Maximizing Algal Growth for Biofuel Production

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Grade Level: Grades 9-12; but the activity could be adapted for both older and younger students.

Activity Dependency: None

Time Required: days to months

Expendable Cost per Group: US$5.00-10.00

Summary:

In this inquiry activity, students will design their own experiment and identify appropriate resources to test how changes in environmental conditions affect algal growth. The activity also includes a simple and inexpensive method for assessing algal density using homemade turbidity tubes.

Engineering Connection:

Engineers play a key role in designing methods for optimizing algal growth for biofuel production. From the type of container (open air or closed system) to the amount of nutrients and light, engineers must manipulate a spectrum of variables to boost cell growth and lipid production.

Engineers also have to design cost-effective technologies that minimize environmental impact. For example, it takes a lot of water to grow enormous quantities of algae. Some environmental engineers are searching for ways to use waste water or salt water instead of fresh water for this process. If artificial aeration and temperature controls are used, engineers must make sure that the system efficiently uses the minimum amount of energy. They have to design reactors that allow light to penetrate to the interior otherwise algae will only grow near the surface. Engineers are also searching for safe and economical ways to extract oil from algae, chemically convert algal oil into biodiesel, and assess/optimize engine performance with thie resulting fuel.

Keywords

Algae, pond water, biofuel, density, photobioreactor, environment, biotic, abiotic

Pre-Requisite Knowledge

Students should have a basic understanding of the many biotic (e.g. algal predators) and abiotic factors (e.g., light source, light intensity, etc.) that affect population densities for algae. They should be familiar with how to record data in a laboratory notebook, how to measure carefully and how to work in small cooperative groups. If they do not have a basic understanding of biotic and abiotic factors that could affect algal growth, then they should be given time to do some background research in this area.

Learning Objectives

After this activity, students should be able to demonstrate:

- Careful questioning
- Experimental design
- Laboratory demeanor
- Research skills
- Laboratory notebook creation/maintenance
- Data collection, analysis and reflection

Materials List

Required materials will vary by student or group, depending on factors they choose to study. Here are a few suggested items:

- Pet Keeper Aquaria
- Air stones (for diffusing air)
- Aquarium pumps or CO2 source
- Algae source
- Water source
- Water collecting containers (for bringing in collected algal samples)
- Nutrient source (if chosen by students)
- Dissolved fertilizer
- Light source (if chosen by students)
- Zooplankton (if chosen by students)
- Aquarium fish (if chosen by students)
- Other (depending on research questions)

To share with the entire class:

- Algae population measuring equipment
    - Turbidity Tube (measured in NTU's-Nephelometric Turbidity Units)
    - Turbidity Meter (using a Vernier probe or equivalent, measured in NTU's)
    - Spectrophotometer (measuring % absorbance at 684 nm)
    - Hemocytometer (measured with optical density, and converted to cells/mL)

Introduction / Motivation

In order to meet the world's growing demand for energy, scientists and engineers around the world are searching for renewable alternatives to petroleum. One potential option is biofuel, or fuel made from biological matter such as prairie grass, corn stalks, soybeans, shrubs – even human and animal waste.

In recent years, a great deal of attention has been given to pond water algae as a potential feedstock for biofuel. Millions of dollars are being invested in research to find economical and environmentally safe technologies for growing, processing and converting algae into biodiesel.

Why are researchers so interested in algae as a feedstock for biofuel?

Algae are rich in lipids, the fat molecules in biological organism that can be chemically converted into biodiesel. Plants with more lipids will ultimately yield more fuel. It is estimated that algae could yield more than 2,000 gallons of fuel per acre per year of production. This far exceeds the volumes from other plants like soybeans, which yield only about 50 gallons of fuel per year.

So what exactly are algae?

The word 'algae' represents a whole host of photosynthetic, heterotrophic organisms. Most people are familiar with macroalgae, or the stringy, green, hair-like fibers that muck up ponds. But, it's the microalgae varieties that have the most potential to be an extraordinary source of energy. Under the microscope, they appear green, red or bluish-green in color. They come in all different shapes including rods and spheres with both smooth and elaborate, star-shaped surfaces. They can be single cells or colonies or chains of many cells.

In addition to their high oil content, there are two other key advantages for using microalgae as an energy source: (1) They consume carbon dioxide, which helps mitigate greenhouse gas effects; and (2) they can grow in places that are unsuitable for food production, which means they will not compete with land and water needed to grow the world's food supply.

Despite the promising potential of algae as a renewable energy source, many questions still remain unanswered. For example, how can we grow algae in a way that maximizes their growth and lipid production while minimizing water usage, energy consumption and cost? Measuring lipid production is beyond the technical capabilities of most high school laboratories. Yet, high schools can focus on finding conditions that maximize algal population densities. In this way, students can actually work on some of the same problems as practicing engineers!

