Contents

Preface

Perhaps one of the greatest challenges humanity faces is how to avoid poisoning our planet as a result of our changes to our global habitat. Our present technologies, although valuable and perhaps necessary, produce pollution that can turn our air and water toxic, remove our protective layer of ozone, increasing the danger of UV radiation.

This manual is being written to introduce the concept and understanding that underlie a hydrogen based economy. With a hydrogen based economy we might be able to reduce emissions into the atmosphere, which could allow our damaged atmosphere to begin to heal itself. This economy, as presented in this manual, would begin and end with water so there would be no toxic byproduct and the emissions would be consist of only water vapor or liquid water.

The hydrogen-based economy would take water as the raw material and use renewable sources of electrical energy plus the action of a catalyst, to break it up into hydrogen and oxygen. It would then, by use of hydrogen fuel cells and the action of a catalyst recombine these two gases to form water and release electrical energy. The electricity in turn would drive other devices, providing heat, light, motion, magnetism and other types of energy.

The United States Department of Energy has written the following* to explain the advantages of fuel cells.

> Greenhouse gases are thought to be responsible for changes in global climate. They trap excess heat from the sun's infrared radiation that would otherwise escape into space, much like a greenhouse is used to trap heat. When we drive our cars, and light, heat, and cool our homes, we generate greenhouse gases. However, if we used hydrogen in very high efficiency fuel cells for our transportation and to generate power, we could significantly reduce the GHG emissions - especially if the hydrogen is produced using renewable resources, nuclear power, or clean fossil technologies.
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> The combustion of fossil fuels by electric power plants, vehicles, and other sources is responsible for most of the smog and harmful particulates in the air. Fuel cells powered by pure hydrogen emit no harmful pollutants. Fuel cells that use a reformer to convert fuels such as natural gas, methanol, or gasoline to hydrogen do emit small amounts of air pollutants such as carbon monoxide (CO), although it is much less than the amount produced by the combustion of fossil fuels.
>
> Fuel cells are significantly more energy efficient than combustion-based power generation technologies. A conventional combustion-based power plant typically generates electricity at efficiencies of 33 to 35 percent, while fuel cell plants can generate electricity at efficiencies of up to 60 percent.
>
> When fuel cells are used to generate electricity and heat (co-generation), they can reach efficiencies of up to 85 percent. Internal-combustion engines in today's automobiles convert less than 30 percent of the energy in gasoline into power that moves the vehicle. Vehicles using electric motors powered by hydrogen fuel cells are much more energy efficient, utilizing 40-60 percent of the fuel's energy. Even Fuel Cell Vehicles (FCVs) that reform hydrogen from gasoline can use about 40 percent of the energy in the fuel.

Hydrogen powered fuel cells offer our planet a chance to reverse some of the destructive changes that are taking place in our environment right now. It is hoped that by allowing the students who will become the citizens, scientists and engineers of tomorrow to experience first hand the advantages of the hydrogen fuel cell, they will become strong positive voices for continued exploration that will let us right some environmental wrongs and live in a cleaner and more sustainable manner.

* http://www.eere.energy.gov/hydrogenandfuelcells/hydrogen/why.html

Correlation of the Investigations with Washington State Standards,

Essential Academic Learning Requirements (science TM draft 3b, 2003 09 24)

Essential Academic Learning Requirements—Science

GRADE 10

Investigation 1 – Observing, Predicting and Questioning
Investigation 2 – Solar Panel Orientation
Investigation 3 – Simple Electrolysis
Investigation 4 – Understanding Electrolysis
Investigation 5 – Hydrogen Power
Investigation 6 – Hydrogen Power in Motion
Investigation 7 – Energy Efficiency
Investigation 8 – Extending our Knowledge

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
1. SYSTEMS: The student understands and uses scientific concepts and principles to understand systems. To meet this standard, the student will:								
1.1. Properties of Systems: Use properties to identify, describe, and categorize substances, materials, and objects and use characteristics to categorize living things.								
PHYSICAL SCIENCE								
Properties of Substances								
1. Recognize the atomic nature of matter, how it relates to physical and chemical properties, and serves as the basis for the structure and use of the periodic table.			●	●				
Motion of Objects								
2. Describe the average speed, direction of motion, and average acceleration of objects, for example, increasing, decreasing, or constant acceleration.								
Wave Behavior								
3. Describe waves, relating the ideas of frequency, wavelength, and speed, and by relating energy to amplitude.								
Energy Sources and Kinds								

