STRATEGIC ENERGY INNOVATIONS

Grade: 9-12

Version 3

June 2018

# Green Transportation

## Certificate

**Learn skills for green transportation careers through experiential activities like developing a solar car, making bio-diesel, and designing a transportation-friendly city**

# CURRICULUM MATRIX: GREEN TRANSPORTATION CERTIFICATE

**25 - 31 hours of coursework**

| Module | | Lesson | | Estimated Time* | Description |
|---|---|---|---|---|---|
| 1.0 | Climate Change and Sustainability | 1.1 | Sustainability: Problems and Opportunities | 80 minutes | Students develop and analyze sustainability definitions, envision a sustainable community, and measure their personal carbon footprints. |
| | | 1.2 | Climate Change | 225 minutes | Students learn about the stages of the Carbon Cycle and how they are being affected by human activity, and investigate the causes and consequences of climate change and opportunities to address it. |
| 2.0 | Transportation Fuels | 2.1 | Energy Sources: Current vs. Ancient Sunlight | 135-180 minutes | Our energy choices have a significant impact on climate change. Students look at the history of transportation, identify renewable vs. non-renewable sources of energy and analyze their effects on climate and sustainability. |
| | | 2.2 | Comparing Transportation Fuels | 45 minutes | Students will learn about different energy sources to power transportation and compare non-renewable and renewable sources of transportation fuel. |
| | | 2.3 | Renewable Transportation Fuels | 90 minutes | Students learn about the sources, production and uses of renewable transportation fuels. |
| 3.0 | Personal Transportation | 3.1 | How Do Cars Work? | 45-90 minutes | Students will learn the basic parts of a car and how the major systems of a car work. Student groups will begin construction of model solar cars. |
| | | 3.2 | Zero Emission Vehicles | 135 minutes | Students will learn about basic electricity and types of electric and hybrid vehicles, including hydrogen fuel cells. |
| | | 3.3 | Comparing Car Options | 90-180 minutes minutes | Students will build and race solar model cars and investigate the pros & cons of available automotive options. |
| 4.0 | Public Transport, Travel & Distribution | 4.1 | Public Transportation Technology: Make Your Way Around | 45-90 minutes | Students will research community transportation options and plan an itinerary while learning about the environmental ramifications of transportation decisions. |
| | | 4.2 | Travel: Plan Your Dream Vacation | 70 minutes | Students will plan a dream vacation and calculate the energy used & greenhouse gases emitted. |
| | | 4.3 | Distribution Technology: How Does Stuff Get to Our Stores? | 45-90 minutes | Truck, train, tanker? Students will evaluate factors, including emissions, in order to make decisions about how to transport products for their dream business. |

| | | | | | |
|---|---|---|---|---|---|
| 5.0 | Transportation Policy, Planning and Design | 5.1 | Existing Policies & Goals | 180-270 minutes | Students will learn about the policy process and develop a school campaign to reduce campus greenhouse gas emissions. |
| | | 5.2 | Potential Policies & Global Best Practices | 135 minutes | Students will research successful programs and policies from around the world and debate the best program/policy to increase green transportation in their community. |
| | | 5.3 | Urban Planning, Design & Innovation | 90 minutes | Students will learn about land use, infrastructure design, and planning for walking and biking. Students will evaluate policy options for GHG reductions as City Council Members of the City of Tomorrow. |
| 6.0 | Green Transportation Careers | 6.1 | Green Transportation Careers | 45-225 minutes | Students will learn about careers and educational opportunities in the Green Transportation sector. |
| | | 6.2 | Green Career Internship | Up to 6 months | Students will complete an internship at a company or organization in the Green Transportation sector. |

* This curriculum is designed to be taught over the course of one semester, but can be adapted to be taught in a shorter time, if necessary. Lessons can also be taught in a stand-alone format. The total instructional time as laid out above is between **25 and 31 hours**, excluding the green career internship.

