

# The Use of Corn and Sugarcane to Produce Biofuel

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The controversy over using food crops to produce fuel provides a new way to engage students in learning important biological concepts. We present instructor's notes and provide information from an American Biology Teacher article we published in 2010 describing a laboratory experiment in which students investigate the process of ethanol fuel production and then integrate their scientific analysis with a discussion of the economic and environmental impacts of ethanol as fuel. This exercise is suitable for college and high school environmental studies, environmental science and biology courses. Because ethanol fuel production is based upon fermentation, students who conduct this experiment will learn about that fundamental biological process while relating that process to significant current events.

**Keywords:** environmental studies, biofuels, fermentation, environmental science, sustainability, corn, sugarcane

## Introduction

This experiment is designed to engage students in consideration of the economic and environmental costs and benefits of using corn and sugarcane for fuel. Students will learn about the biological process of fermentation, comparing the biological efficiency of the fermentation process to produce corn and sugarcane ethanol. The scientific analysis of corn and sugarcane fermentation will be integrated with discussion of the environmental and economic impacts of sugarcane and corn fuel production to draw conclusions about the sustainability of the use of these crops as sources of alternative energy. This laboratory experiment can be readily incorporated into a course unit on climate change and alternative energy; doing so will enhance the interest and relevance of the exercise to students.

We first described this laboratory exercise in an article for *The American Biology Teacher* (Banschbach and Letovsky, 2010). However, this ABLE publication version includes some additional instructor notes. We have used this laboratory in courses ranging from a high school summer workshop on environmental biology to an Introduction to Environmental Studies college-level course for environmental studies majors. Instructors can readily adapt the experiment for their own purposes using the suggestions below.

The timetable for the exercise can be adapted to the needs of a range of classes, as in Table 1. Instructors have much flexibility to expand the work to create a lengthy unit for their course or reduce it to serve as a brief demonstration. For example, we have run the experiment as one three-hour time block, we have also used it for 2 separate two-hour lab periods, and for 1, one-hour in-class discussion with college students in a first-year seminar called Solving Environmental Problems.

**Table 1.** Suggestions for timing of components of the exercise.

Activity	Timing
Discussion of background information	Single class period, at a minimum. If additional time is available, the use of videos or interactive websites, and concept mapping could occupy multiple class sessions.
Hands-on work to carry out fermentation experiment	Single two-hour lab period, is ideal but if less than two hours is available then some steps can be carried out by the instructor (e.g., preparation of the standard yeast solution) to save time.
Follow-up data collection	A check on the CO <sub>2</sub> produced in the fermentation tubes more than 24 hours after the initial experimental period provides useful additional information; This can be done anytime 24 – 48 hours after the experiment was initiated and only requires a few minutes.
Data analysis and discussion	Single class period, at a minimum, although additional classes might be beneficial if this work is an important part of a broader unit of a course.

## Student Outline

### Objectives<sup>1</sup>

1. Consider the economic and environmental costs and benefits of using corn and sugarcane for fuel
2. Understand the process of fermentation to produce ethanol
3. Compare the biological efficiency of the fermentation process for corn and sugarcane
4. Integrate scientific analysis of corn and sugarcane fermentation with information on the environmental and economic impacts of sugarcane and corn production to draw conclusions about the sustainability of the use of these crops as sources of alternative energy

### Background

#### *Economic and Environmental Impacts of Ethanol Production from Corn and Sugarcane*

Biofuels, in the form of ethanol made from corn or sugar, or biodiesel made from soybeans, may represent ways for the United States to reduce its dependence on imported oil and its greenhouse gas emissions. In his 2007 State of the Union address, President Bush announced a national goal to increase the country's consumption of biofuels from the current 5 billion gallons to as much as 35 billion gallons by 2017. This amount of biofuel could substitute for as much as 10% of U.S. gasoline supplies. President Barack Obama pledged support for the corn-based ethanol biofuel industry during his 2008 presidential campaign. Serious concerns about this plan have been raised by scientists, environmentalists and legislators, however (Bourne Jr., 2007).

