An image of Honeywell's Green Jet Fuel produced with algae in a beaker (Provided by Honeywell with permission.)

Biology: Photosynthesis & Metabolism

High School 9 - 12

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Anchoring phenomenon:

Microalgae are a diverse group of single-celled organisms that have the potential to offer a variety of solutions for our liquid transportation fuel requirements. Algal species grow in a wide range of aquatic environments, efficiently use CO_2, and produce high levels of lipids capable of being used as a fuel source.

Essential question about phenomenon/unit:

- How do algae use the process of photosynthesis to transform light energy into stored chemical energy to produce life molecules?
- How do algae use the products of photosynthesis to produce other biological molecules?
- How do algae transform light energy into the chemical potential energy required by a fuel?
- How is carbon cycled between the biosphere and atmosphere?
- How have humans impacted the carbon cycle?
- What are the criteria and constraints for a renewable fuel source?
- Based on these criteria and constraints, does algae biofuel have the potential to be the "new" fuel for the future?

Big Idea:

Living systems depend on the recycling of matter and flow of energy to recombine chemical elements and create biological molecules.

Scientific explanation:

In our modernized world, fossil fuels have become integral to our day-to-day lives. Fossil fuels (a nonrenewable energy resource formed from the remains of organisms that lived long ago) are retrieved from the ground, and used to fuel our cars, power our lights amongst many other uses. But, there is a growing concern regarding the correlation between fossil fuels and environmental pollution. The combustion of fossil fuels alters the carbon cycle, releasing large amounts of carbon back into the atmosphere, faster than it can be sequestered by natural processes. Since carbon dioxide is a greenhouse gas, the increase in atmospheric carbon dioxide has been correlated to a rise in global temperatures. As a result of this growing problem, alternatives to fossil fuels have become more popular. One such alternative is algae biofuel.

Microalgae are a diverse group of single-celled organisms that have the potential to offer a variety of solutions for liquid transportation fuel requirements. Algae efficiently use CO_2, and are responsible for more than 40% of the global carbon fixation, with the majority of this productivity coming from marine microalgae. Algae can produce biomass very rapidly, with some species doubling in as few as 6 hours.

Algae require minerals, light, water and carbon dioxide for efficient growth. Similar to plants, algae use the process of **photosynthesis** to transform light energy into stored chemical energy by converting carbon dioxide and water into glucose and oxygen gas. This process is endergonic as it requires energy, and glucose has more energy than its reactants.

Once produced, the glucose can be used as a food source or converted into other biological molecules, including carbohydrates, lipids, nucleic acids, and proteins. These biological molecules are carbon-based, built from varying ratios of carbon, hydrogen, oxygen, nitrogen, sulfur, and phosphorus. With the use of enzymes, algae produce all necessary biological molecules through metabolism. **Metabolism** is the interconnected web of simultaneous chemical reactions in which molecules are built up (anabolized) or broken down (catabolized). Glucose can be anabolized into oils (a type of lipid) through endergonic metabolic reactions.

All algae produce oils as they contain 2.5 times as much energy per gram as carbohydrates, and are used in a variety of ways by the algae including energy storage. In order to use these **energy-rich oils** for biofuels, they must first be extracted by drying and pressing harvested algae. Once extracted, the crude algae oil is chemically similar to crude fossil fuel oil, and can be used in combustion engines.

In the basic **combustion** engine reaction, extracted oil is "burned" in the presence of oxygen, producing carbon dioxide and water. In addition, the reaction is exothermic, releasing a tremendous amount of thermal energy as the bonds in the oil (storing chemical energy) are broken. This thermal energy is used to power pistons, thereby transforming thermal energy into mechanical kinetic energy. The mechanical kinetic energy of the engine is used to power the rest of the car.

The same amount of carbon dioxide released by the combustion reaction will be used by the algae to replenish the used biofuel , thus closing the carbon cycle. Consequently, algae biofuel is **carbon neutral**.

When designing biofuel solutions, the following factors will need to be considered:

1. Scientific feasibility: What is the science behind the solution? What is the energy story, does it favor the solution? What is the matter story?
2. How is the solution placed within a bigger system / environment?
3. What are the costs: energy costs; environmental costs; human costs; monetary costs?

Algae based biofuels are promising as a potential solution to the growing environmental problems associated with fossil fuels, but as with any solution there are pros and cons.

