Growing Algae for Fuel

Bioenergy Education Initiative

Levels:
Grades 3-12

Content Areas:
Chemistry; Physical Science

Lesson Time:
Several weeks for growth
5 minutes daily to mix algae
15 minutes for algae separation

Next Generation Science Standards:
MS-PS1
MS-PS1-3
HS-PS3-3

Outcomes:
Students will be able to explain, diagram or demonstrate how to grow algae.

Students will be able to collect and interpret growth data.

Students will be able to compare specific factors that affect algae growth.

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6/17

Description & Objectives:
In this lesson, students collect algae samples from the local area and monitor the algae growth using a light meter app for smartphones. After the algae have grown for about three to four weeks, students will collect the algae using a simple filter system, observe how much algae was collected per volume of water, compare growth among different samples (or samples grown under different conditions) and discuss the feasibility of growing algae for energy and bioproducts.

Using This Lesson:
It will take about three to four weeks to grow up enough algae in the bottles to monitor change using a light meter smartphone app. Students can do the extension activities in parallel as they are waiting for their algae to grow. This lesson also includes background reading materials, a series of leading questions to promote classroom discussion and critical thinking, and video links (see Resources page).

Green Power
Algae has the potential to become an important, sustainable source of biomass for making biofuels, food, livestock feed and other products. Some types of algae also produce oils and chemicals. Additionally, many municipal water treatment plants use algae to clean wastewater.

One of the largest algae farms in the U.S., located in Kailua Kona, Hawaii

Algae can grow in areas where food crops cannot. They can also grow using wastewater and seawater for nutrients and water, something conventional crops also can not do. One acre of algae has the *potential* to generate 15-30 times the amount of biomass as a first generation biofuel (e.g., corn). There are challenges to growing algae, such as separating the water from the algae at harvest and keeping contaminants out of the growth ponds. It can also be expensive to grow on a large scale. Nevertheless, as energy use continues to increase worldwide, it is vital we discover more efficient and sustainable ways (like algae power) to meet our energy needs.

Growing Algae for Fuel

Directions:

Preparing the Bottles

This experiment uses clear, 16 oz. (473 ml) plastic soda bottles for collecting and growing algae. Using a measuring cup, pour 8 oz (1 cup) of tap water into each bottle and mark the water level on the side of the bottle with a piece of masking tape. Thoroughly rinse the bottles using tap water and then set them out (with caps off) to dry for 24 hours. This will dissipate any chlorine in the water, which can kill or inhibit algae growth. **Do not** use soap to clean the bottles.

Collecting the Algae

Algae is commonplace and can be found almost anywhere on the planet, including ponds, lakes, creeks, and marshy areas. Before going on a collecting field trip with your students, provide them with background knowledge about algae (see Background) and the important role it plays in the ecosystem.

Students should collect their algae samples in the prepared plastic soda bottles. Have students collect algae from different sections of whatever lake, pond, creek, or stream you visit. Have students label the tape on the bottles with their name, collection location, and date.

Setting up the Algae Growing Bottles:

1. Make the fertilizer-water mix. In a one gallon container of distilled water, add 1 teaspoon of Miracle Grow™ Water Soluble All Purpose Plant Food. Shake the container in a circular motion to dissolve the fertilizer crystals. One gallon contains enough mix to make about 16 algae growing bottles.
2. Have the students slowly pour out their algae samples until their bottles are half full. The sample level should be at the 8 oz. level marked with the masking tape. HINT: Have students pour their samples out into a clean 16 oz. cup in case they accidentally pour out too much.
3. Next, students should fill the rest of their bottles with the fertilizer-water mix (approximately 8 ounces). The bottles should now contain one half algae-water sample and one half fertilizer-water mix.
4. Have students place the caps on their bottles, then shake the bottle and thoroughly mix the contents.
5. Students should then remove the caps from the bottles. Have them place 2"x 2" pieces of coffee filter paper over the tops of their bottles and secure them with small rubber bands. This filter will allow for air transfer. Save the caps.

Materials: Per Group

- Algae samples
- Deionized, spring or well water
- 16 oz. (473 ml) clear plastic soda bottles (enough for each student or small groups); extra for controls
- Miracle Grow™ Soluble All Purpose Plant Food
- Coffee filters
- Scissors
- Small rubber bands
- Luxi Meter app for Apple or Android smartphone
- Gram scale
- 250 ml or 500 ml graduated cylinders

Tips for Growing Algae:

Light: Ideally algae cultures should receive at least 10 hours of sunlight a day, but no more than 18 hours. Place algae cultures on a south-facing windowsill or use a standard fluorescent light about 8-12 inches from the bottles. DO NOT use incandescent lights because they generate too much heat.

