STEAM EDUCATION

H2 GRAND PRIX SPRINT

STEM Education Works®

Horizon Educational

Overview

Course Overview

Instructional Time: *000 min.*

In this course, students will:

- How greenhouse gases and carbon emissions contribute to climate change
- How hydrogen is produced
- How the process of electrolysis works
- How a hydrogen fuel cells works
- Why hydrogen fuel cells are good for the environment

COMMON CORE STANDARDS: CCSS

COMMON CORE STATE STANDARDS INITIATIVE
PREPARING AMERICA'S STUDENTS FOR COLLEGE & CAREER

LST.9-10.1: Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

LST.9-10.3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

LST.9-10.10: By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

CONNECTED STANDARDS: NGSS

NEXT GENERATION SCIENCE STANDARDS

HS-PS1-2: Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties.

HS-PS2-6: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS3-3: Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-LS2-7: Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

HS-ESS3-2: Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

HS-ESS3-4: Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

CONNECTED STANDARDS: ISTE

ISTE® Standards

1.1.d: Students understand the fundamental concepts of technology operations, demonstrate the ability to choose, use and troubleshoot current technologies and are able to transfer their knowledge to explore emerging technologies.

1.3.a: Students plan and employ effective research strategies to locate information and other resources for their intellectual or creative pursuits.

1.3.d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories and pursuing answers and solutions.

1.4.a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts or solving authentic problems.

1.5.b: Students collect data or identify relevant data sets, use digital tools to analyze them, and represent data in various ways to facilitate problem-solving and decision-making.

CONNECTED STANDARDS: ISTE

CSTA K-12 COMPUTER SCIENCE STANDARDS

1O: Assess how similarities and differences among scientific, mathematics, engineering, and technological knowledge and skills contributed to the design of a product or system.

1Q: Conduct research to inform intentional inventions and innovations that address specific needs and wants.

2T: Demonstrate the use of conceptual, graphical, virtual, mathematical, and physical modeling to identify conflicting considerations before the entire system is developed and to aid in design decision making.

3I: Evaluate how technology enhances opportunities for new products and services through globalization.

4Q: Critique whether existing or proposed technologies use resources sustainably.

4R: Assess a technology that minimizes resource use and resulting waste to achieve a goal.

7X: Document trade-offs in the technology and engineering design process to produce the optimal design.

7Y: Optimize a design by addressing desired qualities within criteria and constraints.

CULTURAL CONNECTIONS

Greenhouse gases are gases in Earth's atmosphere that absorb light energy from the Sun and then emit that energy in the form of heat. Common greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Greenhouse gases can be produced via natural processes (like biological respiration, decomposition, and volcanism) or as a result of human activities (like agriculture, industry, and sources of transportation). Over the last two centuries, the concentration of greenhouse gases in our atmosphere has increased significantly, and human activities are almost entirely to blame. An overabundance of these gases in the atmosphere can negatively affect human health and can impact/alter the climate of our planet by trapping heat in Earth's atmosphere via a process called "the greenhouse effect."

One of the most prominent and potent greenhouse gases in our atmosphere is carbon dioxide. Since the beginning of the Industrial Revolution (around 1750), human activities have increased the atmospheric concentration of carbon dioxide by over 50%. (The last time the atmospheric concentration of CO_2 was naturally this high was over three million years ago.) The amount of carbon dioxide and other carbon compounds emitted due to the burning of fossil fuels by a person or group is called a "carbon footprint." And the sources of transportation that people use every day (like cars, trucks, ships, trains, and planes) are one of the biggest contributors to the amount of carbon that humans release into the atmosphere. With this in mind, finding alternative ways to power vehicles – such as using hydrogen fuel cells to power cars – is more important than ever and is a great way to significantly reduce our carbon footprint. Scientists and engineers continue to work on improving the efficiency and effectiveness of hydrogen fuel cells to make this goal a reality. Learn more about hydrogen fuel cells and climate change in this **video** (*https://www.youtube.com/watch?v=v8IW4D5cN50*).

