

PRODUCTION Supplemental Activity #1

### Teacher Preface

This module introduces the video *Hydrogen: The Pollution Solution*, which presents hydrogen as an environmentally friendly alternative to fossil fuel energy. This “MTV-style” video can be effectively used as an engagement piece not only for the Production module, but also for the entire *HOPE* curriculum. (The video may also be used for informal education purposes outside the classroom should the opportunity arise.)

*Hydrogen: The Pollution Solution* predicts that the near future will bring a world that runs on clean hydrogen energy. The transition to hydrogen is depicted as inevitable because hydrogen is the cleanest source of energy and has the potential to be virtually limitless in supply. The video shows how hydrogen technology, like the fuel cell, works in cars and in space shuttles. It demonstrates how use of hydrogen and related technologies will offer students new hydrogen energy job opportunities in a future without pollution.

### Quiz on Pollution Solution

1. Name one kind of fuel that causes pollution.
2. When burned as a fuel, Hydrocarbons generate carbon dioxide, which is also known as \_\_\_\_\_.
3. Cars are cleaner than in the past, but because there are more people, there are a lot more \_\_\_\_\_.
4. Air pollution can damage the \_\_\_\_\_ and cause higher incidences of \_\_\_\_\_ in young children.
5. Ninety eight percent of all the atoms in the universe are \_\_\_\_\_ atoms.
6. There is no harmful car exhaust in a hydrogen-fueled vehicle. When you burn hydrogen in a car, all you get is \_\_\_\_\_.
7. Water is made of \_\_\_\_\_ and \_\_\_\_\_.
8. One way to get hydrogen is by splitting \_\_\_\_\_ molecules.
9. Today, we have cars that run on gasoline and electric cars that run on batteries. The next generation of electric cars will run on \_\_\_\_\_.
10. The \_\_\_\_\_ is a device that runs on hydrogen and has been used to make electricity in spacecraft.
11. In a proton exchange membrane fuel cell, the electrons from the hydrogen atoms can't get through the \_\_\_\_\_. Instead, they have to go around it. This movement creates an electric \_\_\_\_\_.
12. A hydrogen powered \_\_\_\_\_ can be used to power electric cars, ships, and locomotives.
13. Using hydrogen instead of gasoline is good for the \_\_\_\_\_, and good for people's \_\_\_\_\_.

## Solutions & Suggestions

1. Name one kind of fuel that causes pollution.

**Gas, oil, coal**

2. When burned as a fuel, Hydrocarbons generate carbon dioxide, which is also known as \_\_\_\_\_.

**Air pollution**

3. Cars are cleaner than in the past, but because there are more people, there are a lot more \_\_\_\_\_.

**Cars**

4. Air pollution can damage the \_\_\_\_\_ and cause higher incidences of \_\_\_\_\_ in young children.

**Lungs, asthma**

5. Ninety eight percent of all the atoms in the universe are \_\_\_\_\_ atoms.

**Hydrogen**

6. There is no harmful car exhaust in a hydrogen-fueled vehicle. When you burn hydrogen in a car, all you get is \_\_\_\_\_.

**Water**

7. Water is made of \_\_\_\_\_ and \_\_\_\_\_.

**Hydrogen, oxygen**

8. One way to get hydrogen is by splitting \_\_\_\_\_ molecules

**Water**

## Solutions and Suggestions

9. Today, we have cars that run on gasoline and electric cars that run on batteries. The next generation of electric cars will run on \_\_\_\_\_.

**Hydrogen**

10. The \_\_\_\_\_ is a device that runs on hydrogen and has been used to make electricity in spacecraft.

**Fuel Cell**

11. In a proton exchange membrane fuel cell, the electrons from the hydrogen atoms can't get through the \_\_\_\_\_. Instead, they have to go around it. This movement creates an electric \_\_\_\_\_.