Ethanol blended from corn is already widely used in the United States, but not as a stand-alone fuel for cars. Instead, it is blended into conventional gasoline to act as a smog-reducing agent, as well as a gasoline extender. In New England, for example, it is quite common to find gasoline sold with up to 10% ethanol. There are only about 800 service stations in the country presently selling "E 85", a blend containing 85% ethanol and 15% crude-oil based gasoline, and these are concentrated in the Midwest. However, in response to tax breaks offered by the U.S. Congress to encourage biofuel production, there are several hundred new ethanol production factories under construction, again mainly in the Midwest.

There are a number of potential problems with ethanol as fuel. Most fundamentally is the issue of how much "new" energy is produced by either corn- or sugarcane-based ethanol, after allowing for the energy used to produce the crop itself. This is intimately tied to the yield/conversion rate relating an acre of corn or sugarcane to how much ethanol each can produce. Using existing technologies, an acre of sugar cane produces almost twice as much ethanol as an acre of corn. The relatively low yield of corn has important policy implications for the United States in terms of biofuel production. Even if every one of the 70 million acres presently used for corn production in the country were used exclusively to produce corn for ethanol, this would only replace 12% of the country's total gasoline demand. The "new" energy produced by such a drastic conversion would represent less than 2.5% of the total American energy market (Tilman and Hill, 2007).

In terms of greenhouse gas emissions, it is true that as a plant, corn is part of the global carbon cycle, absorbing carbon dioxide from the atmosphere as it grows. Unlike burning fossil fuels, burning of corn ethanol does not result in additional carbon emissions into the atmosphere. However, one also has to consider the fossil fuel used to produce and harvest the corn and then convert it into ethanol. These processes result in considerable amounts of carbon dioxide emissions to the point where driving a car on corn-based ethanol results in only 15% less greenhouse gas emissions than driving the same car on traditional gasoline (Tilman and Hill, 2007).

At first glance, sugarcane-based ethanol production has considerable advantages over corn in terms of greenhouse gas emissions. The world leader in sugarcane-based ethanol production, Brazil, has successfully translated a massive investment into the process into independence from oil imports. Not only does land devoted to sugarcane produce much more ethanol than land devoted to corn, but Brazilian ethanol refineries derive most of their energy from burning sugarcane residue, thus avoiding fossil fuel burning and further cutting the greenhouse gas emissions associated with the production process. Some estimates claim that sugarcane ethanol produced on established plantations offers an 80% reduction of greenhouse gas emissions compared to traditional gasoline.

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<sup>1</sup>Please note that the content the handout contains was first published in 2010 by Banschbach and Letovsky in *The American Biology Teacher*, 72(1):31 – 36.

However, a serious problem with Brazilian sugarcane-based ethanol production is that much of it is done on newly cleared lands from the country's rainforests. In the global carbon cycle, plants and soil contain three times more carbon than exists in the atmosphere. When Brazilian rainforests are cleared to make room for sugarcane production, about 25% of the carbon dioxide previously stored in the forests' trees and plants is released into the atmosphere due to the cutting and burning of trees and the decay of roots. Even more carbon dioxide is released in the first 20-50 years of farming of former rainforest lands, as the carbon-rich soil decomposes. Overall, when tropical rainforests are cleared to produce sugarcane for ethanol, almost 50% more greenhouse gases are emitted compared to the production and burning of the same amount of traditional gasoline (Tilman and Hill, 2007).

The clearing of Brazil's rainforest to produce more sugarcane for the ethanol industry can also be expected to have a serious impact on biodiversity in the country, as countless habitats are destroyed. Furthermore, millions of people go hungry in Brazil, unaided by the country's massive production of sugarcane for fuel (Bourne Jr., 2007). Both sugarcane- and corn-based production of ethanol have the potential to drive food prices up and decrease global food security.