CAREER CONNECTIONS

- **Electrical Engineer** (*https://bit.ly/329uOWt*)**:** Electrical engineers design, develop, and create electrical systems for buildings, vehicles, and products that we use every day. They specialize in understanding how electricity works and how to manipulate electric current in clever ways.
- **Environmental Engineer** (*https://www.youtube.com/watch?v=T2xFDIdjX88*)**:** Environmental engineers collect data and conduct research on how human activities impact the environment. Their job is to find ways to make sure that human needs are met without excessive destruction to the land, water, plants, and animals around us.
- **Chemical Engineer** (*https://www.youtube.com/watch?v=k-7B_YfHWXQ*)**:** Chemical engineers combine the principles of chemistry and engineering to develop solutions to problems in fields like medicine, manufacturing, and energy/fuel production.
- **Racecar Engineer** (*https://bit.ly/3f6s42k*)**:** Racecar engineers play a vital role on a racing team, ensuring that the team's car is working with top efficiency and safety.

CAREER CONNECTIONS

- What are the principles behind hydrogen fuel-cell technology, and how can it be harnessed to power sustainable transportation?
- What engineering and design considerations are necessary to build an efficient and functional hydrogen fuel-cell powered car?
- How can adopting hydrogen fuel-cell technology in transportation contribute to reducing carbon emissions and promoting a sustainable future?

ENDURING UNDERSTANDINGS

- Hydrogen fuel-cell technology offers a viable and sustainable solution for powering vehicles, reducing dependence on fossil fuels, and minimizing carbon emissions.
- Exploring the potential of hydrogen fuel-cell technology in transportation opens opportunities for innovation, research, and development in the field of sustainable energy solutions.

LEARNING OBJECTIVES

- Students will apply design principles to solve various problems within the scope of transportation technology.
- Students will evaluate the feasibility of hydrogen as a fuel source.
- Students will build and iteratively test a hydrogen-fuel cell powered kart.

REQUIRED PRIOR STUDENT KNOWLEDGE

- Foundational knowledge in chemistry, including the composition of water (H_2O) and the process of electrolysis.
- Basic understanding of electricity, circuits, and energy transfer.
- Strong reading comprehension skills, basic understanding of scientific concepts, such as chemical reactions, energy conversion, and the properties of gases.

MATERIALS

- TBD

INSTRUCTOR RESOURCES

- Slide presentation
- **Hydrogen Fuel Cell Research Activity** worksheet teacher key

STUDENT RESOURCES

- **Hydrogen Fuel Cell Research Activity** worksheet
- **Engineer Activity** slide presentation

INSTRUCTOR PREPARATION

- Review the slide presentation and the **Hydrogen Fuel Cell Research Activity** worksheet teacher key

VOCABULARY

climate change: long-term shifts in global temperature and weather patterns

driven gear: the gear that produces the output in a gear system

driver gear: the gear that is connected to a source of power in a gear system, usually a motor

electrolyzer: a device that is used to split water into hydrogen and oxygen gas

fuel cell: a device that produces electricity via a chemical reaction

gear ratio: the ratio between the number of teeth on the driven gear and the number of teeth on the driver gear in a gear system; can also be measured as the ratio between the size or rate of rotation of the driven and driver gears

greenhouse gas: a gas in Earth's atmosphere that contributes to the greenhouse effect by absorbing light from the Sun and emitting it in the form of heat

hydrogen fuel cell: a device that produces electricity via the combination of hydrogen and oxygen gas to form water

Lesson Plan

ENGAGE

Duration: *30 mins.*

STEP 1

Use the slide presentation to introduce the course and to review the cultural connections and career connections.

STEP 2

Use the slide presentation to introduce students to the subjects of hydrogen and hydrogen fuel cells.

STEP 3

Start a discussion by asking your students the following questions:

- *"Have you heard of climate change before? What are some of the causes of climate change? What can you and others do to help reduce the effects of climate change?"*

  (Answers will vary. Greenhouse gas emissions from human activities like agriculture, industry, and sources of transportation are the primary driver of climate change. Reducing our carbon footprint and utilizing clean, renewable energy is the best way to combat climate change.)
- *"Have you ever seen a hydrogen-powered vehicle before? Why do you think hydrogen-powered vehicles are not more common?"*

  (Answers will vary. Some of the reasons why hydrogen-powered cars are not more common include the high cost of producing hydrogen fuel cells and the lack of existing infrastructure like hydrogen refueling stations.)

EXPLORE

Duration: *90 mins.*

STEP 1

Introduce students to the **Hydrogen Fuel Cell Research Activity** worksheet and review the instructions with the class.

STEP 2

Divide students into groups of two to four. Give students time to complete the activity and address any questions that may arise.

Circulate and assist as needed.

