduct.

Your lab report should include the following elements.

Title

Include the name of the lab, the date, and the name of each member of your team.

Introduction

Your lab report should include the following:

- **Purpose**

  Why are you conducting this lab? What problem are you investigating? Write down the purpose of the lab. For example:

  > *The purpose of this lab is to determine the best temperature for sprouting seeds in a greenhouse. We will investigate how placing the same kind of seed in different temperatures affects the length of time it takes the seeds to sprout.*

- **Background Information**

  What do you already know about the subject of the lab? Write a paragraph or two describing what you have learned—whether from your own research, your teacher, a textbook, or another source.

- **Hypothesis**

  What do you expect the outcome of the lab to be? Before beginning the lab, think about a hypothesis with your teammates, and write it in the form of a statement. It's OK if your hypothesis turns out not to be correct. A sample hypothesis:

  > *If the temperature is increased, then the seeds will sprout more quickly.*

Procedure and Materials

How did you conduct your lab? What materials did you use? Write down, in order, the steps you took. Be specific about each step and list the materials used, so that another scientist could use this information to duplicate your lab. Also be concise—don't repeat everything that was included in the lab instructions. You can include drawings of experimental setups in this section.

Results

What happened when you conducted the lab? In this section, include two kinds of information:

- **Quantitative:** Data in the form of numbers, tables, and graphs
- **Qualitative:** Data in the form of descriptions of what you observed during the lab

For example, if you were measuring the sprouting time of seeds planted at different temperatures, you would include a table listing the kinds of seed used, the mass of soil used in each pot, the volume of water added to each pot, and the temperatures that the pots were kept in. You would also include important qualitative data that you observed, for example, "The seedlings sprouted at 24°C wilted quickly."

Conclusions

After analyzing your results, what conclusions have you reached? Was your hypothesis correct? Why or why not?

Write down what you discovered and whether your initial hypothesis was correct. Be clear about what you think happened, and why your data (in the results section) support your conclusion. If your hypothesis turned out not to be correct, write about why you think this was the case. If appropriate, describe how you might design a new experiment to answer questions that were raised by the results of this lab.

Preview the Text

Reading a scientific text can be challenging—but you can increase your comprehension by figuring out the text's topic and purpose before you dive in to read it. By studying the features of a text you can find clues to its topic and purpose.

Learning Goal

▶ Apply pre-reading strategies to increase your comprehension of science texts.

At First Glance

When you look at a reading, what comes to your mind? Do your eyes go straight to a graph or photo? Do you try to make sense of the title? Do you check to see if there are questions at the end of the reading? These are good ways to approach reading something new.

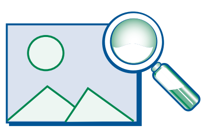
Before you start that first sentence, you're going to try a few strategies for finding your way through a reading. It's like using a road map before you set out on a trip—the map helps you find your way, and it can help you get back on track if you get lost.

Strategies

1 Read the **Title**.

From the title, can you guess what might be the topic of the reading? Write what comes to your mind.

2 View the images.



Are there diagrams, tables, photos, or other pictures? What do they tell you about the reading?

For each image, note your ideas. Also, for:

- **Graphs:** Read labels on the *x* and *y* axes to see what they tell you about the graph.
- **Tables:** Read column and row headings to see what they tell you about the table.

3 Read **Questions and Summaries . . .**

Are there any summaries, sets of questions, or **Questions for Reflection**? Jot down any clues they give you about the topic of the reading.

4 Ask your own questions: **I wonder . . . ?**

What additional questions do you have about the content of the reading? Write them down.

Reading Strategies to Use on Your Own

Here are strategies to try when you read complex material. You may not want to try them all at once, but you'll probably find at least some of them useful.

Preview the Text

Use pre-reading strategies to discover the reading's topic and purpose. Look for clues in the title, images, and summaries or questions. Think of your own questions and write them down as well.

Stop and Think

Read the first paragraph (or more, depending on how difficult the reading is) and then answer these questions:

- **What is the main idea** or most important point? Jot it down in your own words. This will help you make sense of the full reading.
- **Look for examples or other evidence** that supports the main idea. Jot down the evidence or highlight that part of the reading.
- **Explain the main idea** in your own words to someone else. Invite that person to ask you questions. Answering these questions will help you clarify your own thinking.
- **What do you *predict* the author will write about next?** Why do you think so? Write down your prediction.

Troubleshoot

Having trouble making sense of the reading? Try these tips:

- **Reread**, beginning at the place just before you started having trouble understanding.
- **Slow down**. Science readings can be much more difficult to follow than, say, a story. Reading slowly can help.
- **Try to picture** what you're reading about or even draw or sketch it. If the reading has illustrations, look at those, too; they may help you.
- **Highlight** words and sections you don't understand, but ***keep reading***. As you read on, new information may help you understand your highlighted text.
- "**Translate**" a confusing sentence or phrase into your own words—this can help you figure out the gist of a new word or phrase.
- See an unfamiliar word? You can:
  - **Try to guess** the possible meaning from what's around it.
  - **Look at each part of the word.** Are any parts familiar?
  - **Look up its meaning** online or in a print source.
  - **Ask someone** who understands the word to use it in a sentence.

Glossary

Activation energy: The minimum amount of energy needed to get reactants to move fast enough to form products.

Avogadro's law: A gas law stating that equal volumes of gases at the same temperature and pressure contain equal numbers of particles (molecules or atoms).

Bond dissociation energy: The amount of energy required to break a chemical bond.

Boyle's law: A gas law stating that at constant temperature, the volume of a given sample of gas varies inversely proportional with pressure.

Catalyst: A substance that increases the rate of a reaction without being consumed during the reaction. Catalysts provide an alternative path (with a lower activation energy) for the reaction to occur.

Charles's law: A gas law stating that when pressure is held constant, the volume of a gas sample is proportional to its absolute temperature; when the volume of the gas increases or decreases by a certain factor, the absolute temperature increases or decreases by that same factor.

Chemical equation: A means of representing a chemical reaction that (1) identifies the reactants and the products, (2) describes the states of the matter involved in the reaction (solid, liquid, gas, or aqueous solution), and (3) reflects the law of conservation of matter (which states that matter can't be created or destroyed) by including the same numbers and types of atoms on both sides of the equation.

Chemical reaction: A change in which one or more substances are transformed into new substances by the breaking of chemical bonds, rearrangement of atoms, and formation of new bonds.

Combination (synthesis) reaction: A chemical reaction of two substances to form a single product.

Combustion: The chemical reaction between a fuel and oxygen, accompanied by heat and light.