Many mysteries still remain for how to optimize algal growth. This activity gives students the chance to explore some of these mysteries, and maybe even discover something that was previously unknown to science.

Background

This inquiry activity gives students an opportunity to design and test their own photobioreactors to maximize the growth of algal samples that are either collected from local ponds or purchased from biological supply companies.

Depending on the resources available, students have numerous options for measuring changes in their algal population densities (turbidity tubes, spectrophotometers, hemocytometer, etc.).

Engineers use expensive equipment, like spectrophotometers, to monitor algal growth. Most schools do not have access to such costly equipment. To solve this problem, the authors of this activity tested the reliability of homemade turbidity tubes as part of an NSF-funded Research Experiences for Teachers Program. The authors collected pond water samples from more than a dozen locations throughout northeast Kansas. Then they correlated turbidity data with cell count data obtained using a hemocytometer.

It turns out that these cheap, simple-to-make and fun-to-use turbidity tubes provide a fairly reliable method for analyzing algal population density.

Turbidity tubes can be purchased (supplier/cost) or easily made for about $7 each by following these directions:

1. Cut in half an 8 ft length of clear plastic, fluorescent-light protecting tubes ($X, Home Depot).
2. Tape or glue a cloth measuring tape ($X, from hobby store) along the length of each half of the plastic tube. Cut off excess measuring tape.
3. Cover the small end of a #9 rubber stopper ($X, Home Depot) with white duct tape ($X, ---). Use a black sharpie to add crossbars, and then fill in opposite quadrants, resulting in a pattern with 2 black quadrants and 2 white quadrants opposite from each other. You will need 1 stopper for each 4 ft long turbidity tube. The rubber stopper should fit snugly into the bottom end of the tube to prevent leaks.
4. Add turbidity marks as shown in figure below…
5. To use the turbidity tube, gradually fill it with whatever water source you're testing, e.g., pond water. Continue to fill the tube until you can no longer see the black/white quadrants at the bottom. Stop filling at the point at which the quadrants become invisible. This marks the level of turbidity of your sample.

These inexpensive turbidity tubes can be used over and over by pretty much any age at any school.

Before the Activity

- Purchase or make turbidity tubes.
- Collect supplies for making photobioreactors.
- Print copies of the "Project Guide Sheet" (see attachments).

Procedure:

With the Students

Students will decide how to alter biotic and/or abiotic conditions to optimize algal growth. They should have at least part of one class period to fill out a Project Guide Sheet (see attachments) so that they have a clear understanding of the purpose and direction of their research. Students should discuss their plan with the teacher before starting the experiment.

The algal collection and initial set-up of the photobioreactors can be done in one to two class periods, depending on the proximity of algal collection site and the length of those class periods.

Once students have their photobioreactors set-up, they will need 10-20 minutes per class period to record data and alter their set-up, if necessary. They will see first-hand how environmental changes can significantly impact population density, and they can quantitatively analyze these changes over time.

Students can continue to collect and analyze data as time and student interest allow.

Upon completion of this project, students should have a laboratory notebook that clearly shows careful data collection and analysis. This activity provides many opportunities for further research and/or side projects. The only limiting factors to this are time and student interest.

Adaptation for Shorter Time Frames

This activity worked well with high school students as part of a weeklong summer engineering camp. On day 1, students spent about 2 hours designing and setting up photobioreactors. On day 4, students returned to analyze algal growth. Even in this short time period, significant differences in algal growth were observed.

Attachments

Project Guide Sheet

Algae Data Cheat Sheet (Excel Spreadsheet)

PowerPoint Presentation

Safety Issues

Students should wear lab coats and safety glasses when handling their experimental setups. They should follow safe laboratory techniques when using chemicals, e.g., fertilizers, nutrients, etc.

Troubleshooting Tips

Investigating Questions

Students will ask questions like, "What happens to algae growth if we change….?"

This list includes some, BUT NOT ALL of the parameters affecting algal growth that students may choose to investigate.

- Algae species – isolate colonies from the field, purchase individual colonies from biological supply company, or collect communities of algae from local sources.
- Water temperature
- Water source (pond, lake , stream, tap?)
- pH
- Dissolved oxygen levels
- Aeration (aquarium pump, intensity of aeration, carbon dioxide source)
- Nutrient quantities
- Nutrient types (fertilizer, WC Media)
- In-/exclusion of zooplankton (individual or multiple species)
- In-/exclusion of fish (vary fish types?)
- Light source, intensity
- Others?

Contributors

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Supporting Programs

This activity was created during summer 2011 at the University of Kansas as part of the NSF-funded Research Experiences for Teachers program called "Shaping Inquiry from Feedstock to Tailpipe" (https://www.cebc.ku.edu/education/RET-2010.shtml).

Partial support came from the Center for Environmentally Beneficial Catalysis at the University of Kansas, Lawrence, KS (www.cebc.ku.edu).