EXPLAIN

Duration: *60 mins.*

STEP 1

Review the answers to the **Hydrogen Fuel Cell Research Activity** worksheet with your class.

STEP 2

Use the slide presentation to review some of the content from the **Hydrogen Fuel Cell Research Activity** worksheet.

STEP 3

Start a discussion by asking your students the following questions:

- *"Look again at the diagram depicting the inner workings of an electrolyzer. Now look at the diagram depicting the inner workings of a hydrogen fuel cell. In what ways are these processes similar? In what ways are they different?"*

  (Similarities: The process of running an electrolyzer is simply the reverse of running a hydrogen fuel cell. In an electrolyzer, water is turned into hydrogen and oxygen gas. In a hydrogen fuel cell, hydrogen and oxygen gas are turned into water.

  Differences: In an electrolyzer, electric power must be supplied to make the reaction run. In a hydrogen fuel cell, the combination of hydrogen and oxygen gas creates energy in the form of electricity.)
- *"Would you consider buying and driving a hydrogen-powered vehicle in the future?"*

  (Answers will vary.)

ENGINEER

Duration: *150 mins.*

STEP 1

Introduce students to the **Engineer Project** slide presentation.

STEP 2

Divide students into groups of two to four. Give students time to complete the project and address any questions that may arise.

Circulate and assist as needed.

STEP 3

As your students make their way through the **Engineer Project**, ask them the following questions:

- *"Notice the four small nozzles sticking out of your electrolyzer. What do you think these are for?"*

  (These nozzles allow water to enter the electrolyzer and allow hydrogen and oxygen gas to exit the electrolyzer.)
- *"Notice the red and black plugs on either side of your electrolyzer. What do you think these are for?"*

  (These are the electrodes of the electrolyzer that will allow us to pass electricity through our electrolyzer. The red, positive lead from the battery pack will be plugged into the red plug and the black, negative lead from the battery pack will be plugged into the black plug.)
- *"Notice the green cylinder with the balloon inside of it. What do you think this will be used for?"*

  (This item will serve as our hydrogen fuel tank. This tank will hold the hydrogen gas produced by our electrolyzer.)
- *"Notice white clincher around your piece of tubing. What do you think this is for?"*

  (This clincher will prevent our hydrogen gas from escaping from our hydrogen fuel tank.)
- *"Why do you think we need to inject water into our electrolyzer?"*

  (Water acts as the raw material that the electrolyzer uses to create hydrogen and oxygen gas.)

- *"Why do you think we need to use distilled water (as opposed to tap water) in our electrolyzer?"*

  (Distilled water contains pure H2O. But tap water also contains contaminants that could damage our electrolyzer over time.)
- *"Notice the two small nozzles sticking out of your hydrogen fuel cell. What do you think these are for?"*

  (The nozzle on the top of the hydrogen fuel cell will allow hydrogen gas to flow from our hydrogen fuel tank into our fuel cell. The nozzle on the side of the hydrogen fuel cell will allow us to equalize the pressure inside of the fuel cell. The vents on the top and bottom of the hydrogen fuel cell will allow oxygen gas to enter the fuel cell and will allow water vapor to exit the fuel cell.)
- *"Notice the red and black alligator clips extending from our hydrogen fuel cell. What do you think these will be used for?"*

  (These alligator clips will be used to pass electricity through the motor that will run our hydrogen-powered car.)
- *"What gear ratio are you going to use?"*

  (Answers will vary.)
- *"What gear ratio do you think will work best in long-distance races? Short-distance races? Medium-distance races?"*

  (Small gear ratios will work best in long-distance races. Large gear ratios will work best in short-distance races. Medium-value gear ratios will work best in medium-distance races.)

EVALUATE

Duration: *60 mins.*

STEP 1

Introduce students to the **Evaluate Activity** worksheet and review the instructions with the class.

STEP 2

Divide students into the groups from the Engineer Project. Give your students the chance to test their hydrogen-powered cars in a race against other student groups. Be sure to race on long, short, and medium tracks. Give students the opportunity to test different gear ratio options after each race trial.

Circulate and assist as needed.

Start a discussion by asking your students the following questions:

- *"Previously, we learned about the different categories of hydrogen: black, blue, pink, and green. What category of hydrogen did we produce in the Engineer Project?"*

  (In the Engineer Project, we created hydrogen via electrolysis and used AA batteries to power our electrolyzer. Because we do not ultimately know where the energy came from to charge our batteries, we can't be sure what category of hydrogen we produced. If the energy to manufacture our batteries came from nuclear energy, we produced pink hydrogen. If the energy to manufacture our batteries came from clean, renewable energy, we produced green hydrogen.)