Corn is a leading source of animal feed in the United States, representing a key input for the dairy, poultry and beef industries. As demand for corn to supply the rising number of ethanol refineries soars, so have corn prices, resulting in higher prices for consumers on a wide range of food products. A dramatic illustration of this food versus energy struggle occurred earlier in 2007 in Mexico, when thousands of peasants took to the streets of the capital city to protest the rising prices for corn tortillas, a food staple of the country's poor.

Producing corn-based ethanol is also a water-intensive process. A 50-million gallon ethanol refinery can be expected to use some 150 million gallons of water in the refining process. This is equivalent to the water demand of small town (Barrett, 2007). Already, some Midwestern U.S. states have introduced reductions in water allotments for farm irrigation, as concerns mount about drawing down aquifers in the face of rising water demand from the ethanol industry.

To promote the domestic ethanol industry and in response to extensive lobbying by the nation's corn farmers, the U.S. government has introduced a number of tax and financial incentives for firms in the business. The federal government presently gives refiners of ethanol a 51 cent per gallon tax break to encourage more production in the U.S. Meanwhile, the United States maintains a 53 cent per gallon on imported Brazilian sugar cane-based ethanol. Despite interest in producing sugarcane for ethanol in regions of the United States where sugarcane is grown, including Florida, Louisiana, Hawaii, and Texas (USDA 2006), U.S. government policy will have to change to encourage such production, as long as the price of refined sugar (as food) remains high (Spinner 2006); legislators from Florida are trying to incorporate a mandate for sugarcane usage for some percentage of the U. S. ethanol production into future alternative energy legislation. Up to the present, the larger and more powerful corn lobby has held greater sway in the development of legislation. However, in terms of the efficiency of the basic process that produces ethanol from corn and sugarcane, which raw material is more powerful?

### *The Biological Process of Ethanol Production from Fermentation of Corn and Sugarcane*

Throughout history, humans have taken advantage of the metabolic process of fermentation conducted by yeast to produce ethyl alcohol (ethanol). Although ethanol has the obvious ability to intoxicate, in past times alcoholic beverages also served the important function of providing nutritious (carbohydrate-rich and sometimes protein-rich), safe (free of pathogenic bacteria) beverages during points in human history when food safety and availability were problematic, such as the Middle Ages in Europe (Moore 1993). During more recent times, the process of fermentation by yeast has been co-opted for the production of ethanol fuel. Henry Ford's first car ran on pure ethanol (Bourne, Jr., 2007); ethanol produced for fuel today is 200 proof and contains an additive that allows producers to avoid paying the ethanol-as-beverage tax.

For food or for fuel, the starting point in the ethanol production process is to provide a species of fungi, the yeast (*Saccharomyces cerevisiae*), with a source of carbohydrates (e.g., corn, sugarcane, grapes, barley, etc.) and allow the yeast to use the carbohydrates in the metabolic process called fermentation. The chemical equation for the fermentation process is:



where  $\text{C}_6\text{H}_{12}\text{O}_6$  represents glucose (a simple carbohydrate, a sugar),  $\text{H}_2\text{O}$  is water,  $2\text{C}_2\text{H}_5\text{OH}$  stands for two molecules of ethanol, &  $2\text{CO}_2$  denotes two molecules of carbon dioxide.

The most important part of this process for the yeast is not depicted in the above equation; the yeast breaks down the carbohydrates to release energy that it can use for its metabolic processes during this reaction. Carbohydrates other than glucose

can be used but they must be broken down to release simple sugars (like glucose) that can enter the reaction. Consider corn and sugar cane as raw materials for fermentation. Which raw material do you suppose contains a greater proportion of simple carbohydrates (sugars)? Which contains a greater proportion of complex carbohydrates (e.g., starch)?