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018

## DEMONSTRATION: HYDROGEN FUEL CELL VEHICLE

SEI used the following kit for this demo: Thames & Kosmos Alternative Energy and Environmental Science Fuel Cell X7

Before starting the electrolysis experiment, demonstrate the fuel cell car with students. Students will observe what is happening with the hydrogen fuel cell car, and answer the questions on the Handout: Fuel Cell Demonstration. Students will write down their hypotheses for how the car is able to move using water.

**Instructor Background Information:**
During the hydrolysis process, energy from either the batteries or a solar panel is used to break water into its two component parts, hydrogen and oxygen. When the motor is connected, the process is reversed and the subsequent electrical energy powers the car through a fuel cell. This particular kind of fuel cell is called a proton exchange membrane (PEM) fuel cell. The PEM fuel cell uses an anode with a platinum catalyst and a cathode. The anode attracts the hydrogen and pushes it through the membrane to the cathode, while the electrons are separated, creating a charge. The electrons must pass around the membrane through a wire, generating current. The hydrogen meets the oxygen at the cathode where the two are converted back into water. This process converts the chemical energy stored in the bonds of the hydrogen into electrical energy.[11]

The chemical process for the fuel cell reaction is: $H_2 + 2\ O2 \rightarrow 2\ H_2O$ + Energy

**Activity Instructions:**
To use the hydrogen car, you will need two AA batteries and distilled water (with NO added electrolytes).

1. Fill the back tank of the car almost to the top with distilled water.
2. With the syringe fully closed, connect it to one of the short tubes on either side of the fuel cell by removing the little red plug and inserting the straw from the syringe into the tube securely. **Be careful not to lose the little red plug!**
3. Slowly pull back the handle on the syringe until water flows into the syringe with no bubbles.
4. Pinch the short tube, remove the straw and syringe, and re-plug the short tube with the little red plug.
5. Repeat this process for the other side of the fuel cell.
6. Put the AA batteries into the battery holder.
7. Plug the red wire into the red connection on the fuel cell, and the black wire into the black connection on the fuel cell. As soon as you do this, hydrolysis will start and the tanks on the back of the car will begin to fill with hydrogen and oxygen.
8. **Have students observe that the hydrogen and oxygen tanks are filling**
9. Once you see bubbles coming out of the back tank, the hydrogen and oxygen tanks are full and you are ready to run the car! **This should only take a few minutes.**
10. Unplug the battery connections from the fuel cell.

[11] "A Basic Overview of Fuel Cell Technology". 2018. Smithsonian Institution. http://americanhistory.si.edu/fuelcells/basics.htm.

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018

11. Lift the front wheels of the car slightly while you plug in the connections on the motor to the fuel cell (red to red and black to black). The car will run as soon as the motor is plugged in. **The car moves relatively slowly and can keep going for about 5 minutes.**
12. Have students observe the car moving, then have them observe the oxygen and hydrogen tank levels as it runs.

## ACTIVITY 4: ELECTROLYSIS LAB

Now that students have observed a hydrogen car in action, they will investigate the process that allowed the car to move by completing an electrolysis lab. Materials and instructions for the lab can be found on the Handout: Electrolysis Demonstration and Lab.

**Note:** The instructions indicate that students should light a match to demonstrate the presence of hydrogen gas. For safety, you may want to do this as a demonstration.

## SETTING THE STAGE: ELECTROLYSIS

**Note:** This Setting the Stage information can be read by the instructor in advance of the lesson for background information, but should be presented to students after they have the opportunity to see the hydrogen car, and complete the electrolysis experiment.