Ideal Temperature: 60-80˚ F **Shaking:** Carefully shake the algae daily. This will aerate the algae cultures and expose more algae to light.

Table Sugar - you can often boost algae growth by adding ¼ to ½ tsp (1-2 grams) of sugar weekly.

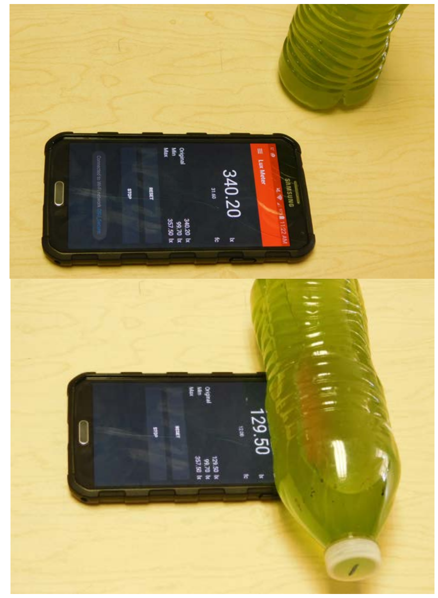
DO NOT store algae in the refrigerator; they need light and warmth to grow.

6. Set the bottles in a well-lit area that is 21˚-26˚ C (70˚- 80˚ F). The liquid should begin to turn noticeably green within four to seven days.
7. Each day, have students cap their algae cultures and shake them well. Mixing the sample will help aerate it and expose more algae to light. Have the students make notes on any changes they observe. For example, ask them to monitor the color of the liquid in the bottle or if they notice any clumps of algae forming.
8. **Option:** You may wish to introduce variables to some of the algae cultures. For example, some algae cultures could receive different amounts of light, or get a weekly sugar boost (see Growing Tips).

Measuring Algae Growth:

Using a light meter you can measure the amount of light that passes through an algae culture. This measure will be an indicator of algae growth. ***Luxi*** is a free light meter app for smartphones that measures illuminance (lx) or light intensity. This app measures the total amount of light present and the intensity of the illuminated surface. You can download the free Luxi app from Google Play. Below are directions on how to measure the light passing through the samples.

1. Create control samples for your class that contains one-half fertilizer-water mix and one-half distilled water using bottles that match the algae cultures. (Represented as lx fsw = fertilizer solution + water)
2. Have students place a capped control bottle on the smartphone where the light meter reads the sample. This will measure the amount of light coming through the fertilizer water mix *without* algae. This number can be used to calculate the amount of light absorbed by the algae.
3. Have students cap their algae cultures so no water can leak out and shake them, so the algae are suspended throughout the water.
4. Students then lay their algae cultures on the cell phone and measure the light intensity coming through the liquid. The amount of light that can pass through the algae cultures will decrease as the algae grow. The percentage of light absorbed by algae is referred to as A = algal light absorbance in the sidebar equation.
5. **To calculate,** students should divide the light intensity reading of their algae cultures (lx afs = algae + fertilizer solution) by the light intensity of a control sample. The algal light absorbance can be calculated using the equation in the sidebar. A fully colonized solution will have an algal light absorbance above 0.3.
6. If possible, measure the amount of illuminance coming through the algae cultures daily, and calculate algal light absorbance. Plot the results on a graph. For best results, take your measurements at the same time of day and in the same place because ambient light quality differs greatly throughout the day.
7. Continue to plot the growth of the algae until the algae growth begins to decline. This means the algae have reached their ***die off point*** and their growth is declining.



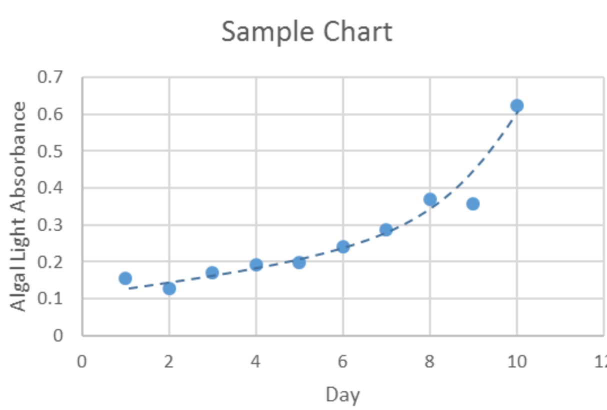
Above: The smartphone app reads the initial amount of ambient light present. Then (bottom) it reads the light passing through the algae culture.