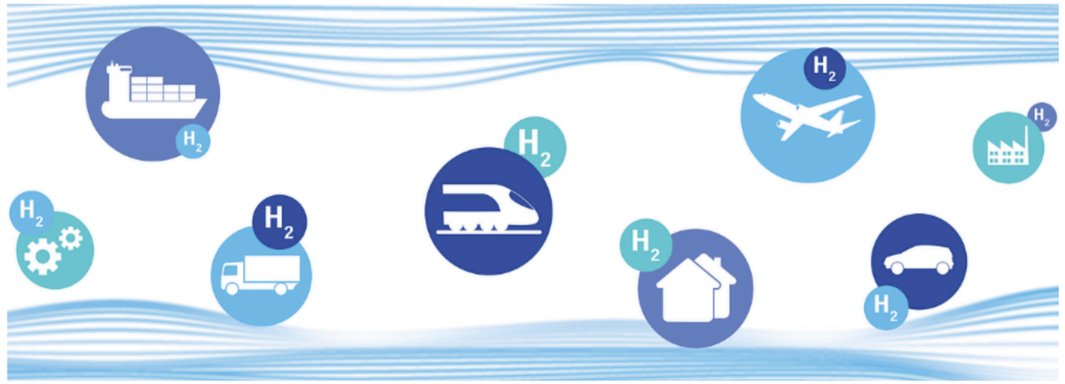
- *"A hydrogen fuel cell needs both hydrogen and oxygen gas to run. But when we ran our hydrogen fuel cell, we had a fuel tank for hydrogen gas but no fuel tank for oxygen gas. Where did the oxygen come from to power our fuel cell?"*

  (While hydrogen makes up a mere 0.00005% of Earth's atmosphere, oxygen makes up 20.95% of Earth's atmosphere. Because there is so little hydrogen in the air around us, we had to create and store hydrogen gas in a fuel tank to make our hydrogen fuel cell run. Oxygen, on the other hand, is relatively abundant in the air around us, so our fuel cell could simply get the oxygen it needed from the air around it.)
- *"Out of the four options available, what gear ratio did you find to work best in long-distance races? Short-distance races? Medium-distance races?"*

  (Students should have found that the smallest gear ratio of ~2.63 worked best in long-distance races, giving the user the highest maximum speed. Students should have found that the largest gear ratio of 6.25 worked best in short-distance races, as it gives the user the highest acceleration. Students should have found that the medium-value gear ratios of 4.8 and ~3.14 worked best in medium-distance races, giving the user a good balance of maximum speed and acceleration.)

Hydrogen Fuel Cell Research Activity

Name: _____ **Date:** _____



QUESTION FOR ANALYSIS:
How do hydrogen fuel cells work, and what role do they play in combating climate change?

KEY CONCEPTS

climate change: long-term shifts in global temperature and weather patterns

electrolyzer: a device that is used to split water into hydrogen and oxygen gas

fuel cell: a device that produces electricity via a chemical reaction

greenhouse gas: a gas in Earth's atmosphere that contributes to the greenhouse effect by absorbing light from the Sun and emitting it in the form of heat

hydrogen fuel cell: a device that produces electricity via the combination of hydrogen and oxygen gas to form water

HYDROGEN PRODUCTION

Read the articles at –

- *https://studentenergy.org/source/hydrogen/*
- *https://studentenergy.org/production/steam-methane-reforming/*
- *https://studentenergy.org/production/electrolysis/*

and answer the questions below:

1. Where is hydrogen found in nature?

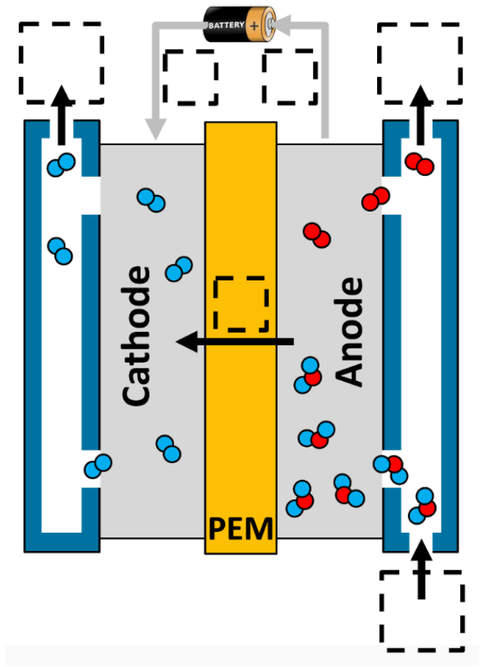
2. What are the two most common methods for producing hydrogen? Give a brief description of each.

