Energy Conservation and Transformation

Next Generation Science Standards

NGSS Science and Engineering Practices:

- ☑ Asking questions and defining problems
- ☐ Developing and using models
- ☑ Planning and carrying out investigations
- ☑ Analyzing and interpreting data
- ☐ Using mathematics and computational thinking
- ☑ Constructing explanations and designing solutions
- ☐ Engaging in argument from evidence
- ☑ Obtaining, evaluating, and communicating information

NGSS Cross-cutting Concepts:

- ☐ Patterns
- ☐ Cause and effect
- ☐ Scale, proportion, and quantity
- ☐ Systems and system models
- ☑ Energy and matter
- ☐ Structure and function
- ☑ Stability and change

NGSS Disciplinary Core Ideas:

- ☑ PS2.A: Forces and Motion
- ☑ PS3.B: Conservation of Energy and Energy Transfer

Initial Prep Time

Approx. 5 min. per apparatus

Lesson Time

1 – 2 class periods, depending on experiments completed

Assembly Requirements

- Scissors
- Small Philips screwdriver

Materials (for each lab group):

- Horizon Electric Mobility Experiment Set
- Distilled water
- AA batteries
- Stopwatch
- Horizon Renewable Energy Monitor or multimeter (optional)

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Lab Setup

- Before the lab starts, you should cut the silicon tubing and prepare the fuel cell as indicated in steps a- c of the "Hydrogen powered car" assembly instructions. This should take no more than a few minutes for each kit.
- Your students will only need the red and black wires, the fuel cell, battery pack, H2 and O2 cylinders, two lengths of tubing, and a syringe to assemble the fuel cell.
- Please note that the PEM fuel cell's membrane should be kept from drying out. It's best to seal it in a plastic bag between uses. Before students use the cell, be sure it's filled with water and that the two small pieces of tubing are attached.
- Some of the parts of the car are quite small (such as tube caps) and can be lost easily. Setting up resource areas on lab tables with labeled containers for each group's pieces can prevent loss of these small parts and help keep the parts of each group's kit separate.
- If you don't have access to a multimeter or Horizon Renewable Energy Monitor, omit the Measurements section of this activity.

Safety

- Battery packs can short out and heat up if the red and black contacts touch each other while the unit is in the on position. Be sure to keep them off when not in use.
- Using regular tap water instead of distilled water will severely shorten the lifespan of the fuel cells. Distilled water can be found at most pharmacies or drug stores.
- Running electric current through dry fuel cells or attaching the battery packs backwards can destroy the fuel cells. Be sure to always connect red to red and black to black.
- Beware of water spills, and don't be surprised if someone tries to start a syringe water fight.

Notes on Fuel Cell Cars:

- Be sure the fuel cell and cylinders are securely attached to the car chassis before running it.
- The steering can be adjusted with the knob on the front of the chassis if the car drifts to one side or the other.

Common Problems

- If performance decreases, purge your fuel cells by opening up the tube caps to allow trapped air to escape.
- If the water level doesn't change after purging the cells, make sure the gaps on the base of the inner cylinders are open so that water can fill them.

Energy Conservation and Transformation

Goals

- Understand how energy can change
- Observe the transformation of energy
- Compare the efficiencies of processes

Background

We can't create or destroy energy, only transform it from one form to another. But why do we talk about energy being used up, wasted, or lost? When energy transforms into a form that we can't use effectively, it can be said to be wasted. Our goal then is to minimize the amount of energy that is wasted in any energy transformation by trying to get as much of the energy as possible to convert into the form we want.

Gasoline-powered cars face this problem every day. The ideal energy transformation is from the chemical potential energy within the fuel to kinetic energy of motion, which causes the car to move. However, most internal combustion engines, which release the stored energy of the fuel by burning it, have terrible efficiency, averaging around 20%.

Efficiency is just the ratio of the output (or useful) energy of a process to its input energy. Efficiency is always a dimensionless number from 0 to 1.0, and is usually written as a percentage from 0% to 100%.

Internal combustion engines, which run on gasoline, have an upper limit of around 40% efficiency. So a majority of the energy transformation of an internal combustion engine does not go into its primary use: motion. Instead, the potential energy of the gasoline is turned into sound, vibration, and a large amount of heat.

Fuel cells, in comparison, regularly achieve 60% efficiency in stacks, and have upper limits approaching 85%. With no moving parts, there's much less energy loss to heat and friction.

How well does a miniature fuel cell approach the efficiencies of its larger cousins? We will run a series of experiments to find out.