Pros	Cons
• Essentially carbon neutral combustion • Drop in replacement for petroleum-based liquid fuels • Renewable • Could recycle both waste CO_2 and wastewater • Higher energy per-acre than other bio-fuels • Can be grown on land unsuitable for other types of agriculture • Scalable • Investments are being made • Research has been underway for 50 years	• Requires controlled temperature conditions • Requires a considerable amount of land and water • Viscosity issues at lower temperatures • Some researchers using genetic engineering to develop optimal algae strains • Requires phosphorus as a fertilizer which is becoming scarce • Fertilizer production is carbon dependent • Relatively high upfront capital costs • Cost per gallon presently too high.

NGSS *Performance Expectations* addressed in this unit:

Standard	PE	DCI	CCC
HS-LS1-5	Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.	**LS1.C: Organization for Matter and Energy Flow in Organisms** The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.	Energy and Matter
HS-LS1-6	Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.	**LS1.B. Growth and Development of Organisms** The sugar molecules thus formed contain carbon, hydrogen, oxygen: their hydrocarbon backbones are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (such as proteins or DNA), used for example to form new cells. As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.	Energy and Matter
HS-PS1-4	Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy.	**PS1.A: Structure and Properties of Matter** A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. **PS1.B: Chemical Reactions** Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of	Energy and Matter

		molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.	
HS-ESS2-6	Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.	**ESS2.D: Weather and Climate** Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. Changes in atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.	Energy and Matter
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	**ETS1.B: Developing Possible Solutions** When evaluating possible solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts..	Influence of Science, Engineeri ng, Technolog y on Society and the Natural World

Summary Table of Activities in Unit

Activity	***Learning Target***	***Evidence Students Could Gain***	***Connection to Phenomena***
Activity 1: Unit Introduction (Initial Model) **Day 1** Students observe microalgae under the microscope to build background for model development. **Day 2** Class discussion of algae observations and demonstration of algae biofuel. Students watch video twice, making notes on model template.	**Develop a model to explain the relationship between parts** of an **algae biofuel system** including **energy and matter inputs and outputs.**	Algae require sunlight to grow Algae ponds get darker as algae grows Algae can be microscopic and come in different shapes. Oil is harvested by pressing the oil out of dried algae.	Develop initial models using prior knowledge and background from video.

Students work in pairs to add ideas to model.			
Activity 2: Combustion Lab **Day 1 & 2** Students will produce biodiesel using canola oil as an algae oil substitute. Students will then burn a sample to collect data on the heat of combustion and use their data to compare it to the burning of fossil fuels. **Day 3** Students will read about the matter and energy transfers that occur within an internal combustion engine.	**Carry out an investigation to produce data for comparing** the **heat** of **combustion of biofuels and fossil fuels**. **AND** **Critically read scientific information** to identify the **matter and energy inputs and outputs** within the **internal combustion engine system**.	Biodiesel contains almost as much energy as diesel from fossil fuels Combustion of biodiesel produces a tremendous amount of thermal energy. The thermal energy released is used to power the car. The thermal energy originates from the sun. Combustion requires a fuel source and oxygen and produces carbon dioxide and water.	**HS-PS1-4** In the basic combustion engine reaction, extracted oil is "burned" in the presence of oxygen, producing carbon dioxide and water. In addition, the reaction is exothermic, releasing a tremendous amount of thermal energy as the bonds in the oil (storing chemical energy) are broken. This thermal energy is used to power pistons, thereby transforming thermal energy into mechanical kinetic energy. The mechanical kinetic energy of the engine is used to power the rest of the car.
Activity 3: Making Oils **Day 1** Students sort cards (carbohydrates and lipids) based on similar patterns in chemical structure. Students will read more about the structure and function of lipids and carbohydrates. Students compare the	**Use models** of **carbohydrates and lipids** to identify **patterns in the structure and function** of these molecules. **AND** **Use a model to provide mechanistic**	Carbohydrates have carbon rings; lipids have carbon chains Both contain C, H, O, but the ratios of C, H, O vary Both store energy, but oils store 2.5 times more Anabolic reactions build larger molecules and require energy.	**HS-LS1-6** Glucose can be used as a food source or converted into other biological molecules. These biological molecules are carbon-based, built from varying ratios of C, H, O, and sometimes N, S, and P. Using enzymes, algae