Divide the light intensity in the algae culture by light intensity in the control sample.

A = log10 (lx afs / lx fsw)

KEY:
A = algal light absorbency
lx afs = algae + fertilizer solution
lx fsw = fertilizer solution + water (control)

Below: This sample chart shows how the algal light absorbance increases during growth.



Filtering Procedure:

1. Have students weigh the coffee filter they will be using to separate the algae. Record this number.
2. Place the coffee filter over the top of a 16 ounce (473 ml) drink cup and secure it with a rubber band around the lip.
3. Slowly pour the algae culture into the coffee filter until the filter is full. Wait until the water drains through. Continue adding the algae culture until all of it is filtered. The green slime on the filter is algae. The filter process is slow and can take up to an hour. (See photos right.)
4. Carefully remove the filter paper and set it on a paper towel.
5. Using a graduated cylinder, have students measure the volume (in milliliters) of liquid they recovered in the cup. Record this number. Discard this liquid and shake out whatever is remaining in the cylinder. Since they won't be using this liquid for growing any more algae, you do not need to worry about contamination between cultures. Students or groups can share cylinders.
6. Allow the filters with the algae to dry. You can do this by placing them in an oven at very low heat for a few hours or by leaving the filter on a counter over a couple of days.

Determining Total Yield and Concentration of Algae

Part 1: Determine the dry weight of the algae on the filter paper.

1. When the filter paper containing the collected algae has completely dried, weigh it again.
2. Then, subtract the weight of the unused filter paper from the weight of the used filter paper. This will give you the weight of the collected algae. For example, if the initial weight of the filter paper was 0.25 grams, but after filtering and drying, the filter weighed 3 grams, the weight of the algae grown would be 2.75 grams (**3 g – 0.25 g = 2.75 g**). The total dry weight yield of the algae would be 2.75 grams.

Part 2: Find the concentration of algae per liter.

1. Divide the dry weight of your algae (in grams) by the volume (in ml) of algae water you collected in your cup, and multiply that by the number by 1,000 ml. For example, if you recovered 2.75 g dry weight of algae and you collected 414 ml (14 oz.) of algae water in your cup, you would divide 2.75 g by 414 ml and multiply by 1,000. **(2.75 g ÷ 414 ml) x 1,000 = 6.64 g/ml**

Chart these numbers across the class and compare the outcomes. Were there a differences in algae growth? Ask students to hypothesize why the differences occurred.

Challenge Option: Ask students to use the information from their samples to calculate how many gallons of their algae growth sample they would need to produce a kilogram of algae. Have students calculate the volume they would need at the beginning of the experiment, and assume they got the same yield at the end.

Expected Outcomes:

Growing the Algae: Tips for growing algae are listed in the side bar on the first page of the lesson. Within four to five days of setting up the experiment, you should be able to see the algae growth solution start to darken and become more green. Within 10 days you will find an even more visible difference and may even see bubbles begin to form at the surface of the algae growth solution.

Chart the algae growth with the Luxi light meter readings. Algae growth should reach its peak by 30 days/4 weeks, though you don't need to wait that long to harvest the algae.

Harvesting the Algae: This is mini version of what biorefineries do to extract oil from algae. They also grow algae for products like agar agar (plastics), fertilizer, fish food, and human food.

Experiment Questions:

Below are basic and advanced level questions and observations students should make from the experiment.