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
4. Understand many forms of energy as they are found in common situations on earth and in the universe.		●			●	●		
EARTH/SPACE SCIENCE								
Nature and Properties of Earth Materials								
5. Correlate the chemical composition of earth materials such as rocks, soils, water, gases of the atmosphere, with properties.			●	●				
1.2. Structure of Systems: Recognize the components, structure, and organization of systems and the interconnections within and among them.								
Systems Approach								
1. Analyze systems, including the inputs and outputs of a system and its subsystems.	●	●	●	●	●			
PHYSICAL SCIENCE								
Energy Transfer and Transformation								
2. Understand that total energy is conserved; analyze decreases and increases in energy during transfers and transformations in terms of total energy conservation.					●		●	
Structure of Matter								
3. Relate the structural characteristics of atoms to the principles of atomic bonding.			●	●				
1.3. Changes in Systems: Understand how interactions within and among systems cause changes in matter and energy.								
PHYSICAL SCIENCE								
Nature of Forces								
1. Identify various forces, and their relative magnitudes, and explain everyday situations in terms of force.								
Forces to Explain Motion								
2. Explain the effects of unbalanced forces in changing the direction of motion of objects.								
Physical/Chemical Changes								
3. Analyze and explain the factors that affect physical, chemical, and nuclear changes and how matter and energy are conserved in a closed system.	●	●	●	●	●	●	●	

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
2. *INQUIRY:* The student knows and applies the skills, processes, and nature of scientific inquiry. To meet this standard, the student will:								
2.1. Investigating Systems: Develop the knowledge and skills necessary to do scientific inquiry.								
Questioning								
1. Study and analyze questions and related concepts that guide scientific investigations.	●	●	●	●	●	●	●	●
Planning and Conducting Investigations								
2. Plan, conduct, and evaluate systematic and complex scientific investigations, using appropriate technology, multiple measures, and safe approaches.	●	●	●	●	●	●	●	●
Explaining								
3. Formulate and revise scientific explanations and models using logic and evidence; recognize and analyze alternative explanations and predictions.	●	●	●	●	●	●	●	●
Modeling								
4. Use mathematics, computers and/or related technology to model the behavior of objects, events, or processes; analyze advantages and limitations of models.					●		●	●
Communicating								
5. Research, interpret, and defend scientific investigations, conclusions, or arguments; use data, logic, and analytical thinking as investigative tools; express ideas through visual, oral, written, and mathematical expression.	●	●	●	●	●	●	●	●
2.2 Nature of Science: Understand the nature of scientific inquiry.								
Intellectual Honesty								
1. Analyze and explain why curiosity, honesty, openness, and skepticism are integral to scientific inquiry.								
Limitations of Science and Technology								
2. Identify and analyze factors that limit the extent of scientific investigation.								●

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
Evaluating Inconsistent Results								
3. Compare, contrast, and critique divergent results from scientific investigations based on scientific arguments and explanations.		●						●
Evaluating Methods of Investigation								
4. Analyze and evaluate the quality and standards of investigative processes and procedures.								●
Evolution of Scientific Ideas								
5. Know that science involves testing, revising, and occasionally discarding theories; understand that scientific inquiry and investigation lead to a better understanding of the natural world and not to absolute truth.	●	●	●	●	●	●	●	●
3. DESIGN: The student knows and applies the design process to develop solutions to human problems in societal contexts. To meet this standard, the student will:								
3.1. Designing Solutions: Apply design processes to develop solutions to human problems or meet challenges using the knowledge and skills of science and technology.								
Identifying Problems								
1. Study and analyze challenges or problems from local, regional, national, or global contexts in which science/technology can be or has been used to design a solution.	●	●	●	●	●	●	●	●
Designing and Testing Solutions								
2. Research, model, simulate, and test alternative solutions to a problem.		●	●					●
Evaluating Potential Solutions								
3. Propose, revise, and evaluate the possible constraints, applications, and consequences of solutions to a problem or challenge.			●				●	●
3.2. Science, Technology, & Society: Know that science and technology are human endeavors, interrelated to each other, to society, and to the workplace								
All Peoples Contribute to Science and Technology								

Investigation → correlates with standards	1	2	3	4	5	6	7	8
1. Analyze how scientific knowledge and technological advances discovered and developed by individuals and communities in all cultures of the world contribute to changes in societies.	●							●
Relationship of Science and Technology								
2. Analyze how the scientific enterprise and technological advances influence and are influenced by human activity, for example, societal, environmental, economical, political, or ethical considerations.								●
Careers and Occupations Using Science, Mathematics, and Technology								
3. Investigate the scientific, mathematical, and technological knowledge, training, and experience needed for occupational/career areas of interest.								
Environmental and Resource Issues								
4. Analyze the effects of natural events and human activities on the earth's capacity to sustain biological diversity.								