**Membrane, current**

12. A hydrogen powered \_\_\_\_\_ can be used to power electric cars, ships, and locomotives.

**Fuel Cell**

13. Using hydrogen instead of gasoline is good for the \_\_\_\_\_, and good for people's \_\_\_\_\_.

**Environment, health**

## Hydrogen Production Jigsaw

### Teacher Preface

Students are split into groups of three. Each group counts off one to three. All of the “ones” read and answer questions to “Electrolysis of Water to Make Hydrogen Gas.” The “twos” read and answer questions to “Using Fossil Fuel Steam Reforming to Produce Hydrogen Gas.” The “threes” read and answer questions to “Photobiologicals Used to Make Hydrogen Gas.”

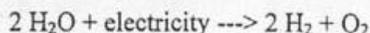
Once each student has read their article and answered their set of questions, they summarize their article for the rest of the group. The teacher should stress that every group member is dependent on other group members in order for each individual to be successful.

Each student is given a copy of the “Various Methods of Hydrogen Production” worksheet and they work on it as a group.

"Ones" read this article and answer questions.

## Electrolysis of Water to Make Hydrogen Gas

What is the chemical formula for water? If you said  $H_2O$ ... you're right! Since part of water is hydrogen and water is both abundant and cheap, it is a perfect source for making hydrogen gas. If we take a 9-volt battery (the kind we put in alarm clocks or smoke detectors) and put the electrodes in water we produce hydrogen gas and oxygen gas by the following reaction.



This process is called the electrolysis of water. This is an environmentally clean method for making hydrogen because its only byproduct is oxygen gas, which is not an environmental pollutant. However, this method does require large amounts of energy.

In order for this method to truly be environmentally clean, the electricity used in the electrolysis must be made from an environmentally clean or "renewable" energy source. There are three main sources of energy for electricity production: fossil fuels, renewable energy sources and photoelectrolysis.

Some common fossil fuels are coal, oil, gasoline, and natural gas. These are used to produce electricity. Fossil fuels are nonrenewable and contribute to pollution. A renewable energy source is limitless while a nonrenewable sources have only a limited amount available. If the electricity used for the electrolysis of water is made from fossil fuels, then the whole process is polluting and nonrenewable. It is less energy efficient to use fossil fuels to make hydrogen and ultimately electricity than it is to just use fossil fuels to produce the electricity.

Electricity can be produced from renewable sources, such as photovoltaic (solar) cells, hydroelectric power, biomass, and wind power. All of these are environmentally clean. However, they each have their limitations (for example, you can't make electricity with a solar cell at night). If the electricity used to electrolyze water is from a solar source then the whole process is environmentally clean and renewable.

The most recently discovered method for splitting water is called photoelectrolysis. The prefix photo- means light, this method uses light to split water directly. Photoelectrolysis is environmentally clean and renewable. With solar electricity, we said that sun light is converted to electricity and then the electricity is used to make hydrogen gas. With photoelectrolysis, the sun light directly makes the hydrogen gas. For this reason, this process is more efficient than solar powered electrolysis. To make this work we mix a catalyst into the water. A catalyst is a substance that increases the rate of a reaction without being used up. So the presence of a catalyst in water enables the production of both the hydrogen gas and oxygen gas. This method requires more research before large scale production can occur. However, it is an exciting possibility for future production of hydrogen gas.

## PRODUCTION

### “Hydrogen Production Jigsaw” Ones

**Questions :** Use extra paper if needed, clearly marking each question.

1. What is the chemical reaction for the electrolysis of water?
2. What equipment do you need to electrolyze water?
3. Identify and define the three main sources of energy mentioned in this article.
4. What are the disadvantages of using fossil fuels as a feedstock for electricity?
5. Identify the advantages and disadvantages of electricity produced from renewable energy.
6. Explain why photoelectrolysis would be preferred over renewable energy methods of electricity production.

**Be thorough when you share this information with your group members!**

“Hydrogen Production Jigsaw”

“Twos” read this article and answer questions.