3. Steam-methane reforming currently accounts for over 95% of the world's hydrogen production. What are the pros and cons associated with producing hydrogen gas via steam-methane reforming? Name at least one of each.

4. What are the pros and cons associated with producing hydrogen gas via electrolysis? Name at least one of each.

5. The diagram to the right shows the inner workings of a PEM (proton exchange membrane) electrolyzer. Complete the diagram by filling in the blanks in the dotted lines using the words from the list below:

- **H_2** (hydrogen)
- **O_2** (oxygen)
- **H_20** (water)
- **H^+** (hydrogen ions / protons)
- **e^-** (electrons)
- **e^-** (electrons)



Hint: The chemical equations representing the reactions inside an electrolyzer are shown below:

Anode Reaction: $2H_2O \rightarrow 4H^+ + O_2 + 4e^-$

Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$

Total Reaction: $2H_2O \rightarrow 2H_2 + O_2$

CATEGORIES OF HYDROGEN

Read the article at –

- *https://www.horizoneducational.com/deconstructing-the-colors-of-hydrogen/t1368*

and answer the question below:

6. Match the following color-themed categories of hydrogen to the correct description/definition:

green hydrogen	Hydrogen produced via electrolysis, driven by nuclear energy
pink hydrogen	Hydrogen produced via extraction from coal; releases large amounts of carbon monoxide (CO) and carbon dioxide (CO_2) into the atmosphere
blue hydrogen	Hydrogen produced via electrolysis, driven by clean, renewable energy like wind and solar
black hydrogen	Hydrogen produced via steam-methane reforming with carbon capture

HYDROGEN FUEL CELLS

Read the articles at –

- *https://www.fchea.org/fuelcells*
- *https://www.horizoneducational.com/fuel-cells-and-fc-stacks-part-1/t1324*

and answer the questions below:

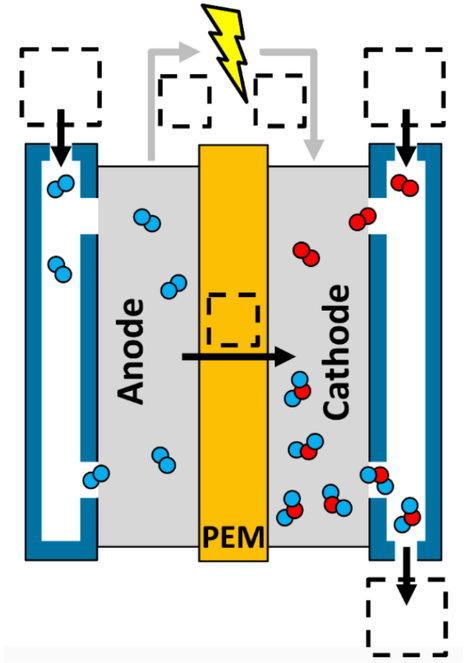
7. What are the benefits of using a hydrogen fuel cell over an engine that burns fossil fuels? Name at least 3.

8. What are some of the limitations associated with hydrogen fuel cells? Name at least 3.

9. What are the 5 main types of fuel cells? Pick one and give a brief description of how it works.

10. The diagram to the right shows the inner workings of a PEM (proton exchange membrane) hydrogen fuel cell. Complete the diagram by filling in the blanks in the dotted lines using the words from the list below:

- **H_2** (hydrogen)
- **O_2** (oxygen)
- **H_20** (water)
- **H^+** (hydrogen ions / protons)
- **e^-** (electrons)
- **e^-** (electrons)



Hint: The chemical equations representing the reactions inside a hydrogen fuel cell are shown below:

Anode Reaction: $2H_2$ $4H^+ + 4e^-$

Cathode Reaction: $4H^+ + O_2 + 4e^-$ $2H_2O$

Total Reaction: $2H_2 + O_2$ $2H_2O$

Read the article at –

- ***https://www.fchea.org/transportation***

and answer the question below:

11. Name three ways that hydrogen fuel cells are being used in the field of transportation today.

Evaluate Activity

Name: _____ **Date:** _____

QUESTION FOR ANALYSIS:
What gear ratio works best in long-distance races? Short-distance races? Medium-distance races?