Compounds: Substances consisting of two or more elements joined chemically.

Decomposition reactions: Chemical reactions in which a molecule breaks down into two or more simpler molecules.

Efficiency: The ratio of the energy output of a system to the energy put into the system.

Electrochemical cell: A device in which an electrical current is generated by a chemical reaction.

Electrode: A solid substance, on the surface of which oxidation-reduction reactions take place.

Electrolysis: The process of splitting water molecules into hydrogen gas and oxygen gas using electricity.

Electrolyte: A substance that forms ions in an aqueous (water) solution.

Endothermic: A kind of chemical reaction in which it takes more energy to breaks bonds in the reactants than is released by the formation of new bonds in the products.

Energy carrier: A substance that transports energy in a usable form from one place to another.

Energy density: The amount of energy contained in a given volume or mass of a substance.

Enthalpy: The amount of energy stored within a system.

Enthalpy of reaction: The change in the energy of the system of a chemical reaction when bonds are broken in the reactants and new bonds are formed in the products.

Exothermic: A kind of chemical reaction in which more energy is released when new bonds are formed in the products than is used when bonds are broken in the reactants.

Fuel efficiency: The distance a vehicle can travel per unit of fuel used.

Fuel reforming: A process in which hydrocarbon fuel reacts with steam at high temperatures to form hydrogen gas and carbon monoxide.

Gas laws: Laws that describe the relationships among the pressure, volume, and temperature of gases.

Gas pressure: The force per unit area exerted on the walls of a container, generated by the collisions of gas particles with the walls of the container.

Gasification: A process in which carbon-rich material, such as coal, reacts with oxygen and steam to create a synthesis gas that is further processed to extract hydrogen gas.

Hydrocarbons: Compounds made up of hydrogen and carbon. Hydrocarbons are frequently used as fuels.

Hydrogen fuel cell: A device that converts chemical energy to electrical energy through a reaction between hydrogen and oxygen.

Law of conservation of matter: Natural law stating that matter can neither be created nor destroyed, though its form can be changed.

Metal hydrides: A chemical compound consisting of hydrogen and at least one metallic element.

Oxidation-reduction reaction: A chemical reaction in which electrons are transferred from one reactant to another, commonly called a *redox reaction*. The reactant that loses electrons is said to have been *oxidized*; the reactant that gains electrons is said to have been *reduced*.

PEM fuel cell: A fuel cell in which protons travel from the anode to the cathode through a membrane. PEM stands for both Polymer Exchange Membrane and Proton Exchange Membrane. The most commonly used fuel cell in vehicles, it is also being investigated for use in stationary applications and other portable applications.

Products: Substances that are present after a chemical reaction takes place.

Reactants: Substances that are present before a chemical reaction takes place.

Reaction rate: The speed at which a chemical reaction takes place.

Reproducible Masters

This section includes reproducible masters for student and teacher use.

SCIENCE NOTEBOOK ASSESSMENT

Name: ______________________________ **Date:** ______________

Use the following assessment to make sure that you have completed all the necessary elements of your science notebook. Your teacher will use these criteria and point assignments to evaluate your work.

Student Checklist	Criteria	Maximum Possible Points	Teacher Score
	Table of Contents (10 points)		
	Lists titles of entries sequentially.	5	
	Includes page numbers that correspond with the entry titles.	5	
	Lab Notes (40 points)		
	Includes observations, notes, sketches, and calculations for the following: Activity 1: • Model Fuel Cell Car Lab Activity 2: • Chemical Reactions Lab 1 or 2 • Catalysts Lab Activity 3: • Water Electrolysis Lab Activity 4: • Behavior of Gases Demonstrations	40	
	Hydrogen Technology Research Project Notes (40 points)		
	Includes information about the following: • Hydrogen Basics • Hydrogen as a Fuel • Hydrogen Gas Production • Hydrogen Storage	40	
	Accepted Style (10 points)		
	Entries are in blue or black ink, not pencil.	5	
	Entries are dated, and pages are numbered.	5	
	Total Points	**100**	

Comments:

HYDROGEN TECHNOLOGY RESEARCH PROJECT ASSESSMENT

Name: ______________________________ **Date:** ______________

Use the following assessment to make sure that you have completed all of the necessary elements for your Hydrogen Technology Research project. Your teacher will use these criteria and point assignments to evaluate your work.

Student Checklist	Criteria	Maximum Possible Points	Teacher Score
	Background Memos (40 points)		
	The Background Memo about hydrogen production: • Shows a clear understanding of how each production method works (including related scientific principles) • Describes the current pros and cons of each method	20	
	The Background Memo about hydrogen storage: • Shows a clear understanding of how each storage method works (including related scientific principles) • Describes the current pros and cons of each method	20	
	Recommendations (60 points)		
	For each start-up, the team addresses the key questions (on functionality, adoption, and environmental consequences).	20	
	For each start-up, the team makes a recommendation that is well thought out and clearly based on the information about functionality, adoption, and environmental consequences.	20	
	Team members show a command of the concepts they are discussing when they make their recommendations, and are able to answer questions from audience members.	20	
	Total Points	**100**	

Comments:

MODEL FUEL CELL CAR LAB

In this lab, you will assemble a model fuel cell car, produce the hydrogen to fuel it, and then operate the car on a "test track."

Purpose

To observe how a hydrogen fuel cell can be used to power a vehicle and to consider some of the challenges to building real fuel cell cars.

Materials

- Model fuel cell car kit
- 1 L distilled water
- Tape measure
- Air-tight plastic bag for storing fuel cell

Procedure

1. Before beginning to assemble your car, read through all the assembly instructions. Lay out the parts listed in the instructions, and confirm that you have everything you need.

2. Assemble the car.

3. Follow the instructions in the manual for producing the hydrogen to fuel your car.
   Note: Be sure to use distilled water. Tap water or bottled water will contaminate the fuel cell and may cause it to stop working.

4. Take your car to the "test track" (a flat surface that is smooth and free from obstacles). Align the wheels as much as possible to help ensure that your car will travel in a straight line.

5. Conduct a few "trial runs," running the car as described in the instruction manual. If the car does not move immediately, give it a *slight* nudge to help it overcome the starting friction. The fuel cell must be fully hydrated in order for the car to work at maximum efficiency. Before collecting any data about fuel used or distance traveled, run your car three or four times to be certain that the membrane is fully hydrated. (Each time you run the car, you will first need to produce the hydrogen. These trial runs will also give you a chance to note and correct any problems with the car.)