**Using Fossil Fuel Steam Reforming to Produce Hydrogen G**

Every day about 100,000,000. ft<sup>3</sup> of hydrogen is made in industry. About 99% of this hydrogen is made from fossil fuels by a process call steam reforming.

Fossil fuels are compounds like coal, oil, gasoline, and natural gas. These were originally plant and animal life millions of years ago. The plants and animals died, decomposed and became covered by rocks and dirt. This adds heat and pressure to the plant and animal remains which slowly turns these remains into compounds of carbon and hydrogen such as methane (CH<sub>4</sub>), propane (C<sub>3</sub>H<sub>8</sub>), butane (C<sub>4</sub>H<sub>10</sub>), and octane (C<sub>8</sub>H<sub>18</sub>). We call these compounds fossil fuels.

Since fossil fuels are readily available and they contain hydrogen, they are a good resource or “feedstock” for production of hydrogen. When we expose fossil fuels to high temperature steam we produce hydrogen gas and a byproduct, carbon dioxide gas. We call this method steam reforming.

This is the cheapest way to make hydrogen gas. Unfortunately, it produces the same amount of carbon dioxide as burning the fossil fuel. Carbon dioxide is thought to have a negative affect on the environment. However, hydrogen gas powered cars are more efficient than gasoline cars, so the amount of carbon dioxide produced to fuel a hydrogen car would be anywhere from one-half to one-fifth of the amount produced to fuel a gasoline car.

There are two disadvantages to this method. The first is that the energy produced from this method is more expensive than if we just burned the fossil fuel. The second is that this method still relies on fossil fuels which are a non-renewable source of energy. Non-renewable means we will someday run out of the energy source.

## PRODUCTION

### Questions:

Use extra paper if needed, clearly marking each question.

1. The volume of the trailer of an eighteen-wheeler is about 2200. ft<sup>3</sup>. How many 18-wheeler trailers would you need to contain all of the hydrogen made every day by industry? Show your work.
2. How many cubic feet of hydrogen gas is made daily by methods other than steam reforming? Show your work.
3. Give three examples of fossil fuels.
4. What is the original source of fossil fuels?
5. Why do we consider fossil fuels to be non-renewable?

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6. What are the two elements that make up fossil fuels?
  
7. If you react each of the elements you listed in the answer to #6 with oxygen, what two products would you get?
  
8. What must be done to get hydrogen gas out of fossil fuels?
  
9. What is the byproduct of this process?
  
10. Why is 99% of all hydrogen gas made from fossil fuels?
  
11. What are the long-term disadvantages to making hydrogen gas by this method?

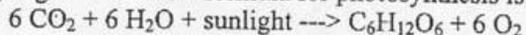
**Be thorough when you share this information with your group members!**

"Hydrogen Production Jigsaw"

"Threes" read this article and answer questions.

### Photobiologicals Used to Make Hydrogen Gas

When you took biology you learned about photosynthesis. As you recall, photosynthesis is the method by which plants take sunlight, water and carbon dioxide and make sugars and oxygen gas. The basic formula for photosynthesis is:



All of the fruits, vegetables, and grains you eat come from plants using photosynthesis. In fact, all of the meat and dairy products you eat come from animals that eat fruits, vegetables, and grains that come from photosynthesis. This means that all of the energy your body takes in comes from the energy in sunlight! You are a solar powered system!

What if we could get plants to make hydrogen gas for us?

Guess what. We CAN! There are kinds of plants called algae. Algae are simple, one-cell plants without roots, stems, or leaves. All algae use photosynthesis to make the energy needed to thrive. Some kinds of algae naturally split water into hydrogen gas and oxygen gas.

Unfortunately, this hydrogen gas production only occurs efficiently at low light intensities in the absence of oxygen and carbon dioxide gases.