structure and function of these two biological molecules. **Day 2** Students use Lego pieces to model how metabolism works. Students read more about anabolism and catabolism, including which require or release energy (connecting back to endergonic/ exergonic).	**accounts** of how **biological molecules are rearranged** with the **input or release of energy**.	Catabolic reactions break down molecules and release energy. Glucose is anabolized to form oil.	produce all necessary biological molecules through metabolism. With endergonic, metabolic reactions glucose can be anabolized into oils (a type of lipid).
Activity 4: Process of Photosynthesis **Day 1** Students use pop beads to model the process of photosynthesis. **Day 2** Students complete a reading assignment with various visual models to learn more about the specific mechanisms of photosynthesis.	**Use a model** to explain how **matter and energy interacts** with **photosynthetic organisms**. **AND** **Use multiple types of models** to explain how **matter and energy interacts** with **photosynthetic organisms**.	Energy and matter inputs – light, carbon dioxide and water Energy and matter outputs – chemical, glucose, oxygen, and water (full process) Light reactions break water apart and form oxygen molecules Calvin cycle uses stored energy from light reactions to fix carbon dioxide into glucose.	**HS-LS1-5** Algae require minerals, light, water and carbon dioxide for efficient growth. Similar to plants, algae use the process of photosynthesis to transform light energy into stored chemical energy by converting carbon dioxide and water into glucose and oxygen gas.
Activity 5: Energy in Chemical Reactions Students make observations of two chemical reactions. One reaction is endothermic, while the other is exothermic. Students use an animation and definition of	**Revise a model based on evidence** to explain the **changes in matter and energy** within **chemical reactions**.	Baking Soda and vinegar is an endothermic reaction because it shows a drop in temperature. Calcium chloride and baking soda is an exothermic reaction because it shows an increase in temperature. Burning fuel (combustion) is an exothermic	**HS-PS1-4** Photosynthesis is endergonic as it requires energy, and glucose has more energy than its reactants. As glucose is anabolized into oils, even more energy is stored (from ATP). Combustion of oil releases the stored energy that originally came from the

endothermic and exothermic to revise the chemical equations (model) for both reactions. (Explain relation to endergonic and exergonic.) Predict what type of energy change would occur in photosynthesis and combustion.		(exergonic) reaction because a car gets hot. Photosynthesis is an endergonic reaction because more energy (light) is needed.	sun (exergonic).
Activity 6: Carbon Cycle of Fuels Students compare the fossil fuel carbon cycle to the biofuel carbon cycle.	**Use models to analyze** the **impact that two fuel systems** have on the **cycling of carbon**.	Carbon dioxide from the atmosphere is needed to make both fuels (photosynthesis) Both fuels produce carbon dioxide when burned Fossil fuels take millions of years to produce Biofuels take only weeks to produce	**HS-ESS2-6** Carbon dioxide is a greenhouse gas, and the increase in atmospheric carbon dioxide has been correlated to a rise in global temperatures. Both fossil fuels and biofuels rely on photosynthesis to fix carbon and produce carbon dioxide when burned, but the amount of time to produce either fuel is drastically different.
Activity 7: Democs (**DE**liberative **M**eeting **O**f **C**itizen**S**): Bioenergy Students will discuss the ethical and social issues around bioenergy (biofuels).	**Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including costs, safety, reliability, an aesthetics as well as possible**	There are different stakeholders concerning biofuels Biofuels affect different areas of society There are pros and cons to biofuels	When designing biofuel solutions, the following factors will need to be considered: 1. Scientific feasibility: What is the science behind the solution? What is the energy story, does it favor the solution? What is the matter story? 2. How is the solution placed within a

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<td>social, cultural, and environmental impacts.</td>
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<td>bigger system / environment?
3. What are the costs: energy costs; environmental costs; human costs; monetary costs?</td>
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<td>Activity 8:

Final Model/ Explanation

Students use learnings from the unit to complete a final model for the unit.</td>
<td>Develop a model to explain the relationship between parts of an algae biofuel system including energy and matter inputs and outputs.</td>
<td colspan="2">Matter Story: Algae use water and carbon dioxide from their environment to produce glucose and oxygen. The glucose can be anabolized to produce oils. These oils are extracted and refined for use in cars. When the oils are combusted (fuel and oxygen), carbon dioxide and water are reproduced. These products can then be used again by the algae.