KEY CONCEPTS

driven gear: the gear that produces the output in a gear system

driver gear: the gear that is connected to a source of power in a gear system, usually a motor

gear ratio: the ratio between the number of teeth on the driven gear and the number of teeth on the driver gear in a gear system; can also be measured as the ratio between the size or rate of rotation of the driven and driver gears

Test your hydrogen-powered cars in a race against other student groups! Race on long-distance, short-distance, and medium-distance tracks. In each case, record the gear ratio that you used and use a stopwatch to record how long it took for your car to complete the track. Try different gear ratios on each track to determine which gear ratio works best in each case.

LONG-DISTANCE RACE

Gear Ratio	Time
6.25	
4.8	
~3.14	
~2.63	

Best: _____

SHORT-DISTANCE RACE

Gear Ratio	Time
6.25	
4.8	
~3.14	
~2.63	

Best: _____

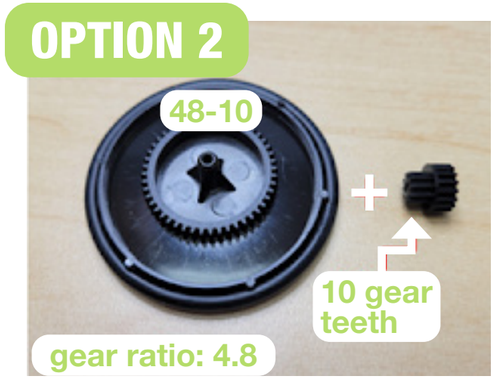
MEDIUM-DISTANCE RACE

Gear Ratio	Time
6.25	
4.8	
~3.14	
~2.63	

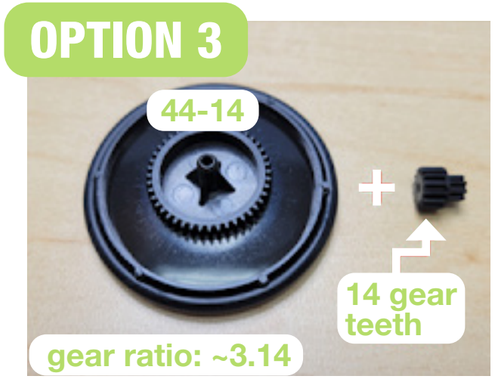
Best: _____

OPTION 1

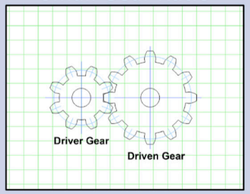
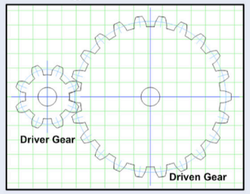
OPTION 2



OPTION 3

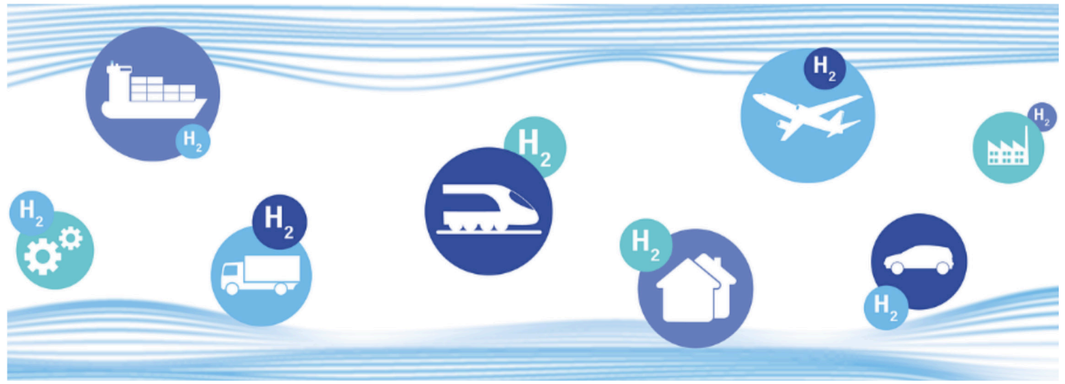


OPTION 4

	Pros	Cons
Small Gear Ratio 	Small radius of driven gear yields higher RPM output, resulting in a higher maximum speed (**good** for **long-distance races**)	Small radius of driven gear yields lower torque output, resulting in lower acceleration (**bad** for **short-distance races**)
Large Gear Ratio 	Large radius of driven gear yields higher torque output, resulting in higher acceleration (**good** for **short-distance races**)	Large radius of driven gear yields lower RPM output, resulting in a lower maximum speed (**bad** for **long-distance races**)