**The Science of Electrolysis and Fuel Cells**

- **Electrolysis** is the process of the decomposition of molecules into smaller elements by passing an electric current through a liquid or solution containing ions, which is called an **electrolyte**.
- In this case, the electrolysis process uses a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction – the creation of oxygen gas and hydrogen gas from water. This process is typically conducted in a unit called an **electrolyzer**, which range in size.[12]
- In the electrolysis experiment, we added an electrical current to salt water using **electrodes** (conductors through which electricity enters or leaves an object, substance, or region), and the electrical current split the oxygen and hydrogen molecules in the water apart, creating oxygen gas on one electrode and hydrogen gas on the other. We were able to collect the hydrogen gas.
    - This is fundamentally the opposite of what happens in a fuel cell. In a fuel cell, the two separate gases – hydrogen and oxygen – are combined to produce electricity and heat. Electricity is created when positively charged hydrogen ions move across an electrolyte while their electrons conduct electric current, and the ions combine with oxygen to create water ($H_2O$), the main byproduct of fuel cells.[13]
    - These two processes together are what make the demonstration car work: first electrolysis (powered by a battery or a solar panel) splits the water into its component gases, and then the fuel cell uses those gases to create electricity.

[12] "Hydrogen Production: Electrolysis | Department of Energy". 2018. *Energy.Gov*. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis.
[13] "A Basic Overview of Fuel Cell Technology". 2018. Smithsonian Institution. http://americanhistory.si.edu/fuelcells/basics.htm.

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018

**Applications of Electrolysis and Hydrogen Fuel Cells**[14]

- The hydrogen gas produced by electrolysis can be used in fuel cells, which can power cars, public transit buses, and even backup power systems
- A huge advantage of electrolysis for hydrogen gas production is that hydrogen can be produced on the spot, which cuts out distribution costs and allows for consistent production (which is why we can power entire fleets of buses using hydrogen gas!)
- The production of hydrogen gas via electrolysis is an exciting and innovative way to generate clean energy with zero greenhouse gas emissions
    - However, electrolysis is only as clean and emissions-free as the source of the electricity used to power the electrolyzer
- The good news is electrolysis is compatible with large-scale renewable and non-greenhouse gas-emitting forms of electricity, meaning fuel cells can be powered by wind, solar, or nuclear electricity
    - This is important because wind and nuclear are typically used for large-scale production and use, so electrolysis and hydrogen fuel cells offer a way to integrate these clean forms of energy into small-scale everyday use, such as personal vehicles which can't be powered directly by wind!
- Because hydrogen fuel cells emit only water, there are no carbon dioxide emissions and no air pollutants produced by the fuel cell
- Fuel cells can operate at higher efficiencies than combustion engines, and can convert the chemical energy in the fuel to electrical energy with efficiencies of up to 60%[15]
    - Compare this to the fact that most fossil fuel burning power plants are only 35% efficient!
    - Fuel cells work like batteries, but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied

## DISCUSSION: ELECTROLYSIS

Check for understanding by facilitating a discussion after the demonstration and lab are complete.

- Ask students to reflect on their lab. What is electrolysis, and what is the result of that process?
- How is electrolysis related to how the car moved in the demonstration?
- What process(es) allowed the hydrogen fuel cell car to move?
- Show the following video on hydrogen fuel cells to clarify the science behind how these cars are able to move utilizing electrolysis and fuel cells.
    - https://www.youtube.com/watch?v=imV_uflzxPY

[14] "Hydrogen Production: Electrolysis | Department of Energy". 2018. *Energy.Gov*. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis.
[15] "Fuel Cells | Department of Energy". 2018. *Energy.Gov*. https://www.energy.gov/eere/fuelcells/fuel-cells

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018

# HANDOUT: FUEL CELL DEMONSTRATION

Name: _____ Date: _____

**Demonstration**

Record your observations and hypotheses during the hydrogen fuel cell car demonstration. What do you think is happening during this process? Refer back to your answers here when completing the lab.