6. Collect the data you need to calculate the fuel efficiency, and record the data in your science notebook.

7. When you are finished using the car, remove the fuel cell and seal it in an air-tight plastic bag.

Analysis

1. Calculate your car's fuel efficiency in m/L (meters traveled per liter of hydrogen).

2. For your car to travel 300 miles, how many times would it need to stop for refueling? What volume of hydrogen would be required for your car to travel 300 miles without stopping to refuel?

LAB REPORT ASSESSMENT

Name: ______________________________ **Date:** ______________

Use the following assessment to make sure that you have completed all of the necessary elements for your lab report. Your teacher will use these criteria and point assignments to evaluate your work at the end of the module.

Student Checklist	Criteria	Maximum Possible Points	Teacher Score
	Introduction (30 points)		
	Describes the purpose for the lab and the problem under investigation.	10	
	Includes background information related to the problem under investigation.	10	
	Includes a hypothesis that describes the expected outcome of the lab (when applicable).	10	
	Procedure and Materials (20 points)		
	Includes a concise, step-by-step procedure.	15	
	Lists the materials used at each step in the procedure.	5	
	Results (20 points)		
	Includes quantitative data collected in the form of numbers, tables, or graphs.	10	
	Includes qualitative data that describe what occurred when the procedure was conducted.	10	
	Conclusions (30 points)		
	Describes what was learned during the lab about the problem under investigation.	10	
	Indicates whether or not the initial hypothesis was correct, and why this was or was not the case.	10	
	Describes how the data presented support the conclusions reached.	10	
	Total Points	**100**	

Comments:

CHEMICAL REACTIONS LAB 1

In this lab, you will carry out and observe the chemical reaction between baking soda and citric acid. Baking soda, also known as *sodium bicarbonate*, is a white powder commonly used to help baked goods rise. Citric acid, a weak acid and natural preservative, is found in citrus fruits and is used to add a sour taste to food and soft drinks. During the lab, you will measure the temperature of the different substances.

Purpose

To examine the temperature changes associated with chemical reactions.

Materials

- Safety goggles
- Styrofoam coffee cup
- 250 mL beaker
- 25 mL citric acid solution ($H_3C_6H_5O_7$)
- Thermometer
- 15 g baking soda ($NaHCO_3$)
- Stirring rod
- Timer, stopwatch, or watch/clock with a second hand
- Sink with running water

Procedure

1. Put on your goggles. Place the styrofoam coffee cup in the beaker for stability.
2. Pour the citric acid solution into the coffee cup.
3. Record the initial temperature of the citric acid solution. Leave the thermometer in the cup.
4. Predict what you think will happen to the temperature of the solution when you add baking soda to the citric acid. Record your prediction in your science notebook.
5. Add the baking soda and stir gently with the stirring rod.
   Note: Do not stir the mixture with the thermometer!
6. Check the temperature every 5–10 seconds until it becomes stable. Record the final temperature of the solution.
7. Wash the contents of the cup down the sink with running water and throw the cup away. There are no hazardous chemicals involved in this reaction, so it is safe to dispose of the materials this way.

Analysis

What happened to the temperature of the citric acid solution when you added the baking soda?

CHEMICAL REACTIONS LAB 2

In this lab, you will carry out and observe the chemical reaction between zinc and hydrochloric acid. Zinc is a metallic element. Hydrochloric acid is the aqueous solution of hydrogen chloride gas. During the lab, you will be measuring the temperature of the different materials.

Purpose

To examine temperature changes associated with chemical reactions.

CAUTION: Hydrochloric acid is a corrosive and dangerous substance. Use all safety precautions, and do not let it touch your skin. The reaction in this lab produces hydrogen gas, which, as you know, is highly flammable. **Make sure that there are no open flames in the room when you conduct the lab.**

Materials

- Safety goggles
- Fume hood (if one is available)
- Styrofoam coffee cup
- 250 mL beaker
- 100 mL hydrochloric acid (HCl)
- Thermometer
- 0.5 g granular zinc (Zn)
- Stirring rod

Procedure

1. Put on your goggles. In a fume hood, if one is available, place the styrofoam coffee cup in the beaker for stability.
2. Pour the hydrochloric acid into the coffee cup.
3. Record the initial temperature of the hydrochloric acid. Leave the thermometer in the cup.
4. Predict what you think will happen to the temperature of the solution when you add the zinc. Record your prediction in your science notebook.
5. Add the zinc and stir gently with the stirring rod.
   Note: Do not stir the mixture with the thermometer!
6. Check the temperature every 5–10 seconds until it becomes stable. Record the final temperature of the solution.
7. Give your teacher the cup for disposal.

Analysis

What happened to the temperature of the hydrochloric acid when the zinc was added?

MORE EQUATIONS

Now that you know how to balance a chemical equation, you can take another look at the chemical reactions you studied in the Chemical Reactions Lab. Look at the following information about each reaction, and then create a balanced equation for each one.

Reaction 1: Baking Soda and Citric Acid

In this reaction, baking soda and citric acid solution combine to produce carbon dioxide gas. This is an acid-base reaction in which an acid (the citric acid) and a base (the sodium bicarbonate) react to form a salt (in this case, sodium citrate) and water. The reaction produces water, the compound sodium citrate, and carbonic acid. However, the carbonic acid immediately decomposes into carbon dioxide and water, so the final products are sodium citrate, water, and carbon dioxide.

The reactants are:

- Citric acid solution—$H_3C_6H_5O_7$ (an aqueous solution)
- Sodium bicarbonate—$NaHCO_3$ (a solid)

The products are:

- Sodium citrate—$Na_3C_6H_5O_7$ (an aqueous solution)
- Water—H_2O (a liquid)
- Carbon dioxide—CO_2 (a gas)

Tip: This equation is somewhat complicated. Just remember to make a list of the number and kind of atoms on both sides of the equation, and, when you're trying to balance the equation, start by looking at the formula of the most complex compound.

Reaction 2: Hydrochloric Acid and Zinc

In this lab, a reaction took place between the hydrochloric acid and the metal zinc. The reaction is an acid-metal reaction. In acid-metal reactions, the acid and the metal react to form a metal salt (in this case, zinc chloride) and hydrogen gas.

The reactants are:

- Hydrochloric acid—HCl (an aqueous solution)
- Zinc—Zn (a metal)

The products are:

- Zinc chloride—$ZnCl_2$ (an aqueous solution)
- Hydrogen gas—H_2 (a gas)

CATALYSTS LAB

You can't escape chemical reactions—they happen everywhere you go, even in the bathroom. If you have hydrogen peroxide in your home medicine cabinet, you may have noticed an expiration date on the bottle. This is because hydrogen peroxide slowly, but spontaneously, breaks down over time. The rate of this reaction depends on the concentration of the hydrogen peroxide, the temperature at which the solution is stored, and whether there are other substances present that will catalyze the decomposition reaction. In this lab, you will add different substances to hydrogen peroxide to see if and how each one affects the rate at which hydrogen peroxide decomposes.