Hydrogen Fuel Cell Research Activity – TEACHER KEY

Name: _____ **Date:** _____



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- *https://studentenergy.org/source/hydrogen/*
- *https://studentenergy.org/production/steam-methane-reforming/*
- *https://studentenergy.org/production/electrolysis/*

and answer the questions below:

1. Where is hydrogen found in nature?

   Hydrogen can be found in many compounds where it is combined with other elements. Examples include hydrocarbons (like natural gas, coal, and petroleum) and water.

2. What are the two most common methods for producing hydrogen? Give a brief description of each.

   Steam-Methane Reforming: In this process, methane (CH4) is allowed to react with extremely hot steam (H2O) in a low-pressure environment. This reaction allows the elements involved to recombine and form hydrogen gas (H2), carbon monoxide gas (CO), and carbon dioxide gas (CO2).
   Electrolysis: In this process, electricity is passed through water (H2O) to separate its hydrogen atoms from its oxygen atoms. This results in the production of hydrogen gas (H2) and oxygen gas (O2).

3. Steam-methane reforming currently accounts for over 95% of the world's hydrogen production. What are the pros and cons associated with producing hydrogen gas via steam-methane reforming? Name at least one of each.

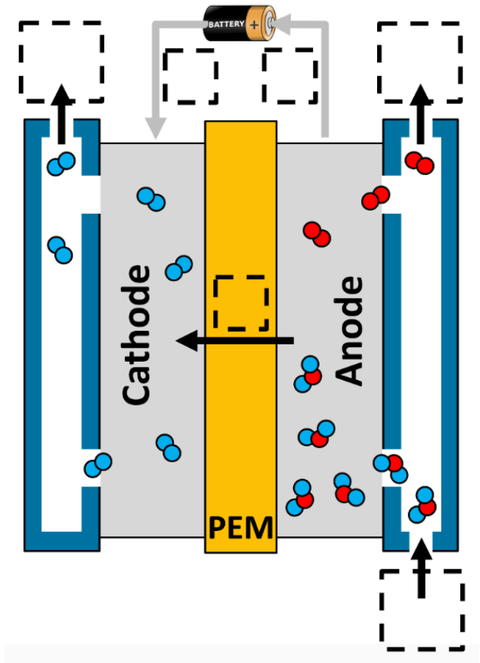
   Pros: Steam-methane reforming is very cost effective when it comes to producing hydrogen gas with a high level of purity.
   Cons: Producing hydrogen gas via steam-methane reforming creates greenhouse gases and carbon emissions as a byproduct. These emissions can negatively affect human health and contribute to global climate change. Steam-methane reforming also requires large amounts of energy to heat the steam that is used in the process.

4. What are the pros and cons associated with producing hydrogen gas via electrolysis? Name at least one of each.

   Pros: As long as the electricity used to run the process of electrolysis is generated from a clean source like wind or solar energy, electrolysis produces no greenhouse gases or carbon emissions.
   Cons: Electrolysis requires a significant amount of energy to produce hydrogen gas. About 39 kWh of electricity and 8.9 liters of water are required to produce just 1 kg of hydrogen gas.

5. The diagram to the right shows the inner workings of a PEM (proton exchange membrane) electrolyzer. Complete the diagram by filling in the blanks in the dotted lines using the words from the list below:

   - **H_2** (hydrogen)
   - **O_2** (oxygen)
   - **H_20** (water)
   - **H^+** (hydrogen ions / protons)
   - **e^-** (electrons)
   - **e^-** (electrons)



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- ***https://www.horizoneducational.com/fuel-cells-and-fc-stacks-part-1/t1324***

and answer the questions below:

7. What are the benefits of using a hydrogen fuel cell over an engine that burns fossil fuels? Name at least 3.

   Answers could include:

   Because they have no moving parts, they are quiet and rarely require maintenance or repair.
   Because they run via chemistry (rather than combustion), they are extremely efficient.
   They work continuously as long as they're supplied with hydrogen and oxygen fuel.
   They provide instant power/torque.
   Unlike electric vehicles, which take a lot of time to recharge, cars powered by a hydrogen fuel cell can be refueled with hydrogen gas relatively quickly.
   They are scalable; they can be combined in series to form large fuel cell stacks.
   Because they only produce heat, electricity, and water as they run, they are clean and safe for the environment.