Energy Story: Algae capture light energy and transform it into chemical energy. This chemical energy is stored in the bonds of the glucose. As glucose is anabolized into oils, more energy is added (from the bonds of ATP) as more bonds are formed. When the extracted oil is combusted, the chemical energy is transformed into thermal energy. The thermal energy is harnessed to power the pistons, transforming it into mechanical kinetic energy. In the end, all energy is dispersed, mostly into the air as unusable thermal energy.</td>
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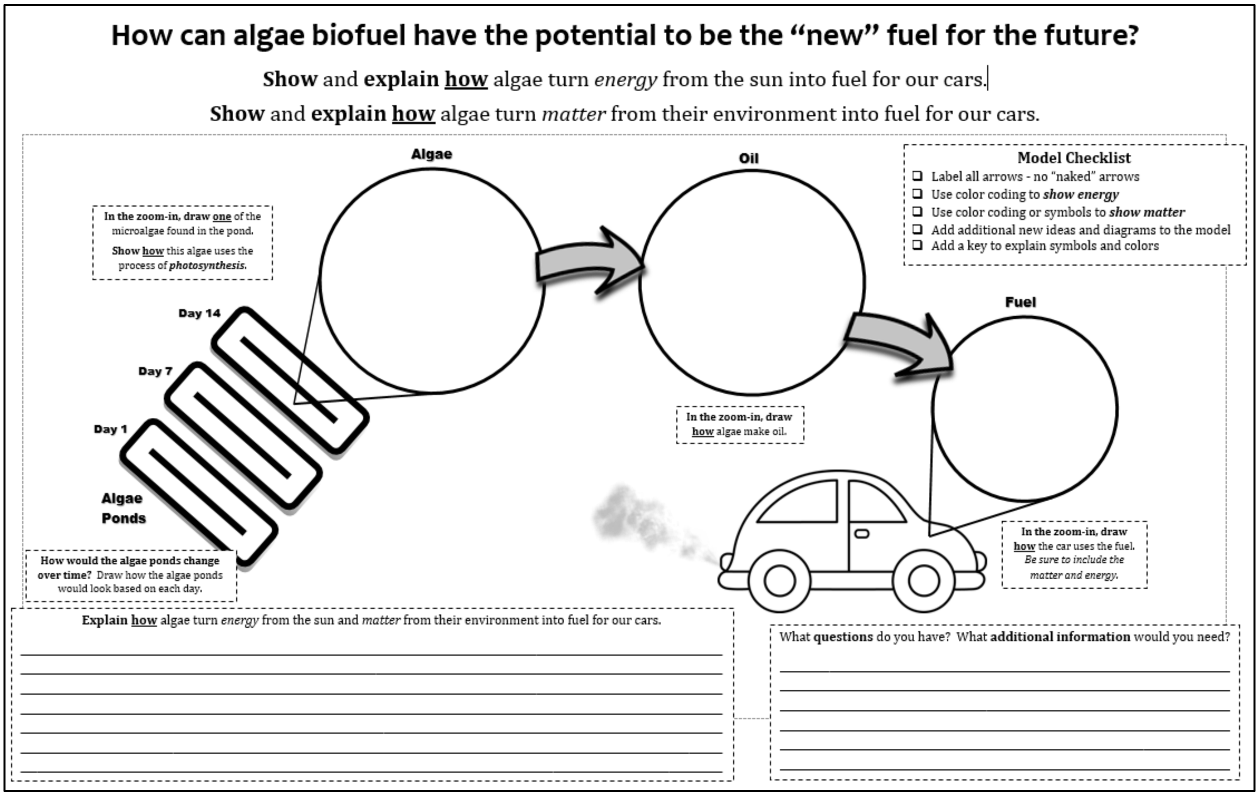
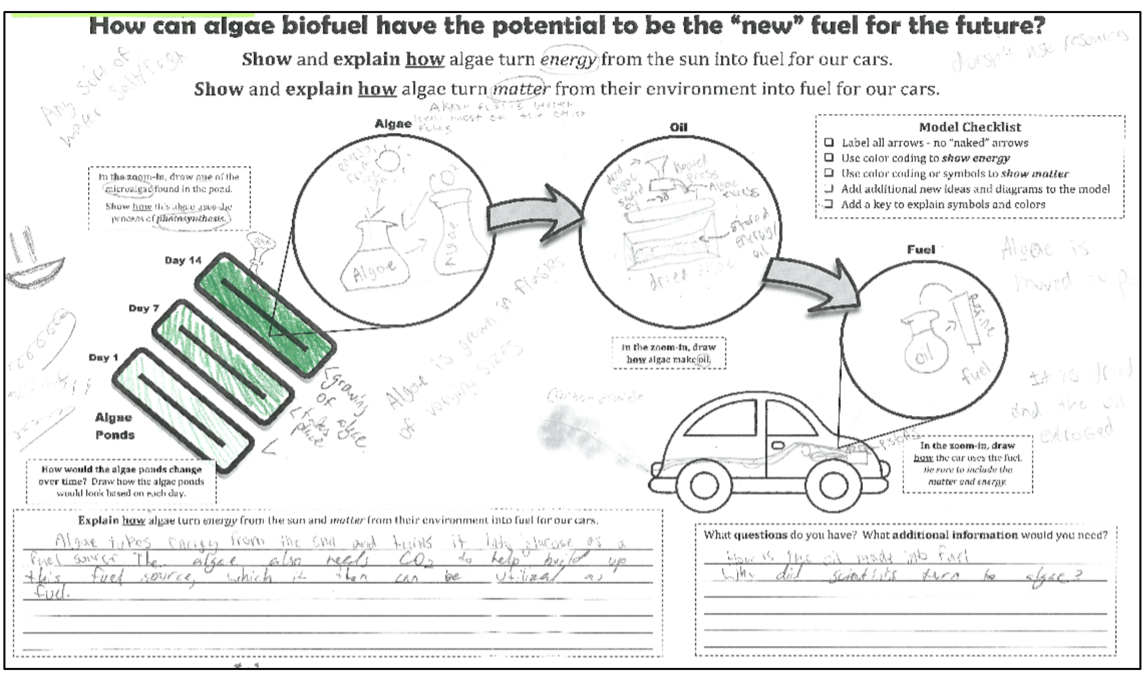
Model Template