Purpose

To understand the role of catalysts in chemical reactions.

Materials

- Safety goggles
- 90 mL hydrogen peroxide (H_2O_2)
- Three 50 mL beakers
- Liquid dish soap
- Stirring rod
- Small piece (approximately 1 cm^3) of potato
- Stopwatch or watch/clock with a second hand
- Three wooden splints
- Matches
- Scoopula
- 0.5 g powdered manganese dioxide (MnO_2)

Procedure

1. Put on your safety goggles.
2. Pour 30 mL of hydrogen peroxide into each of the three beakers. Squeeze one drop of liquid dish soap into each beaker and stir.
3. Make a table similar to the following for recording your data:

Catalysts Data Table

Substance	Time(s)	Notes/Observations
H_2O_2 only	—	
H_2O_2 + potato	to 40 mL mark:	
	to top of beaker:	
$H_2O_2 + MnO_2$	to 40 mL mark:	
	to top of beaker:	

4. Assign each team member one of the following tasks:
    - Adding the catalysts to the hydrogen peroxide
    - Timing the reaction
    - Recording the data
    - Conducting the glowing splint tests
5. Add the small piece of potato to one of the beakers. Use a stopwatch or a clock with a second hand to keep track of the time it takes for bubbles to first reach the 40 mL mark on the beaker and to then reach the top of the beaker. Record the times and any notes or observations in your data table.
6. Prepare a glowing splint by lighting a wooden splint and then blowing out the flame. Place the glowing end of the splint directly over the foam. Does the splint glow more strongly or reignite? Record your observations in your data table.
7. Add 0.5 g manganese dioxide powder to another beaker. Track and record the time it takes for bubbles to first reach the 40 mL mark on the beaker and to then reach the top of the beaker.
8. Perform a glowing splint test. Record the times and any notes or observations in your data table.
9. Observe the third beaker. Is there any noticeable change since you first poured the liquid into the beaker? Prepare a glowing splint to test for the presence of any released gases in this beaker. Does the splint glow more strongly or reignite?

ELECTROCHEMISTRY PRESENTATION ASSESSMENT

Names: ______________________________ **Date:** ______________

Use the following assessment to make sure that your team's presentation includes all the required content.

Your teacher will use these criteria and point assignments to evaluate your work.

Student Checklist	Criteria	Maximum Possible Points	Teacher Score
	Knowledge of Content (75 points)		
	Includes elements representing the following:		
	• A balanced chemical equation describing the reaction	20	
	• The structure of the electrochemical cell in which the reaction takes place, including electrodes, electrolyte, and mixing barrier (if appropriate)	20	
	• Electrons and ions and their behavior during the reaction	20	
	• Electric current produced or supplied to the electrochemical cell	15	
	Delivery of Information (25 points)		
	Addresses the assignment creatively.	10	
	Is engaging for the audience.	5	
	Employs effective presentation skills (for example, written materials are neat and easy to read, presenters speak clearly and use complementary body gestures, and images are easily visible).	10	
	Total Points	**100**	

Comments:

ELECTROCHEMISTRY PRESENTATION PEER ASSESSMENT

Name: ______________________________ **Date:** ______________

Use the following assessment to evaluate each Electrochemistry Presentation. Be sure to provide feedback and comments that you think will be helpful to the presenters.

Presenters' Names: ______________________________

Process or device: ______________________________

Criteria	Yes	No
The presentation included the following elements:		
• A balanced chemical reaction for the redox reaction		
• A description of the electrochemical cell, including the location and role of the following components: anode, cathode, electrolyte, and mixing barrier (if appropriate)		
• A demonstration of the behavior of electrons and ions		
This presentation did the following:		
• Offered an activity format that was creative and interactive		
• Helped me understand the redox reaction and the electrochemical cell in which it occurs		
Give a one-sentence summary of the reaction:		
A question I have about the content of the presentation is . . .		
An element of the presentation that was effective in keeping my attention or conveying an idea was . . . (you may list more than one):		

CHEMICAL EQUATIONS

Name: ______________________________ **Date:** ____________

Using the process you learned in **Balancing Act: Chemical Equations**, write balanced chemical equations for the following reactions. To guide you through the process, some of the steps of the process are partially filled in.

Here are some chemical formulas you may find useful:

Ammonia: NH_3 (*g*)	Nitrogen Dioxide: NO_2 (*g*)
Carbon Dioxide: CO_2 (*g*)	Oxygen: O_2 (*g*)
Hydrogen: H_2 (*g*)	Propane: C_3H_8 (*l*)
Iron: Fe (*s*)	Silver: Ag (*s*)
Iron Oxide (Rust): Fe_2O_3 (*s*)	Silver Sulfide: Ag_2S (*s*)
Nitrogen: N_2 (*g*)	Sulfur: S (*g*)
Nitric Oxide: NO (*g*)	Water: H_2O (*l*)

1. Combustion of liquid propane

Word Equation: ____________ + ____________ → ____________

Unbalanced Equation: $C_3H_8\ (l) + O_2\ (g) \rightarrow CO_2\ (g) + H_2O\ (l)$

Reactants: 3 C, 8 H, 2 O

Products: ___ C, ___ H, 3 O

Balanced Equation: ______________________________

Check your answer by taking an inventory of the atoms in the balanced equation.

Reactants: ___ C, ___ H, 10 O

Products: ___ C, ___ H, ___ O

2. Rusting (oxidation) of iron

Word Equation: iron + → iron oxide

Unbalanced Equation: ____________________

Reactants: ____Fe ____O

Products: 2 Fe 3 O

Balanced Equation: ____________________

Reactants: ____Fe ____O

Products: ____Fe ____O

3. Tarnishing of silver

Word Equation: silver + sulfur → silver sulfide

Unbalanced Equation: ____________________

Reactants: ____Ag ____S

Products: ____Ag ____S

Balanced Equation: ____________________

Reactants: ____Ag ____S

Products: ____Ag ____S

4. Haber Process (formation of ammonia)

Word Equation: hydrogen + nitrogen → ammonia

Unbalanced Equation: ____________________

Reactants:

Products:

Balanced Equation: ____________________

Reactants:

Products:

5. Production of the pollutant nitrogen dioxide from nitric oxide

Word Equation:

Unbalanced Equation:

Reactants: **Products:**

Balanced Equation:

Reactants: **Products:**

MODULE QUIZ

Name: ______________________________ **Date:** ______________

1. Describe how the atomic structure of the element *hydrogen* affects the way that this element behaves in relation to other atoms and molecules.