1. Why do the oxygen and hydrogen tanks begin to fill when the battery is plugged in?

2. Why is the hydrogen tank twice the size of the oxygen tank?

3. Why are the hydrogen and oxygen stored in tanks surrounded by water?

4. What happens to the oxygen and hydrogen tank levels as the car runs?

5. What kind of energy makes the motor run?

6. If there is no battery connected, where is the electricity coming from when the car runs?

If you race the hydrogen fuel cell car against a solar car:

1. What do you notice about the difference in speed and operation between the two cars?

2. What factors make the cars go different speeds?

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018

## HANDOUT: ELECTROLYSIS LAB

Name: _____ Date: _____

Follow the instructions below to complete the electrolysis lab, and then answer the questions at the bottom. As you observe the results of the experiment, take note of how the outcome might translate to powering a vehicle.

**Materials:**

- Bowl or tub, e.g., 4"x 4" or 4" in diameter, approx. 3" deep (plastic, glass or ceramic)
- Measuring cup or graduated beaker (ml)
- Distilled water
- Salt
- Aluminum foil
- Electrical leads (with alligator clips)
- Paper clips (if leads do not have alligator clips)
- 9-volt battery
- Test tube
- Long-stick matches (for teacher use)
- Measuring teaspoon
- Ruler
- Scissors

The following experiment is designed for groups of 2-3.

**Procedure:**

1. Fill the tub/bowl with distilled water within about 1 inch from the top. Pour this water into a large measuring cup or graduated beaker.
2. Add salt to the water (4 teaspoons of salt for every 200ml of water) and stir until ALL the salt is dissolved (this may take a minute or two).
3. Pour the salt water back in to the tub/bowl. Salt makes your water conductive, meaning it allows an electrical current to travel through it more easily.
4. Create your electrodes. Cut two identical pieces of aluminum foil, roughly 10 cm long and 8 cm wide. Fold about 1 cm of the aluminum foil width-wise, and then make the next fold in the opposite direction, accordion style. You should end up with a 1 cm by 8 cm rectangle of foil folded tightly together. Repeat this with the other piece of foil.
5. Fold the top 1 cm of the foil rectangle over, so that you can hook it on the edge of your bowl.

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018

6. Use paper clips, or alligator clip wires if your leads have them, to attach the red lead onto the bent end of one of the electrodes. Use another paper clip or clip to attach the black lead onto the bent end of the other electrode.
7. Attach the red and black clips onto the battery terminals. DO NOT let the electrodes touch one another! This will cause a short circuit.
8. Hook the bent end of the electrode, with the plugs attached on the outside, onto the edge of the bowl. Make sure at least 3/4 of the bottom part of the electrode is submerged in the salt water.
9. The reaction should start immediately. Look at the electrode that is producing gas bubbles. What terminal on the battery is it attached to?
10. You should have seen that the electrode producing the most gas is connected to the negative terminal, which means this electrode is the cathode. The gas being formed at the cathode is hydrogen gas. We can perform a simple test to prove that hydrogen gas is indeed being formed. You will need a test tube and a match.
11. First, detach your electrodes. Then, bend the long part of your negative electrode in half long ways, like a hot dog. This will help you concentrate the space the bubbles will be produced over.
12. Reattach your electrodes to the side of the bowl and the battery to start electrolysis.
13. Fully submerge the test tube in the water so that it is entirely filled with water. Turn the test tube upside down, so the opening is facing down and under the surface of the water. The test tube should still be full of water with no air bubbles at the top.
14. Keeping the opening of the test tube submerged, move the test tube over where the bubbles are being produced. As the bubbles go into the tube, the water level in the test tube should start to decrease. This may take 3-5 minutes. Position the test tube to enable as many bubbles as possible to go into the tube.
15. When the test tube is 100% empty of water, you know that it is full of gas. Ask your teacher to test your hypothesis by using a match. Keep the test tube inverted, and pull it from the water and quickly over the flame. What do you hear?

**Questions**

1. What kind of gas(es) was/were produced by this reaction? Which gas created a noise at the end of the experiment?

2. How does the chemical process you just observed relate to how the car moved in the demonstration?

Production and distribution of this document is exclusively limited to Strategic Energy Innovations. www.seiinc.org © 2018