This method of making hydrogen has only recently been discovered and will require some more research to make it economically feasible. One of the hurdles that researchers must overcome is the inefficiency of the process. In fact, there are two processes. One is a water-splitting or water oxidation process that produces oxygen; the other is a hydrogenase process that produces hydrogen. The oxygen producing process actually inhibits hydrogen production.

Scientists will need to experiment with various kinds of algae to determine which kind produces the hydrogen gas most efficiently. Then they will try to extend the life span of the algae for more efficient production. In the end, they will try to make the hydrogen gas reaction proceed in naturally occurring environments (i.e. oxygen environment and noon hour sun light intensities). Once these obstacles have been conquered, mass production of hydrogen gas from algae can be tested on a large scale.

This process will take considerable time and effort, but if these barriers can be overcome we will have an inexpensive, clean, renewable source of energy as long as there is sunlight!

PRODUCTION

“Hydrogen Production Jigsaw” - “Threes”

Questions :

Answer these questions on your own paper.

1. Explain what photosynthesis is?
2. What is the original source of all the energy your body uses? Explain.
3. Explain what algae are. Identify one place you have seen algae in your life.
4. Some algae produce hydrogen gas, Under what conditions does this occur?

PRODUCTION

"Hydrogen Production Jigsaw" - "Threes"

5. Identify at least one obstacle to producing hydrogen gas with algae given the conditions mentioned on #4.
  
6. How could the obstacle you mentioned in #5 be overcome?
  
7. What are two other current obstacles to producing hydrogen gas by this method?
  
8. What is the benefit to overcoming these obstacles?

**Be thorough when you share this information with your group members!**

"Hydrogen Production Jigsaw"

### Various Methods of Hydrogen Production

Discuss and answer these questions with the members of your group. Each group will submit one set of written responses.

Group Number \_\_\_\_\_

1. What characteristic makes an energy source renewable?
2. In order for an energy source to be environmentally clean, what requirements must it meet?
3. How much hydrogen gas is produced in a **week**?
4. Which of the three methods of hydrogen gas production is most widely used today?
5. Describe how hydrogen gas is made from the method identified in #4.

## PRODUCTION

### "Hydrogen Production Jigsaw"

#### Various Methods of Hydrogen Production

Group Number \_\_\_\_\_

6. Which of the three methods of hydrogen gas production is the most polluting?
7. Which of the three methods of hydrogen gas production is not renewable?
8. Which method of hydrogen gas production would you choose to use in the middle of a desert? Explain your answer.
9. There are two methods of hydrogen gas production identified in these articles that have been recently discovered and require research to make them commercially viable. You have been given the power to decide how much research money should be spent on each of these sources. Discuss with your group what percentage of your budget you would give to each of these methods. When you have come to an agreement record your decision on your answer sheet. Explain why you chose to spend the money this way.
10. Discuss with your group which *currently available* method of hydrogen production is the best and which is the worst. Consider all factors. When you have come to an agreement record your order of preference on your answer sheet. Explain your answers.

## PRODUCTION

### "Hydrogen Production Jigsaw"

## Solutions and Suggestions

### Electrolysis of Water to Make Hydrogen Gas

#### Answers:

1. The chemical reaction for the electrolysis of water is:  $2 \text{H}_2\text{O} + \text{sunlight} \rightarrow 2 \text{H}_2 + \text{O}_2$
2. To electrolyze water you need a source of electrical current and water.
3. The three main sources of energy mentioned in this article are fossil fuels, solar power, and photoelectrolysis.
4. The disadvantages of using fossil fuels as an electrical source are that burning fossil fuels produces environmental pollutants and fossil fuels are nonrenewable.
5. The advantages of solar electricity are that it is a clean and renewable energy source. The disadvantages of solar electricity are the limitations of the solar power. For example, solar cells are only efficient in areas with plenty of sunlight and will not produce electricity during the night. To get hydroelectric power you must live relatively close to a river or waterfall. To get wind power you need lots of wind and open spaces for the windmills.
6. Photoelectrolysis is a preferable method over solar electricity because it is a direct conversion from light to hydrogen gas and is therefore more efficient than converting sunlight to electricity to hydrogen gas.