Ethanol is a by-product of the process that is toxic to the yeast cells once the alcohol concentration reaches a certain level; this is why alcoholic beverages produced solely from fermentation (e.g., beer, wine) don't reach alcohol concentrations exceeding ~18% without supplementation. Therefore, the fermentation of raw materials such as sugarcane or corn must be followed by distillation to remove excess water in the mixture and reach the desired 200 proof (100%) concentration. Notice that carbon dioxide (CO<sub>2</sub>) is another by-product of the fermentation process listed in the equation above. Does this present any problems for the argument that ethanol is a green (environmentally-friendly) fuel? Why or why not?

In laboratory, your group will design an experiment to compare the rate of the yeast's fermentation of corn v. sugarcane. Consider the background information you've read and develop a research hypothesis for your group's experiment. Record your research hypothesis and a null hypothesis for the experiment.

### Methods

To assess the rate of fermentation you will measure the rate of carbon dioxide production by the yeast in specially-designed fermentation tubes. Each solution you test will consist of a standard yeast solution (yeast, water, NaCl) and added raw materials of interest: feed corn, raw sugarcane or other materials to serve as controls. Remember that the purposes of testing controls in any experiment include: 1) providing a baseline for comparison and 2) ensuring that you can be confident in your experimental techniques. For controls, your options include: 1) adding no carbohydrates to the standard yeast solution; and 2) giving the yeast glucose or sucrose, a highly efficient starting material for the fermentation process. Your instructor will tell your group how many fermentation tubes are available for your group's experiment. The experimental design that you develop should involve replication of each solution that you test.

Be sure that you record the standard recipe for the yeast solution, the type of yeast used, the specific solutions and number of replicates that your group tests, as well as any other procedures used by your group. You will need this information for your lab report in scientific paper format on this work. Each group should calculate rates of CO<sub>2</sub> production (milliliters of CO<sub>2</sub>/minute) for each solution tested. We will work together as a class to analyze the data and produce presentation quality tables and/or graphs.

### Lab Report in Scientific Paper Format

Students will write reports on this experiment. The report should follow the format discussed in class. In preparing your Discussion section for this report, however, you must consider not only your group's results in relation to your research hypothesis; you must also consider your results in the broader context of the future of ethanol as fuel. In particular, answer the following questions:

1. Which raw material, corn or sugarcane, was biologically more efficient for fermentation? Cite your group's key findings to support your answer. Explain why this raw material was more efficient than the other; cite any references you consult.
2. What did the controls for your experiment demonstrate? Describe what you learned from the results of each control solution that your group tested.
3. What do you perceive to be the major disadvantages to the use of corn for ethanol fuel production? What are the benefits? Do you think the U.S. government should continue to promote the use of corn from ethanol production? Explain.
4. What are the pros and cons for the use of sugarcane for ethanol fuel production in Brazil? What about in the United States? For regions of the U.S.A. that produce sugarcane, is its use to produce ethanol fuel a desirable renewable energy option? Why or why not?
5. In terms of global food security, what kinds of biofuels are most desirable (or least harmful)?

Be sure to cite all references you use in your discussion section. Use (author, year) format in the text of the paper; present full references in a Literature Cited section at the end of the paper.

## References

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## Supplemental Student Handout on Data Analysis