Correlation of the Investigations with Washington State Standards,

Essential Academic Learning Requirements (science TM draft 3b, 2003 09 24)

Essential Academic Learning Requirements—Science

GRADE 8

Investigation 1 – Observing, Predicting and Questioning
Investigation 2 – Solar Panel Orientation
Investigation 3 – Simple Electrolysis
Investigation 4 – Understanding Electrolysis
Investigation 5 – Hydrogen Power
Investigation 6 – Hydrogen Power in Motion
Investigation 7 – Energy Efficiency
Investigation 8 – Extending our Knowledge

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
1. SYSTEMS: The student understands and uses scientific concepts and principles to understand systems. To meet this standard, the student will:								
1.1. Properties of Systems: Use properties to identify, describe, and categorize substances, materials, and objects and use characteristics to categorize living things.								
PHYSICAL SCIENCE								
Properties of Substances								
1. Use physical and chemical properties to sort and identify substances, for example, density, boiling point, and solubility.								
Motion of Objects								
2. Describe the positions, relative speeds, and changes in speed of objects.								
Wave Behavior								
3. Describe sound, water waves, and light, using wave properties such as wavelength, reflection, refraction, transmission, absorption, scattering, and interference.								
Energy Sources and Kinds								

Investigation → correlates with standards	1	2	3	4	5	6	7	8
4. Understand that energy is a property of matter, objects, and systems and comes in many forms, including stored energy, energy of motion, and heat energy such as heat, light, electrical, mechanical, sound, nuclear, and chemical.		●		●		●		
1.2. Structure of Systems: Recognize the components, structure, and organization of systems and the interconnections within and among them.								
Systems Approach								
1. Describe how the parts of a system interact and influence each other.		●	●	●	●			
PHYSICAL SCIENCE								
Energy Transfer and Transformation								
2. Determine factors that affect rate and amount of energy transfer; associate a decrease in one form of energy with an increase in another.		●	●		●	●		
Structure of Matter								
3. Understand that all matter is made up of atoms, which may be combined in various kinds, ways, and numbers to make molecules of different substances.			●	●				
1.3. Changes in Systems: Understand how interactions within and among systems cause changes in matter and energy.								
PHYSICAL SCIENCE								
Nature of Forces								
1. Know the factors that determine the strength and interactions of various forces.								
Forces to Explain Motion								
2. Understand the effects of balanced and unbalanced forces on the motion of objects along a straight line.								
Physical/Chemical Changes								
3. Understand physical and chemical changes at the particle level, and know that matter is conserved.				●		●		

Investigation → **correlates with standards**	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***
2. INQUIRY: The student knows and applies the skills, processes, and nature of scientific inquiry. To meet this standard, the student will:								
2.1. Investigating Systems: Develop the knowledge and skills necessary to do scientific inquiry.								
Questioning								
1. Generate questions that can be answered through scientific investigations.	●							●
Planning and Conducting Investigations								
2. Plan, conduct, and evaluate scientific investigations, using appropriate equipment, mathematics, and safety procedures.		●	●	●	●	●	●	●
Explaining								
3. Use evidence from scientific investigations to think critically and logically to develop descriptions, explanations, and predictions.		●	●	●	●	●	●	●
Modeling								
4. Correlate models of the behavior of objects, events, or processes to the behavior of the actual things; test models by predicting and observing actual behaviors or processes.								
Communicating								
5. Communicate scientific procedures, investigations, and explanations visually, orally, in writing, with computer-based technology, and in the language of mathematics.		●		●		●	●	●
2.2 Nature of Science: Understand the nature of scientific inquiry.								
Intellectual Honesty								
1. Understand the operational and ethical traditions of science and technology such as skepticism, cooperation, intellectual honesty, and proprietary discovery.								
Limitations of Science and Technology								
2. Understand that scientific investigation is limited to the natural world.								
Evaluating Inconsistent Results								