Basic Level Questions

1. Under what conditions do algae grow best? ***Algae grow best when they receive 10 -15 hours of sunlight a day and the temperature stays between 60-80˚ F.***
2. Will the algae culture eventually die? Why or why not? ***Yes, the algae culture will eventually die when they have completely consumed the available nutrients. In this case, the nutrients include the fertilizer-water mix, sugar if used, and any other nutrients that were in the water with the algae sample when it was collected.***
3. Does the color of the algae tell you anything about their health? ***Yes, brightly colored algae is actively growing. When algae begins to die off, the water will begin to look clearer.***
4. How do the bottles of algae growth solution compare to algae's natural habitat? ***The bottles contain food or nutrients for the algae to survive and thrive. Sunlight is able to penetrate the bottles and reach the algae. The room temperatures will affect growth, as will the amount of aeration in the water from shaking the bottles.***
5. What variables affect the health of the algae? ***Light, temperature, and nutrient levels.***
6. What is the difference between total yield and concentration? Why measure both? ***The total yield will be influenced by the volume you have in your bottle on the day you measure it. Different students or groups may have different volumes left. By calculating the concentration, you can compare how well your algae bottles grew without worrying about differences in volume between the bottles.***
7. How might you grow algae commercially? ***Commercial algae biorefineries use mechanical aerators and sometimes artificial light to maximize the algae growth. They may provide a higher concentration of*** CO_2***. Some industries grow algae in ponds, or event in the ocean.***

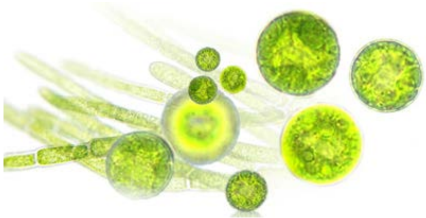
Advanced Level Questions

This lesson lends itself to further exploration and adaptation. Here are some suggestions of ways students can conduct their own experiments with algae.

- Students can explore what happens if tap water replaces the deionized water. Explore other variables that can affect algae growth.
- Students can think about how this experiment relates to the real world and where algae get their macro and micronutrients.
- Put an aquarium air pump in an additional algae culture and compare the grow of algae in that container to another without an air pump.
- Have students design a way to grow algae commercially (not using ponds). Their designs should include the following requirements:
  - o Maximum light contact with all algae;
  - o Use minimum space;
  - o Circulate the water so the algae gets equal exposure to sunlight;
  - o Ways to add and remove algae from the system
- The filtering process takes a lot of time and some algae still pass through the filter. Have students design other ways to more efficiently remove the algae from water.

Algae and Energy

What are Algae?



Microalgae image. Source: Renewable Energy Global Innovations.

Algae is the informal term for a large and diverse group of photosynthetic organisms. They use light energy (or other forms of energy like sugar), water, carbon dioxide and a few inorganic nutrients to grow. Algae range in size from microscopic, single-celled forms (microalgae), to large seaweeds (macroalgae), such as giant kelp, which can grow over 100 feet long[1]. While algal cells photosynthesize and contain chlorophyll, they are not considered true plants because they do not have true roots, stems or leaves.

Seaweed, a form of macroalgae, is harvested on a massive scale in China. Source: Scottish Assoc. for Marine Science.

Algae can be found almost everywhere on the planet and they play a vital role in many ecosystems. For example, algae provide the foundation for the aquatic food chains that support the fisheries in the oceans and inland waterways. Algae also helps produce much of the oxygen we breathe.

Algae can grow in virtually any environment that has carbon dioxide, sunlight, minerals and enough water. The limiting factor in algae growth is often sunlight or minerals. When sunlight is limited, some kinds of algae can take in organic substances, like plant matter, as food.

Many kinds of algae grow in ponds, lakes, rivers, streams, oceans, puddles and waterfalls. Algae also grow in very damp, yet not aquatic, habitats. For example, the rocks surrounding a creek or river may be damp enough to support a lush carpet of algae. Rainforests can also be damp enough to support algae on the trunks of trees.

Algae for Biofuels

It is vital we continue to discover more efficient and sustainable ways (like algae power) to meet humans' increasing energy demands. Biofuel produced from algae is one form of bioenergy that shows promise as a sustainable energy resource.

Researchers are studying various types of algae and methods for growing it to make feedstock for biofuel. Oil can be extracted from algae and then be converted into biofuel. Algae could *potentially* produce up to 60 times more oil per acre than land-based plants (corn)[3]. That oil could be used to produce electricity, or to make biofuel for cars and other machines that run on gasoline or diesel fuel.

There are several benefits to using algae as an energy feedstock. Algae can grow in areas where food crops cannot. They can also grow using wastewater and seawater for nutrients and water; something conventional crops also can not do.

There are challenges to growing algae, such as separating the water from the algae at harvest, and keeping contaminants out of the growth ponds.