### Fermentation Lab Data Analysis

#### *Calculation of fermentation rates*

1. Calculate the average CO<sub>2</sub> production (in ml) for each treatment at each time interval (e.g., 5, 10, 15, 20, ...) up to 60 minutes (or the last time interval that had measurable gas production). To do this for each treatment or control group, add up the volume of CO<sub>2</sub> produced for all replicates and divide by the total number of replicates. Do this for each time interval individually. Your instructor may also ask you to calculate standard deviation to graph with the average CO<sub>2</sub> production at each time interval.
2. Plot average volume of CO<sub>2</sub> produced vs. time for each treatment and control group in a line graph. In Excel, use the “scatterplot” chart option. Put volume of CO<sub>2</sub> produced (in ml) on the y-axis and time (in minutes) on the x-axis. Place the data for all treatment and control groups on the same set of axes so that you can readily compare them. Be sure to label your axes and include the units for each variable.
3. Calculate the average rates of CO<sub>2</sub> production versus time for each treatment and control group. Rate is equal to volume of CO<sub>2</sub> produced divided by time. How can you estimate this from the graph you produced in part 2?
4. Prepare a bar graph that depicts average rates of fermentation for each treatment and control group. In Excel, use the “column” chart option. Put rate of CO<sub>2</sub> production (in ml/minute) on the y-axis and treatment/control group on the x-axis. Label the axes of your graph appropriately. Why is a bar graph appropriate for these data but a line graph more appropriate for the data you plotted in #2 above?

#### *Interpretation of Data*

With your group, discuss the questions on page 9 of the lab handout, in preparation for writing a lab report on this experiment.



## Materials

### For a class of 25 students

#### Standard Yeast Solution

Each group of students will need 200 ml of their own yeast solution. To prepare this, each group will need: 200 ml warm water, 0.2 g NaCl, and 7.0 g dry Fleischmann's Rapid-Rise® yeast.

#### Equipment Needs

An electronic balance will be needed for each group to weigh the NaCl.

Each group will need a 200 ml (or larger) flask for their yeast solution, as well as a graduated cylinder to measure the water for that solution.

Each group will need several 100 ml beakers and several fermentation tubes to use for the experiment. They'll need one beaker and tube for each replicate in your experiment; each group should set up more than one beaker/tube for corn, sugarcane, sucrose and control (just yeast) tests for replication. Each fermentation tube holds 20 ml of solution. Fig. 1 is a Kimble Kimax® fermentation tube for measuring CO<sub>2</sub> production in milliliters using graduations on the blind end of the tube. Note that if these tubes are not available, standard test tubes may be substituted to create a fermentation apparatus. Refer to the diagram on page 4 of: <http://www.radford.edu/jkell/RespirationEx5.pdf>



**Figure 1.** Fermentation tube.  
Photo from Fisher Scientific online catalog (#09-219), 2008.  
<http://www.fishersci.com/>

#### Test Materials

Each group will weigh their test material on the electronic balance to achieve the desired mass. The amount of test material needed for an individual replicate will be allocated to one 100 ml beaker so that yeast solution can be added, mixed and then the beaker's contents poured directly into one fermentation tube. Each group will need labeling tape to label each

beaker (e.g. corn, sugarcane, glucose and control).

The test materials should include: corn (ground from dried corn available at feed stores); sugarcane (available canned at Asian food markets or fresh at large outdoor markets or specialty produce stores (if you live near a major city), and either glucose or sucrose, as a positive control. Students can also select materials from outdoors (e.g., grass, leaves, moss, berries on campus shrubs) or from the dining hall (cereals, fruits, etc.). To pulverize all materials, a mortar and pestle for each group of students or a blender will be needed. Students need 2 g of each material to be tested for each replicate that they test in a fermentation tube.

#### Data Collection

A stopwatch will be useful for each group of students to keep track of data collection timing.

#### Data Analysis

Microsoft Excel facilitates calculation of means and standard deviations, as well as graphing data.

## Notes for the Instructor

### Suggestions Regarding Procedures

After discussing the issues surrounding ethanol (based upon their reading in the student handout and any other material instructors choose to provide), students work in small groups to develop a plan for an experiment to compare the rate of the yeast's fermentation of corn v. sugarcane. Instructors should ask students to devise the research hypothesis for their planned experiment. An example hypothesis would be: *Different materials will vary in their rate of fermentation by the yeast.* The students may predict that sugarcane will be fermented more rapidly than corn because of the presence of abundant simple sugars in sugarcane but more complex carbohydrates (starch) in corn. Students may wish to test other materials that are readily available outside the classroom or brought in by the instructor such as grass, moss, cereals (processed or whole), berries, etc. Allowing each student group to test a material of their choosing enhances student engagement in the project. Instructors may wish to provide students with a protocol handout (as in Table 2).