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
3. Provide more than one explanation for events or phenomena; defend or refute the explanations using evidence.								●
Evaluating Methods of Investigation								
4. Describe how methods of investigation relate to the validity of scientific, experiments, observations, theoretical models, and explanation.								
Evolution of Scientific Ideas								
5. Explain how scientific theory, prediction or hypothesis generation, experimentation, and observation are interrelated and may lead to changing ideas.								
3. DESIGN: The student knows and applies the design process to develop solutions to human problems in societal contexts. To meet this standard, the student will:								
3.1. Designing Solutions: Apply design processes to develop solutions to human problems or meet challenges using the knowledge and skills of science and technology.								
Identifying Problems								
1. Identify and examine common, everyday challenges or problems in which science/technology can be or has been used to design solutions.	●		●	●	●	●		●
Designing and Testing Solutions								
2. Identify, design, and test alternative solutions to a challenge or problem.		●						●
Evaluating Potential Solutions								
3. Compare and contrast multiple solutions to a problem or challenge.								
3.2. Science, Technology, & Society: Know that science and technology are human endeavors, interrelated to each other, to society, and to the workplace								
All Peoples Contribute to Science and Technology								

Investigation ➔ correlates with standards	1	2	3	4	5	6	7	8
1. Know that science and technology have been developed, used, and affected by many diverse individuals, cultures, and societies throughout human history.	●							
Relationship of Science and Technology								
2. Compare and contrast scientific inquiry and technological design in terms of activities, results, and influence on individuals and society; know that science enables technology and vice versa.								
Careers and Occupations Using Science, Mathematics, and Technology								
3. Investigate the use of science, mathematics, and technology within occupational/career areas of interest.								
Environmental and Resource Issues								
4. Explain how human societies' use of natural resources affects quality of life and the health of ecosystems.								

Using the Fuel Cell Model Car Kit

Filling the electrolyzer

Before starting the electrolyzer, the bottom of the fuel cell storage cylinders should be completely filled with distilled water with no air space or other gas in the cylinders. If you need to add distilled water to the fuel cell, do so in this way:

Place the fuel cell on a flat surface and turn it upside down, so that the removable stoppers are facing up. Remove the stopper from the hydrogen storage cylinder. Add distilled water to the storage cylinder until the water reaches the top of small tube in the center of the cylinder. Tap the fuel cell lightly on the table to help water flow into the area surrounding the membrane and metal current-collecting plates. Add more water until it starts to overflow through the small tube in the center of the cylinder. Replace the stopper, making sure it fits tightly with no air trapped inside the cylinder. A small air bubble will not cause problems, and can be ignored. However any significant amount of air remaining in the cylinder will affect fuel cell performance; if this occurs you should try the filling procedure again.

Fill the oxygen storage cylinder in the same way.

Turn the fuel cell right side up. The open ends of the cylinders are now facing up. The lower portion of both cylinders should be completely filled with water.

Use only distilled water

It is absolutely required that only distilled (de-ionized) water be used in the reversible fuel cell. Damage to the membrane and reduced performance will result if tap water is allowed to enter the device. If students are using the fuel cell without close supervision, it might help to put tape or a sign on the water taps to prevent mistakes. There is no need for any tap water when using the fuel cell. For the same reason, students should rinse their hands before putting a finger into water that may be used in the electrolyzer or fuel cell. Student snacks may provide a source of ions that poison the membrane. Rinsing will probably prevent this.

Illuminating the Solar panel

The solar panel can be permanently damaged by overheating, usually the result of being too close to the light source.

A 75 watt PAR30 incandescent lamp is recommended for use with the *Fuel Cell Model Car Kits* and should be kept a minimum of 20 cm (8 inches) away from the solar panel. Other lamps can also provide good results, for example an 85 watt reflector (R) spot lamp. If you are using a different light source, you could occasionally touch the surface of the solar panel to ensure it is not overheating. The solar panel can be safely operated in bright sunlight. Do not use homemade reflectors made of foil or paper as they may cause overheating.

The surface of the solar panel should be evenly illuminated. The nature of solar panels makes the current output dependent on the darkest spot on the panel. As a result, although the bright spots from your PAR lamp may be shining strongly on the solar panel, if a corner of the panel is in relative darkness, that dark area will limit the output current regardless of how brightly the light shines on other areas.

Because the electrolyzer membrane is hidden inside the device, you cannot see the hydrogen and oxygen bubbles forming, and it may be difficult to get a sense of which lamp placement works best. Temporarily connecting the solar panel to the load box ammeter (set LOAD to SHORT CIRCUIT) will allow you to experiment with the best lamp placement. The solar panel properly illuminated by a 75 watt PAR lamp at 20 cm will typically produce 200 mA short circuit current. When you generate hydrogen using this level of illumination, you will need about 10 minutes to fill the storage cylinder.