### Using Fossil Fuels to Produce Hydrogen Gas

#### Answers:

1.  $100,000,000. \text{ft}^3 / 2200. \text{ft}^3 = 45,450$  eighteen-wheeler trailers
2.  $100,000,000. \text{ft}^3 \times 0.01 = 1,000,000. \text{ft}^3$  of hydrogen gas produced daily from non-fossil fuel sources.
3. Three examples of fossil fuels are (*choose three of the following*) oil, coal, gasoline (octane), natural gas (methane), propane, and butane.
4. The original source for fossil fuels is animal and plant life from millions of years ago.
5. A renewable energy source is one which will not ever run out. There is a limited supply of fossil fuels, so they are non-renewable.
6. Fossil fuels are made of carbon and hydrogen primarily.
7. If these elements were reacted with oxygen you would get  $\text{CO}_2$  (carbon dioxide) from carbon and  $\text{H}_2\text{O}$  (water) from hydrogen.
8. To get the hydrogen gas out of fossil fuels we expose the fossil fuel to hot steam.
9. Another product of this process is carbon dioxide ( $\text{CO}_2$ ).
10. Ninety-nine percent of all synthesized hydrogen gas is made from fossil fuels because it is the least expensive method.
11. The long term disadvantages of making hydrogen gas from this method are the energy produced from the hydrogen gas is more expensive than energy made straight from the fossil fuels and the fact that we will someday run out of fossil fuels.

PRODUCTION  
"Hydrogen Production Jigsaw"

Photobiologicals Used to Make Hydrogen Gas

**Answers:**

1. Photosynthesis is the process by which plants can change sunlight, water, and carbon dioxide into sugar and oxygen gas.
2. The original source of all the energy my body uses is the sun.
3. Algae is a simple plant without roots, stems, or leaves. I've seen algae in a pond.
4. The conditions in which algae produces hydrogen gas are no oxygen gas or carbon dioxide gas and low sunlight.
5. One obstacle of producing hydrogen gas through algae is that the process produces oxygen gas which will prohibit the reaction from proceeding.
6. To overcome this obstacle you would have to remove the oxygen that is produced by the algae.
7. Two other current obstacles are (*choose two of the following*) that this reaction only occurs at low light levels, that we don't know which algae is the most efficient at producing hydrogen gas, that algae have a short life span, and that this reaction has never been attempted on a large scale.
8. The benefit of overcoming these obstacles is that we would have an inexpensive, renewable, clean source of energy for decades to come.

Various Methods of Hydrogen Production

**Answers:**

1. The characteristic that makes an energy source renewable is it must have an unlimited original energy source.
2. In order for an energy source to be environmentally clean it must have byproducts that do not have a negative affect on the environment.
3. 700,000,000. ft<sup>3</sup> (or 3,181,000 eighteen-wheeler trailers full) of hydrogen gas is produced every week.
4. The method of hydrogen production that is most widely used today is mixing fossil fuels with high temperature steam.
5. The method that is most polluting is steam reforming.
6. In steam reforming fossil fuels are exposed to high temperature steam. This produces hydrogen gas and carbon dioxide.
7. I would choose solar cell electrolysis to make hydrogen gas in the middle of the desert because sunlight is plentiful and in a desert solar cell electricity would be efficient. This is also a clean and renewable source of power.
8. *Various answers are acceptable as long as students have adequately supported their answers.*
9. *Various answers are possible as long as students have adequately supported their answers.*

**Additional Instructional Note:**

By the end of 1994, energy produced by hydrogen gas was about 50% more expensive than energy produced by gasoline. This hydrogen was produced by fossil fuel steam reforming. Currently the only other method of large scale hydrogen production is via electrolysis using either fossil fuels or solar power as the energy source.