To assess the rate of fermentation, students measure the rate of carbon dioxide production by the yeast in graduated fermentation tubes (available from scientific glassware suppliers such as Fisher Scientific). These tubes have a blind end that traps gases and allows students to measure the production of carbon dioxide in milliliters on a scale on the tube (see Fig. 1 included with list of materials and equipment needed). Students test a standard yeast solution (Fleischmann's Rapid-Rise yeast®, water, NaCl) and added raw materials of interest: ground feed corn, ground raw sugarcane (available either at fresh produce markets or canned at Asian food markets), other materials they are interested in testing (as

mentioned above) and some controls. Note that if your school or college department does not own these special fermentation tubes, a similar system may be created from standard test tubes, one inverted in the other (see page 4 of this handout: <http://www.radford.edu/jkell/RespirationEx5.pdf>).

Before the students develop their plan for what solutions to test, instructors should introduce the concept of testing controls in an experiment. Discuss the need for a positive control (to show that the standard yeast solution will rapidly ferment a material known to be an excellent raw material for fermentation (e.g., glucose or table sugar—sucrose, if that is more readily available). The students should also be prompted to think about an appropriate negative control (to show that given no raw material for fermentation, the standard yeast solution will produce little carbon dioxide, e.g., add nothing to the standard yeast solution or add water equivalent to the amount of the other materials to be tested). The experimental plan that students develop should involve replication of each solution they choose to test; the amount of replication achieved will depend upon the number of student groups in the class and the number of fermentation tubes, but, regardless, the

concept and purpose of replication should be explained to students as necessary to ensure generalizability and repeatability of any results obtained.

Within a two-hour lab period, students will be able to set up the experiment and collect sufficient data for analysis, with sugarcane and any positive controls (e.g., glucose) fermenting rapidly (results within 20 minutes). To save time in lab, we ground the corn and sugarcane shortly before lab and stored them in the refrigerator, but if time allows, students may be asked to grind their own materials using blenders or mortars and pestles, depending upon the materials. If the sugarcane to be used in the experiment is wet, the ground corn should also be wetted to achieve approximately the same moisture level. We found that wetting of the corn was best done after grinding. While collecting data in lab, students will wonder if the corn solutions ever “catch up” to the level of CO<sub>2</sub> produced in the other solutions tested so, if possible, tubes should remain set up and examined again at 24 to 48 hours past the starting time. This follow-up data collection can be made fairly quickly, so it need not take place during another scheduled class period.