2. Describe three properties of hydrogen gas.

3. Read the following chemical equation:

$$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(l)$$

This equation describes both the combustion of hydrogen gas and the reaction of hydrogen with oxygen that occurs in fuel cells—but you know from observation that the two processes are very different. Explain why they are so different in terms of the role of catalysts and activation energy.

4. Imagine that you have just gotten a grass stain on your favorite pair of jeans. Unfortunately for you, grass stains can be really difficult to get out of natural fabrics such as cotton because the pigmented compounds in grass react with the fabric fibers, forming tight chemical bonds. The longer the stain is left untreated, the more likely it is the stain will become permanently "set."

   a. Experienced launderers use cold water to remove stains such as these. Why might cold water work better than hot water in this situation? Explain your reasoning.

   b. Some laundry detergents include an enzyme, which is a biological catalyst. What is the purpose of adding enzymes to laundry detergent?

MEASURING VOLTAGE

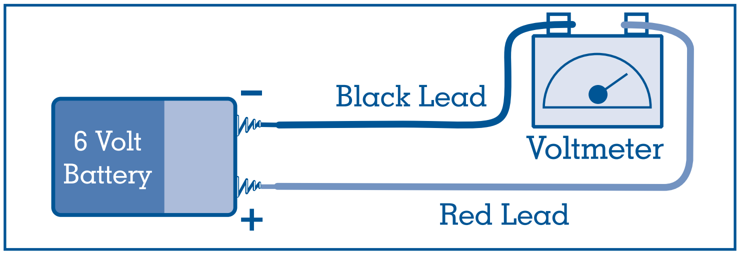
To measure the actual voltage supplied by the battery in the Water Electrolysis Lab, follow these steps:

1. Practice using the voltmeter (or a multimeter set to measure voltage) by measuring the voltage supplied by the 6 V battery alone:

   a. Set the voltmeter to measure direct current (DC voltage).

   b. Attach the voltmeter leads to the battery terminals as shown in **Figure 1**: red from the V (voltage) or "+" connection on the voltmeter to the positive terminal of the battery; black from the COM (common) or "–" connection on the voltmeter to the negative terminal of the battery.

Figure 1: Test the Battery Voltage

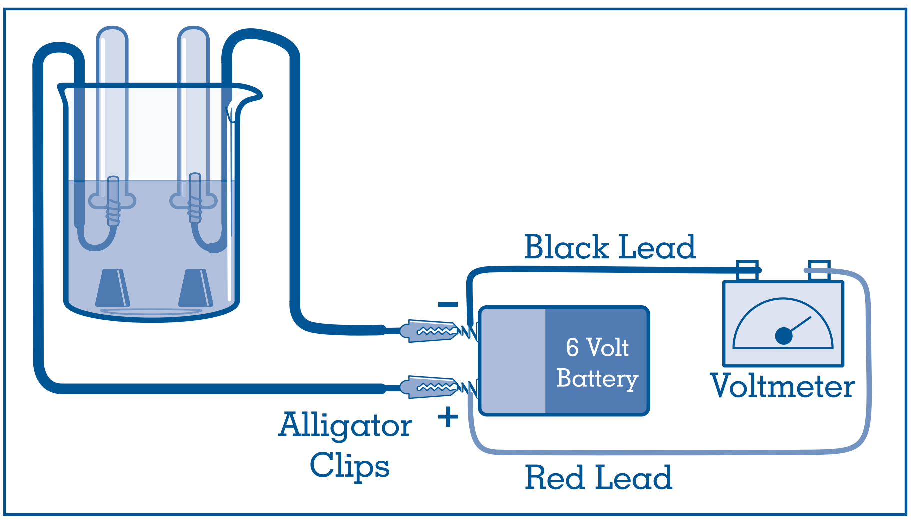


   Note: It is possible for the meter to show a value higher than the theoretical voltage of the battery (6 V).

2. Measure the voltage of the circuit while the electrolysis reaction is occurring:

   a. Connect the voltmeter in the electrolysis circuit across the battery, as shown in **Figure 2**.

Figure 2: Setup to Measure the Battery Voltage



   b. Begin the electrolysis. Measure and record the voltage.

   c. Disconnect the voltmeter from the circuit.

RM 3.6

CALCULATING THE ENERGY EFFICIENCY OF ELECTROLYSIS

Name: ______________________________ **Date:** ______________

The energy efficiency of the electrolysis reaction can be expressed as:

$$\% \text{ Efficiency of Electrolysis} = \frac{\text{Energy Content of } H_2 \text{ Produced}}{\text{Electrical Energy Supplied}} \times 100 \qquad \text{(Equation 1)}$$

To calculate the efficiency, first calculate the electrical energy supplied and the energy content of the hydrogen produced, as outlined in the following steps.

Step 1: Calculate the electrical energy supplied.

- The electrical energy supplied is equal to the electrical power (P) multiplied by the length of time (t) the power is supplied:

$$\text{Electrical Energy Supplied} = P \times t \qquad \text{(Equation 2)}$$

For an electrical circuit, power (P) is the voltage (V) multiplied by the current (I):

$$P = V \times I \qquad \text{(Equation 3)}$$

- Plug Equation 3 into Equation 2, and write the resulting equation:

$$\text{Electrical Energy Supplied} = \underline{\hspace{6cm}} \qquad \text{(Equation 4)}$$

- Enter the data from your electrolysis reaction, with V in volts, I in amps, and t in seconds, and calculate the energy supplied:

$$\text{Electrical Energy Supplied} = \underline{\hspace{1cm}}\text{ V} \times \underline{\hspace{1cm}}\text{ A} \times \underline{\hspace{1cm}}\text{ s} = \underline{\hspace{1cm}}\text{ joules} \qquad \text{(Equation 5)}$$

- A joule (j) is a unit of energy. Your electric bill probably uses a different unit of energy, the kilowatt-hour (kWh). Convert joules to kilowatt-hours as follows:

$$\text{Electrical Energy Supplied (kWh)} = \frac{\text{Electrical Energy Supplied (j)}}{3{,}600} \qquad \text{(Equation 6)}$$

- Enter your result from Equation 5:

$$\text{Electrical Energy Supplied (kWh)} = \frac{\underline{\hspace{2cm}}}{3{,}600} = \underline{\hspace{1cm}}\text{ kWh} \qquad \text{(Equation 7)}$$

Step 2: Calculate the energy content of the hydrogen produced.