Procedure

1. Insert the cylinders into the frame of the car. Fill them with about 40 mL of distilled water.
2. Uncap the tube on the O2 side of the fuel cell.
3. Fill the syringe with distilled water and fill the fuel cell using the syringe.
4. Replace the cap on the O2 tube.
5. Insert the fuel cell into the frame of the car in front of the cylinders. Attach the H2 and O2 sides of the fuel cell to the H2 and O2 cylinders with the longer tubes, which will prevent the hydrogen and oxygen gases from escaping.
6. Connect the battery pack to the fuel cell using the red and black plugs, then turn on the battery pack. You should see the fuel cell start to generate hydrogen and oxygen gas.
7. Once you see bubbles start to escape the H2 cylinder, turn off and disconnect the battery pack.
8. Connect the red and black wires to the car chassis to start the car.

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Observations

Experimentation

1. You've produced hydrogen and oxygen from water. Now, connect the fuel cell to the motor. What happens?

Students should notice the motor begins to run and can make note of any particular aspect of the car's performance: sound of the motor, whether it goes in a straight line or not, how long it runs, etc.

2. What could you change about your car that might make the car run faster? Design an experiment to try to make the car run faster. Describe it and record your results below.

Using less water in the cylinders to decrease weight, running the car on a different surface, decreasing friction, and others may be acceptable answers.

3. What if you wanted to make your car run for a longer time? How would you alter your car to achieve that? Design an experiment you could run and describe it below.

Answers may differ from the previous question, but some may be similar. However, it should be noted that to make the car run longer it could also have bigger fuel tanks, generate more hydrogen, or be picked up so that the wheels spin freely.

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Measurement

For this section, you will need a multimeter or the Horizon Renewable Energy Monitor. For an introduction to using a multimeter, click here.

1. Measure the current in Amps and the voltage in Volts while generating hydrogen and oxygen. Record your answers below:

(Answers will vary, but check that they are within reason, i.e. not 100V or >1A.)

Current: ____________ A

Voltage: __________ V

2. Voltage is equal to the current multiplied by the resistance (V = IR), so according to your data what is the resistance of the fuel cell?

Resistance: ___________ Ω

3. Lift the front wheels to keep the car in one place and measure the current in Amps and the voltage in Volts while the car is running. Record your answers below:

Current: ____________ A

Voltage: __________ V

4. P = I • V, where P is power, I is current, and V is voltage. Calculate the power required to split water and the power to run the car and record your answers below:

Power (generating): ____________ W

Power (running): ____________ W

5. How do you explain the results you just calculated in terms of the efficiency of the fuel cell?

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Analysis

1. Make a scientific claim about what you observed while running the fuel cell car.

Claim should reference energy use, transformation, and/or conservation in the running car.
Example: "The most effective way to increase the car's running time is to reduce friction."

2. What evidence do you have to back up your scientific claim?

Evidence should cite data in Observations and/or Experimentation sections.
Example: "The car ran for 18 seconds unmodified. Reducing weight made it run for 2 seconds more. Running it on a smoother surface made it run for 8 seconds more."

3. What reasoning did you use to support your claim?

Reasoning can draw from Background section and/or other materials used in class.
Example: "We read about reducing friction as a way to increase efficiency."

4. Use your observations to design an experiment you could run to try to increase the energy efficiency of the fuel cell. Describe your experiment below.

Change pressure/temperature of the water/gases, construct it with different materials, decrease the weight of the car, reduce friction, and more are all ideas that could be tested. Students should identify control and experimental setups, and define the variable to be tested.

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Conclusions

1. Would it ever be possible to use 100% of the electric energy produced by the fuel cell to move the car? Why or why not?

Answers should cite the Law of Conservation of Energy and mention the ways in which energy is converted that do not result in kinetic energy.

2. Do you think your fuel cell achieved the levels of efficiency of the fuel cell stacks described in the Background section? Why or why not?

Comparing the energy required to split the water with the energy produced by recombining it yields much less than the efficiencies described in the Background. The reasons are that the fuel cell is much smaller and not a stack as described. Students may also cite their calculations to back up their assertion.

3. Why is it important for machines to have high efficiency?

Wasted energy means that more materials, fuels, and resources are needed to achieve the desired result. At the very least, this means it costs more. At worst, this also contributes to the eventual heat death of the universe.

4. Based on your results, do you think fuel cells are a good energy source for cars?

Students may take either position on this question, provided they are able to cite information from their experiments to back up their stance.