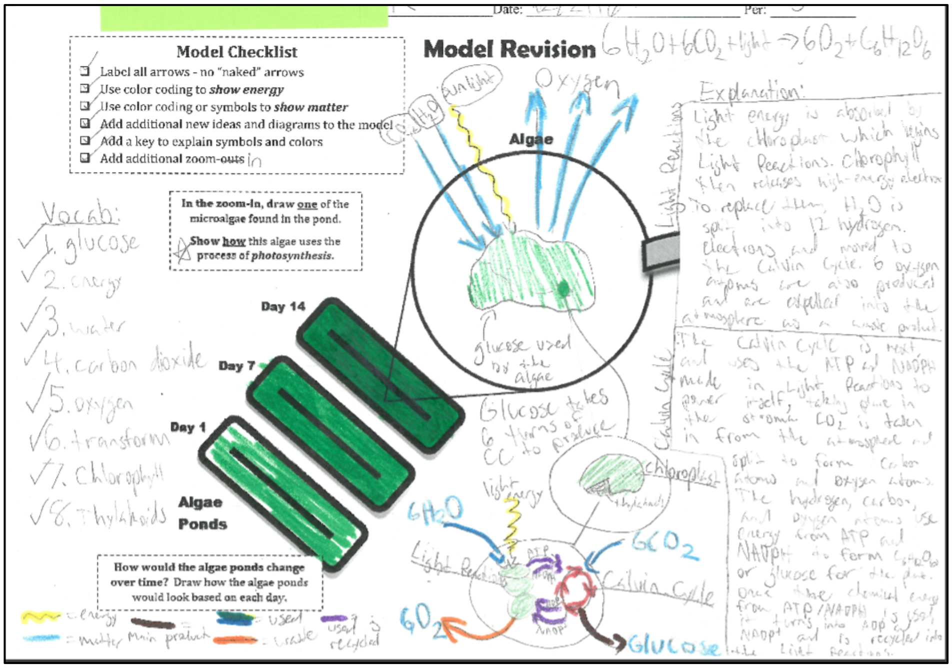


Additional Documents:

Initial Model Example



Model Revision Example



Final Model Example