Additionally, although algae can produce high quantities of oil per acre, it requires millions of gallons of water per acre. The current algae growing systems that are not part of a wastewater treatment plant, use fossil fuel-based fertilizers to feed their algae. Extracting the algae from the water is cost prohibitive when such a small quantity of algae are produced per volume of water.

Despite these challenges, many researchers and startup companies are busy attempting to resolve these problems and create a green oil boom.

Wastewater treatment using algae. This plant is part of a startup company using this process in developing countries to provide clean water and save energy. Source: Haaretz

Algae's Many Uses and Products

The business of growing algae for its environmental benefits (cleaning wastewater) *and* bioproducts is evolving to make algae biofuels and bioproducts more financially viable.

Algae is used to make an array of bioproducts including fertilizer, livestock feed, infant formula, human food supplements, and cosmetics.

To make algae production profitable, companies and municipalities are bundling algae's many uses and bioproducts. For example, a municipal wastewater treatment facility can pretreat its sewage in algae ponds. This step reduces the costs of pretreatment with equipment that runs on fossil fuels. The algae grown at the plant can then be harvested. After the oil is extracted from the algae to make biofuel, the remaining algae can be used to produce fertilizer, fish food, cosmetics or other products, providing yet another source of revenue.

Algae for Commercial Buildings

In Hamburg, Germany algae production technology was incorporated into the outside walls of an apartment building.

The apartment, called the Bio Intelligent Quotient, became the world's first building to have a photo bioreactor incorporated into its facade. The algae is grown in flat panel glass bioreactors on the outside of a five-story, 15-unit apartment complex. The algae and solar thermal heat are harvested in a closed loop system which stores and uses the heat to generate hot water. The algae produces energy, plus it helps control light and shade in the building.

The Bio Intelligent Quotient, is an apartment building in Hamburg, Germany. Algae-powered energy technologies heat the water and air in the building. Source: New York Times[5].

The algae is also filtered out, collected and fed into an external biogas plant which sends power to the local electricity grid. Heat is also drawn off the algae in a heat exchanger and distributed throughout the building to help heat air, and pretreat hot water. Excess heat is stored below the building in geothermal boreholes. The energy is drawn from the boreholes with heat pumps during times when as needed.[4]

The people who live in the 15 apartments have no heating bills and their feedback has been positive on living in the building.

The main problem with the algae building design is the initial cost. The total expenses are estimated to be $762 per square foot—a lot more than a typical apartment building[5]. The algae-powered energy technologies will significantly reduce ongoing energy costs (perhaps get them to zero), but a substantial up front cost was necessary to see the long-term benefit.

Resources

[1, 2] *Algae Basics: What are Algae?*; All About Algae.com; Retrieved from http://allaboutalgae.com/what-are-algae/.

[3] *Energy 101: Algae-to-Fuel*, Office of Energy Efficiency and Renewable Energy; Retrieved from https://energy.gov/eere/videos/energy-101-algae-fuel.

[4] *This Algae-Powered Building Actually Works*, by Ben Schiller, Fast Company. July 16, 2014. Retrieved from https://www.fastcoexist.com/3033019/this-algae-powered-building-actually-works.

[5] *When Algae on the Exterior is a Good Thing*, by David Wallis, The New York Times. April 24, 2013. Retrieved from http://www.nytimes.com/2013/04/25/business/energy-environment/german-building-uses-algae-for-heating-and-cooling.html.

Next Generation Science Standards

DISCIPLINARY CORE IDEAS:
MS-PS1: Matter and Its Interactions

PERFORMANCE EXPECTATIONS:
MS-PS1-3: Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.

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.

PRACTICES:
- Planning/carrying out investigations
- Constructing explanations/ design solutions

CROSSCUTTING CONCEPTS:
- Energy/matter: Flows, cycles, conservation

VIDEO RESOURCES
Lecture 5: Feedstocks Aquatic Biomass & Urban Wastes
Time: 0:52-3:20
Lecture 18: Photosynthetic Organisms & Animals Time: 0:50-3:35

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Resources:

Algae Basics: What are Algae?; All About Algae.com. Retrieve from http://allaboutalgae.com/what-are-algae/.

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When Algae on the Exterior is a Good Thing, by David Wallis, The New York Times. April 24, 2013. Retrieve from http://www.nytimes.com/2013/04/25/business/energy-environment/german-building-uses-algae-for-heating-and-cooling.html.