- For every kilogram of hydrogen that reacts with oxygen to produce water, 39 kWh of energy is released. So:

$$\text{Energy Content of } H_2 \text{ Produced} = m \times 39 \frac{\text{kWh}}{\text{kg}} \quad \text{(Equation 8)}$$

(m is the mass of hydrogen in kg)

- You can calculate the mass of the hydrogen as follows:

$$m = \rho \times V \quad \text{(Equation 9)}$$

(ρ is the density of hydrogen gas and V is the volume of hydrogen gas produced in milliliters)

- Plug Equation 9 into Equation 8, and write the resulting equation:

$$\text{Energy Content of } H_2 \text{ Produced} = \quad \text{(Equation 10)}$$

- Using $\rho = 0.08988$ kg/mL, enter your result for the volume of hydrogen produced, and calculate the energy content:

$$\text{Energy Content of } H_2 \text{ Produced} = 0.08988 \frac{\text{kg}}{\text{mL}} \times \_\_\_\_ \text{ mL} \times 39 = \_\_\_\_ \text{ kWh} \times \frac{\text{kWh}}{\text{kg}}$$

(Equation 11)

Step 3: Calculate the efficiency.

- Plug in the results from Step 1 and Step 2:

$$\text{Energy Efficiency} = \frac{\text{Energy Content of } H_2 \text{ Produced}}{\text{Energy Supplied}} \times 100$$

$$\text{Energy Efficiency} = \_\_\_\_\_ \times 100 = \_\_\_\_\_\_\% \quad \text{(Equation 12)}$$

Step 4: Check your answer.

Does your answer make sense? The efficiency can't be less than 0 and it can't be greater than 100%. If your answer isn't between 0 and 100, double-check your calculations. Make sure that you entered the following:

- The time in seconds (which should be a big number)
- The voltage in volts
- The current in amps (not milliamps)
- The volume of hydrogen in milliliters

HYDROGEN PRODUCTION BACKGROUND MEMO: ELECTROLYSIS

Name: ______________________________ **Date:** ______________

With your teammates, find the answers to the following questions. You can find resources to help you on the **Ford PAS Web site**.

1. Describe the molecules involved and the chemical reactions that take place in hydrogen production by electrolysis. Include a balanced chemical equation.

2. What equipment and materials are used or would be used in the commercial production of hydrogen by electrolysis? Is electrolysis currently technologically feasible on a large scale? If not, what are some of the predictions about when, if ever, it might be?

3. What are the possible energy sources for the electricity needed in the electrolysis process?

4. What are the benefits of using electrolysis to produce hydrogen gas?

5. What are the drawbacks, including environmental problems, of producing hydrogen gas by electrolysis? (For example, take into consideration the energy sources used to generate the electricity involved.)

6. What are the costs associated with electrolysis? How does the current cost of hydrogen from electrolysis compare to the cost of a conventional fuel, such as gasoline? Is this likely to change?

RM 3.8

HYDROGEN PRODUCTION BACKGROUND MEMO: REFORMING

Name: ______________________________ **Date:** ______________

With your teammates, find the answers to the following questions. You can find resources to help you on the **Ford PAS Web site**.

1. What fuel is most commonly used in fuel reforming, and where is it found? What are some alternative sources of hydrocarbons that could be used in fuel reforming?

2. Describe the molecules involved and the chemical reactions that take place in fuel reforming. Include a balanced chemical equation for the most commonly used fuel and for an alternate fuel.

3. Describe the equipment and materials used in the commercial production of hydrogen by reforming. How is reforming currently being used on a large scale?

4. What are the benefits of using the process of reforming to produce hydrogen gas?

5. What are the drawbacks, including potential environmental problems, of producing hydrogen gas by reforming?

6. What are the costs associated with the reforming of hydrogen? How does the current cost of hydrogen from reforming compare to the cost of a conventional fuel, such as gasoline? Is this likely to change?

RM 3.9

HYDROGEN PRODUCTION BACKGROUND MEMO: GASIFICATION

Name: ______________________________ **Date:** ______________

With your teammates, find the answers to the following questions. You can find resources to help you on the **Ford PAS Web site**.

1. What are the different sources of carbon-rich material that can be used in the gasification process?

2. Describe the molecules involved and the chemical reactions that take place in the gasification of coal or biomass. Include a balanced chemical equation and note any differences between coal gasification and biomass gasification.

3. Describe the equipment and materials that are used or would be used in the production of hydrogen by gasification. Is gasification currently technologically feasible on a large scale? If not, what are some of the predictions about when, if ever, it might be?

4. What are the benefits of using the gasification of coal to produce hydrogen gas? What are the benefits of using biomass?

5. What are the drawbacks, including potential environmental problems, of producing hydrogen gas by gasification? How do these drawbacks depend on the carbon-rich material used?

6. What are the costs associated with gasification? How does the current cost of hydrogen from gasification compare to the cost of a conventional fuel, such as gasoline? Is this likely to change?

EXPLORING STATES OF MATTER

Name: ______________________________ **Date:** ______________

What makes matter go from one state to another? What happens to the particles as matter moves from one state to another? Use the **States of Matter Simulation** on the **Ford PAS Web site** to explore how matter changes states and what happens on the microscopic level as it does so.

Solids, Liquids, and Gases

1. Open the simulation. Explore the "Solid, Liquid, Gas" tab in the simulation, looking at oxygen and water.
2. Test your predictions (from State Your Matter) about how particles in each state of matter behave for oxygen and water. Record the temperature and illustrations for each substance in each state.

Substance	Solid	Liquid	Gas
Oxygen	Temperature: Illustration:	Temperature: Illustration:	Temperature: Illustration:
Water	Temperature: Illustration:	Temperature: Illustration:	Temperature: Illustration:

Phase Changes

1. Explore the "Phase Changes" tab in the simulation, looking again at oxygen and water.
2. For the Initial Sample of each, describe the following in the data table:

   a. Temperature

   b. Pressure

   c. Movement of molecules

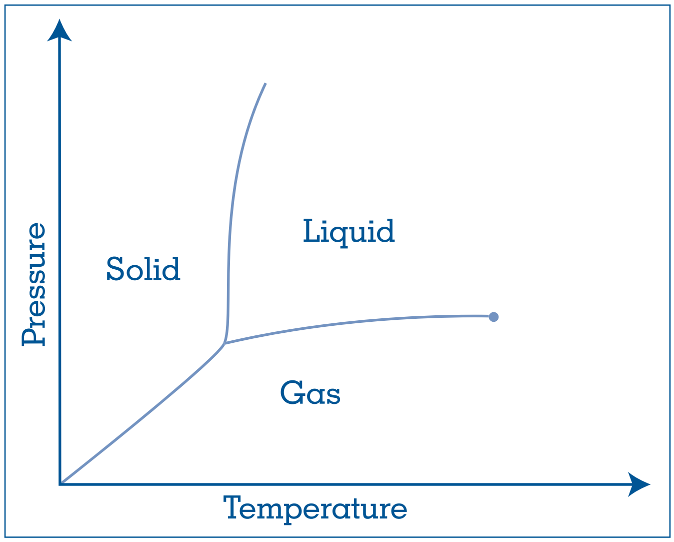
   d. Distance between molecules

3. Add heat until the red dot on the phase diagram (on the bottom right side of the simulation screen) reaches a point just past the "s" in "Gas." Fill in the second column.
4. Push down on the lid until it is slightly above the hose for the pump. Fill in the information in the third column.
5. Pump the handle for 10 complete pumps. Each pump will add four molecules of the substance. Fill in the fourth column of the table.
6. Select "Reset All" before exploring the next gas.

Substance	OBSERVATIONS			
	Initial Sample	Heat Added	Lid Pushed Down	After 10 Pumps
Oxygen	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:
Water	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:	• Temperature: • Pressure: • Movement of molecules: • Distance between molecules:

Analysis

1. How does temperature relate to the kinetic energy of molecules? Briefly summarize or draw a graph to describe this relationship.
2. How and why does a change in temperature affect the pressure inside a container?
3. Explain the following phase diagram by relating what you know about states of matter, temperature, and pressure.



PHYSICAL PROPERTIES OF MATTER TABLE

Name: ______________________________ Date: ______________

Physical Property	Solids	Liquids	Gases
Compressibility			
Density			
Volume (that is, what happens *to the volume* when matter is put into a container)			
Shape (that is, what happens *to the shape* when matter is put into a container)			
Diffusion			
Expansion with heating			

GAS LAWS AT A GLANCE

Boyle's Law

At constant temperature, if the pressure of a sample of gas decreases, the volume of the gas will increase, and vice versa.

Charles's Law

At constant pressure, gases tend to expand in volume as they are heated.

Avogadro's Law

At the same temperature and pressure, equal volumes of gases have the same number of particles.

ANALYZE THE BEHAVIOR OF GASES

Name: ______________________ **Date:** ____________

Fill in the following table for each Behavior of Gases Station. For the first three questions, select the appropriate variables (if any).

		Station Number					
		1	2	3	4	5	6
Which condition(s) changes *first* in this demonstration or scenario?	Pressure						
	Volume						
	Temperature						
What changes as a result of the *first* change?	Pressure						
	Volume						
	Temperature						
What stays the same throughout this demonstration or scenario?	Pressure						
	Volume						
	Temperature						
Describe what happens to the gas in this demonstration or scenario.							

RM 4.5

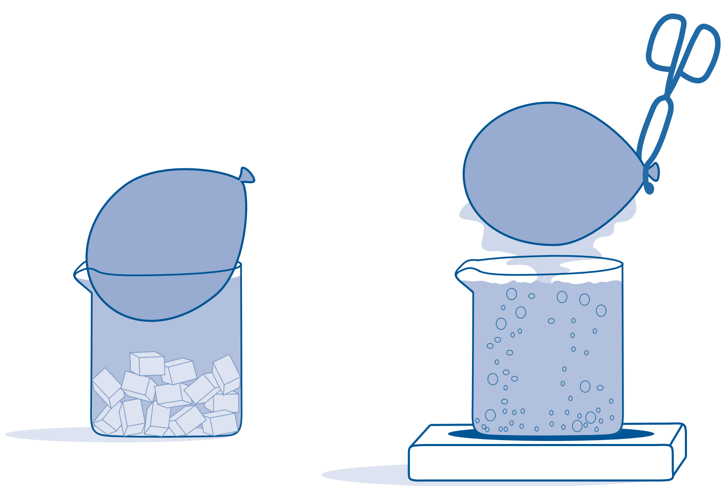
BEHAVIOR OF GASES STATION 1

Materials

- Safety goggles
- Two 1 L beakers
- Ice
- Water
- Hot plate
- Two round balloons
- String
- Tongs

Procedure

1. Put on your safety goggles. Fill one beaker three-quarters full with ice and water.
2. Fill the second beaker three-quarters full with water, place it on the hot plate, and heat it until the water is boiling.
3. Blow up the balloons so that they are the same size (roughly 8–10 cm in diameter) and tie them.
4. Place one balloon in the ice water and use the tongs to hold the other over the hot water.
5. Describe what happens to the balloons using **Analyze the Behavior of Gases**.
6. Cast your vote: Which gas law accounts for what happens to the balloons?

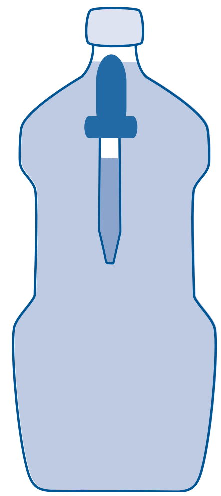


BEHAVIOR OF GASES STATION 2

Materials

- Plastic 1 or 2 L soda bottle with cap (label removed)
- Water
- Eyedropper

Procedure



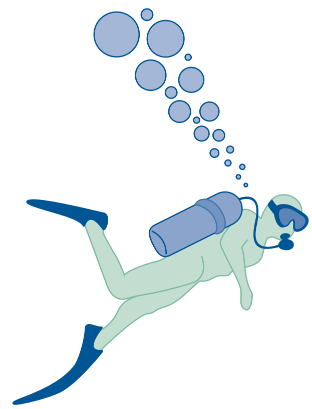
1. Fill the bottle with water so that it is full.
2. From your water source (NOT from the bottle!), draw water into the eyedropper until it is approximately one-quarter to one-half full.
3. Put the eyedropper into the bottle, which should overflow. The eyedropper should float in the bottle. If it doesn't float, take it out, remove some water from the eyedropper, and try again.
4. With the eyedropper inside, refill the plastic bottle.
5. Twist the cap onto the bottle tightly.
6. Squeeze the bottle and note what happens. Release it and note what happens. Squeeze again and note what happens to the water level in the eyedropper.
7. Describe what happens in the bottle and eyedropper using **Analyze the Behavior of Gases**.
8. Cast your vote: Which gas law accounts for what happens to the water in the eyedropper?