8. What are some of the limitations associated with hydrogen fuel cells? Name at least 3.

   Answers could include:

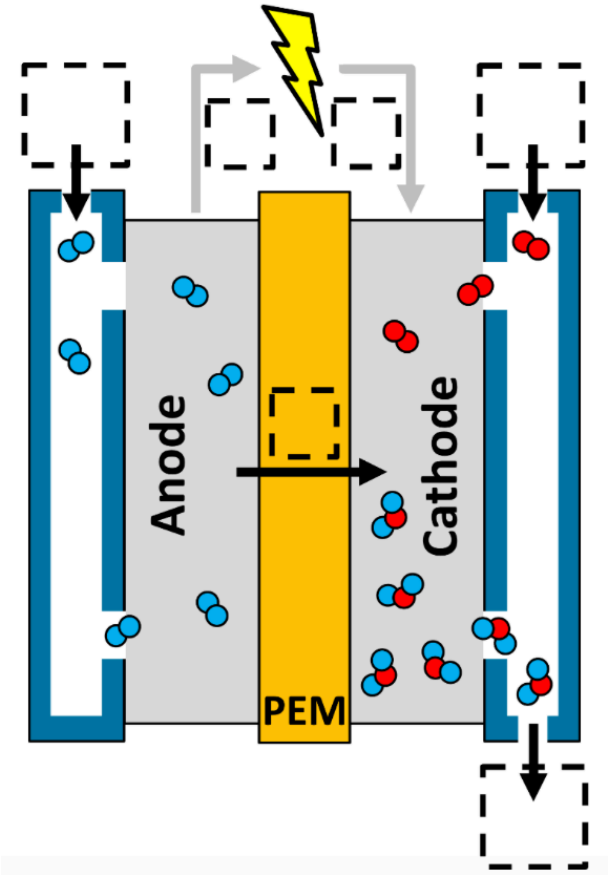
   - A hydrogen fuel cell is only as clean as the method used to produce the hydrogen gas fuel that it uses to run. If the burning of fossil fuels is used to produce this hydrogen gas via steam-methane reforming or electrolysis, then the emissions from these fossil fuels are indirectly associated with the running of a hydrogen fuel cell that uses this hydrogen.
   - Because compressed hydrogen gas is highly flammable and explosive, using or storing it improperly can be dangerous.
   - Currently the cost of producing practical hydrogen fuel cells is very high. Lowing these production costs in the future is important if we want to implement the wide-spread use of hydrogen fuel cells and convince consumers to buy hydrogen-powered vehicles.
   - In order to make the wide-spread use of hydrogen-powered vehicles a reality, there needs to be plenty of hydrogen refueling stations available. Without this infrastructure, it will be hard to convince consumers to buy hydrogen-powered vehicles in the future. Currently, there are only 48 hydrogen vehicle fueling stations in the U.S., and nearly all of them are in California.

9. What are the 5 main types of fuel cells? Pick one and give a brief description of how it works.

   The 5 main types of fuel cells are alkaline fuel cells, molten carbonate fuel cells, phosphoric acid fuel cells, proton exchange membrane fuel cells, solid oxide fuel cells, direct methanol fuel cells.

10. The diagram to the right shows the inner workings of a PEM (proton exchange membrane) hydrogen fuel cell. Complete the diagram by filling in the blanks in the dotted lines using the words from the list below:

- **H_2** (hydrogen)
- **O_2** (oxygen)
- **H_20** (water)
- **H^+** (hydrogen ions / protons)
- **e^-** (electrons)
- **e^-** (electrons)



Hint: The chemical equations representing the reactions inside a hydrogen fuel cell are shown below:

Anode Reaction: $2H_2$ $4H^+ + 4e^-$

Cathode Reaction: $4H^+ + O_2 + 4e^-$ $2H_2O$

Total Reaction: $2H_2 + O_2$ $2H_2O$

Read the article at –

- ***https://www.fchea.org/transportation***

and answer the question below:

11. Name three ways that hydrogen fuel cells are being used in the field of transportation today.

Answers will vary.