Keeping the membrane hydrated

If the fuel cell is new, or the membrane has dried out since its last use, the cell will not work at full capacity on the first filling. Gas production will be slow, and power from the fuel cell will be limited. To obtain reproducible behavior after a prolonged period of non-use, it is necessary to re-hydrate the membrane. To a limited extent, you can hydrate the membrane by filling the electrolyzer with distilled water and letting it sit at least 20 minutes before use. For even better hydration, put the device through a complete cycle: generating 10 ml of hydrogen and then using it.

If you expect to use the fuel cell within the next few days, to avoid the fuel cell drying out, simply leave water in the storage cylinders. If you want the students to start with an empty device, you could discard the water just before the class.

If you plan to store the fuel cell for a longer time, it's recommended that you drain the fuel cell and store it in a zippered plastic bag to keep it hydrated.

Fuel cell stops working before it runs out of hydrogen?

On occasion, you may notice that the fuel cell slows or stops working even though visible quantities of hydrogen and oxygen are present in the storage cylinders. There are two possible causes:

Air was left in the cylinders when you filled the electrolyzer. If a significant amount of air is mixed with the hydrogen, eventually as the hydrogen is consumed in the fuel cell, the remaining gas mixture will contain proportionally less and less hydrogen, until the fuel cell stops working. Don't allow any air bubbles to remain when you fill the cylinders, as described in *Filling the electrolyzer*.

Hydrogen has diffused through the membrane. The hydrogen molecule is very small and readily diffuses through the membrane, contaminating the oxygen side. This effect is more evident when the membrane is dry, and of course increases the longer that hydrogen remains in contact with the membrane. You can minimize this effect in several ways:

- Ensure the device is properly hydrated, which is also recommended for other reasons (see *Keeping the membrane hydrated*)
- Do not allow hydrogen to sit in the fuel cell for a long time. Instead, generate and use the gases in the same laboratory session.
- Often when you generate gases in the electrolyzer, in order to observe the classic "2-to-1" hydrogen-to-oxygen ratio, you will stop generating before hydrogen starts to escape through the upper reservoir. However, if you do continue generating gases past the point at which hydrogen escapes, you will have surplus oxygen to combine with the accumulated hydrogen. Then later when the fuel cell is consuming hydrogen and has used up almost all of it, the effect of some hydrogen having diffused into the relatively larger amount of oxygen will not be significant.

Water leaking from the fuel cell?

With time and exposure the plastic stoppers on the bottom of the storage cylinders may shrink slightly resulting in a water leakage. Should this occur, the problem can easily be corrected. Turn the cell upside down and remove the plastic stopper from the leaking cylinder. Place the stopper on a firm surface, and with the palm of your hand, press the stopper flat, expanding it to its original size. Refill the storage cylinder with distilled water, then press the stopper back into place.

Car won't move on a smooth surface?

If it appears that the motor is not strong enough to drive the car, make sure that you filled the electrolyzer properly (see *Filling the electrolyzer*), and that you have generated enough (5-6 ml) hydrogen. In addition, it may be necessary to lubricate the gears in the car's drive mechanism.

Using the Load Box

It is advisable to keep the load box OFF unless it's needed. The battery will last indefinitely if the load box is turned off after use. If changing the battery becomes necessary, use a small Phillips driver to remove the front panel.

You may notice that if you connect the load box voltmeter to the fuel cell immediately after using it as an electrolyzer, you will see a voltage displayed that is apparently greater than the ideal fuel cell voltage—more than 1.23 V. The problem is not in the load box. Because of a transient surface layer on the catalyst, the initial output voltage of the device really is higher than the voltage of a normal fuel cell. This layer disappears in a few seconds of use.

If you attempt to use the load box ammeter or voltmeter to measure current or voltage at the model car motor, electrical noise from the motor will produce false meter readings. The meters are designed for use with the lamp, motor, and resistive loads supplied in the load box.

Goggles

Although goggles may not seem necessary, it is good practice to wear them throughout your science experiences with chemicals. No experimenters have had their vision damaged by wearing appropriate eye protection but many have suffered eye damage because they did not put their eye protection in place! Students should wear goggles even for demonstrations.

Student questions

It is strongly suggested that students answer the questions using full sentences that restate the question. The answers provided in the Teaching Supplement use this style. It is much easier for students to study from their lab notes and the skill of writing in sentences will be needed as students write up their future investigations in the manner of a scientific report.