BEHAVIOR OF GASES STATION 3

You were at a party the other day and noticed that there were two identical balloons in the corner. The balloons were *exactly* the same size, but they behaved very differently. One balloon bumped into the ceiling, while the other lay on the floor. When you asked your host, she said that the floating balloon was filled with 1 mole of helium and the other was filled with 1 mole of air. (Clearly, your host was a science teacher.)

Which gas law accounts for the fact that one balloon floats while the other doesn't?

BEHAVIOR OF GASES STATION 4



You went SCUBA diving the other day (and you didn't even know you knew how!). As you were descending into the depths of the ocean, you noticed the bubbles breathed out by a fellow diver rising to the surface. Fascinated, you watched them as they rose, noting that they got larger and larger as they approached the water's surface.

Which gas law accounts for the bubbles changing in size?

BEHAVIOR OF GASES STATION 5

Materials

- Safety goggles
- Vacuum pumper
- 5 large marshmallows

Procedure

1. Put on your safety goggles. Place the marshmallows in the chamber of the vacuum pump apparatus.
2. Snap on the lid.
3. Use the pump to remove air from the chamber.
4. Describe what happens to the marshmallows using **Analyze the Behavior of Gases**.
5. Cast your vote: Which gas law accounts for what happens to the marshmallows?

BEHAVIOR OF GASES STATION 6

Your friend was making dinner the other day. It smelled delicious! You were hanging around the kitchen, when your friend asked you to check the turkey to see if it was done.

"How do I do that?" you asked.

Your friend replied, "Just open the oven door to see if the button has popped."

"What button?" you asked, confused.

"In the syringe thermometer in the turkey," your friend answered. "The button pops out when your turkey is done."

Which gas law accounts for the fact that the syringe pops?

HYDROGEN STORAGE BACKGROUND MEMO: COMPRESSION

Team Members:____ **Date:** ________________

Work with your team to find the answers to the following questions. You can use the resources on the **Ford PAS Web site.**

1. How does this storage method work? Describe what happens to the hydrogen during the storage process, and what the on-board storage system and refueling process would look like.

2. What are the benefits of this storage method?

3. What are the disadvantages of this storage method?

4. According to your research, how likely is this storage method to be used as a long-term solution to the hydrogen storage problem?

HYDROGEN STORAGE BACKGROUND MEMO: LIQUID HYDROGEN

Team Members:____ **Date:** _______________

Work with your team to find the answers to the following questions. You can use the resources on the **Ford PAS Web site.**

1. How does this storage method work? Describe what happens to the hydrogen during the storage process, and what the on-board storage system and refueling process would look like.

2. What are the benefits of this storage method?

3. What are the disadvantages of this storage method?

4. According to your research, how likely is this storage method to be used as a long-term solution to the hydrogen storage problem?

HYDROGEN STORAGE BACKGROUND MEMO: METAL HYDRIDES

Team Members:____ **Date:** ________________

Work with your team to find the answers to the following questions. You can use the resources on the **Ford PAS Web site.**

1. How does this storage method work? Describe what happens to the hydrogen during the storage process, and what the on-board storage system and refueling process would look like.

2. What are the benefits of this storage method?

3. What are the disadvantages of this storage method?

4. According to your research, how likely is this storage method to be used as a long-term solution to the hydrogen storage problem?

HYDROGEN STORAGE BACKGROUND MEMO: NEW TECHNOLOGIES

Team Members:____ **Date:** ________________

Work with your team to find the answers to the following questions. You can use the resources on the **Ford PAS Web site.** Look at one or two of the new technologies being developed, and answer the questions for each technology. Because you are looking at very new technologies, you might not be able to find detailed answers to each question—just do the best you can.

1. How do the storage methods work? Describe what happens to the hydrogen during the storage process, and what the on-board storage system and refueling process would look like for each method.

2. What are the benefits of this storage method?

3. What are the disadvantages of this storage method?

4. According to your research, how likely is this storage method to be used as a long-term solution to the hydrogen storage problem?

NUENERGY MEETING PRESENTATION ASSESSMENT

Team Members' Names: ________________________________ **Date:** ________

Use the following assessment to make sure that your team's presentation includes all the necessary elements.

Your teacher will use these criteria and point assignments to evaluate your work.

Student Checklist	Criteria	Maximum Possible Points	Teacher Score
	Recommendation (40 points)		
	For each start-up, the team makes a recommendation that is well thought out and explicitly connected to information about functionality, adoption, and environmental consequences.	40	
	Knowledge of Content (30 points)		
	Team members show a command of the scientific concepts they discussed when they made their recommendations and are able to answer questions from audience members.	30	
	Delivery of Content (30 points)		
	The team members exhibit good oral presentation skills by: • Speaking loudly and clearly enough for the audience to hear and understand; • Making eye contact • Varying pitch, tone, and volume so the presentation is not delivered in a monotone.	20	
	The presentation makes good use of time, using all or nearly all the time available without exceeding the time limit.	10	
	Total Points	**100**	

Comments:

MODULE TEST

Name: ______________________________ **Date:** ______________

1. Using your knowledge of how pressure, volume, and temperature are related for gases, explain why a properly inflated football might feel like it needs more air when you take it outside to have a catch on a chilly autumn day.

2. Current popular methods of producing hydrogen for fuel, such as steam reforming of natural gas, are energy-inefficient and produce pollutants. Wouldn't it be much better if hydrogen could be produced from a renewable resource, such as plants? In 2001, scientists demonstrated that photosynthesis (the process by which green plants make sugar from carbon dioxide, water, and sunlight) can be redirected to produce hydrogen. The specifics of producing hydrogen from photosynthesis are a bit complicated, but photosynthesis itself is a fairly simple endothermic chemical reaction in which sunlight, carbon dioxide gas (CO_2), and water (H_2O) combine to form an aqueous solution of glucose ($C_6H_{12}O_6$) and oxygen gas (O_2).

Use this information about photosynthesis to do the following:

a. Write a balanced equation for the photosynthesis reaction.

b. Describe what happens to the molecules and energy during the photosynthesis reaction. What is the role of sunlight, and how does it affect the molecules? Be sure to identify whether the reaction is endothermic or exothermic.

3. Describe the similarities and differences between batteries and fuel cells. Identify the different components of batteries and fuel cells and explain their functions. Describe the chemical reactions that take place within and the flow of electrons through each device.

4. Describe the pros and cons of using fuel cells to power vehicles. How do these compare to the pros and cons of using hydrogen-powered fuel cells for non-transportation energy needs?

5. If you were deciding on your own which companies, if any, NuEnergy should invest in, would you make the same recommendation that your team did? Why or why not? (A thorough answer to this question will incorporate some information from the three key questions you answered in your Hydrogen Technology Report.)

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Activity 2

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