**Table 2.** Example of Fermentation Experiment Protocol for Students

1. To prepare the active yeast culture you will need: 200 ml warm water, 0.2 g NaCl, and 7.0 g dry rapid-rise yeast. Weigh the NaCl on an electronic balance and add to a flask of warm (~ 38 – 43°C /100 – 110°F) water, along with the package of yeast provided to your group. Swirl to mix. This is the standard yeast culture that you will mix with your test materials/control materials.
2. Your group will have three small beakers and three fermentation tubes to use for the experiment. Each beaker and tube is for one solution in your experiment; you should have more than one beaker/tube for corn, sugarcane, sucrose and control (no added material – just yeast) tests for replication. Each fermentation tube holds 20 ml of solution.
3. You will prepare each test material, using an electronic balance to weigh the material and achieve the desired mass. The amount of test material needed for an individual replicate should be allocated to one small beaker so that yeast solution can be added and mixed; then the beaker’s contents poured directly into one fermentation tube. Start by labeling each beaker: corn, sugarcane, sucrose, etc. Then weigh out: 2 g each of ground corn, pulverized sugarcane, oats or other raw material of interest for additional substrates.  Additional controls (positive and negative) will be done by some groups in the workshop.  For the positive control, add 2 grams of sucrose; for the negative control, add no test material to the yeast for this control solution.
4. Pour 20 ml of yeast solution into each of your three labeled beakers; keep the leftover yeast solution in case there is a spill and/or some other need to remix a test solution. Add the appropriate test material to each labeled beaker. Be sure that beakers are labeled to avoid confusion. Swirl the beaker to mix the test material with the yeast.
5. Label each of your three fermentation tubes to match the labels on your three beakers. Pour the contents of each labeled beaker into the matching labeled fermentation tubes, 20 ml per tube. Invert the tube while covering the opening with your thumb to fill the blind end of the tube with solution. Once you do this, you must begin collecting data; this is time zero for your experiment. You and your group members can decide whether to begin all tests at once or to stagger the starting times.
6. Record the volume of CO <sub>2</sub> produced in the blind end of each tube at five minute intervals for an hour. By recording CO <sub>2</sub> production over time, you are collecting all of the information needed to calculate fermentation rate for each replicate. We will compile the data on the board and discuss the process of data analysis.



### Suggestions Regarding the Data Analysis and Report

Each group of students may analyze their data by entering it into Excel and plotting the volume of carbon dioxide produced over time for each raw material and control. Replicate treatments should be averaged prior to plotting. Once the students produce a graph depicting carbon dioxide production over time (example below in “Examples of Results” section), instructors may lead a discussion about the trends in the data and how to calculate rate of carbon dioxide production for each treatment.

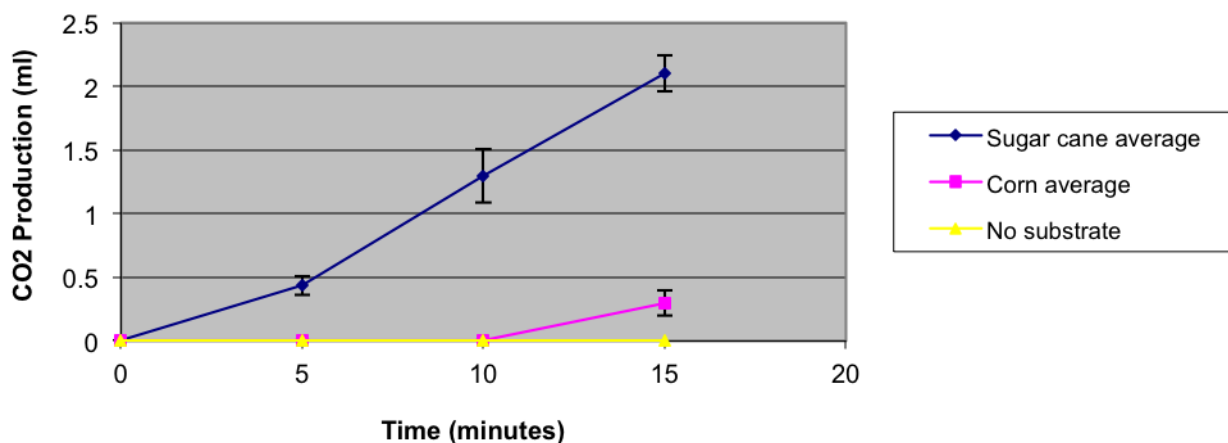
Students should be prompted to remember that the rate of carbon dioxide production is a measure of fermentation rate of each raw material and, therefore, reflects efficiency of the given raw material for ethanol production. The rate is simply the slope of the plot of carbon dioxide v. time. It can be calculated as volume of carbon dioxide divided by time for a given portion of the experiment. We asked the students to produce

a summary bar graph depicting the mean rate of carbon dioxide production for each material and control tested (example in “Examples of Results” section below). If students test materials other than corn and sugarcane and run both positive and negative controls, their graphs will feature more x-axis categories.

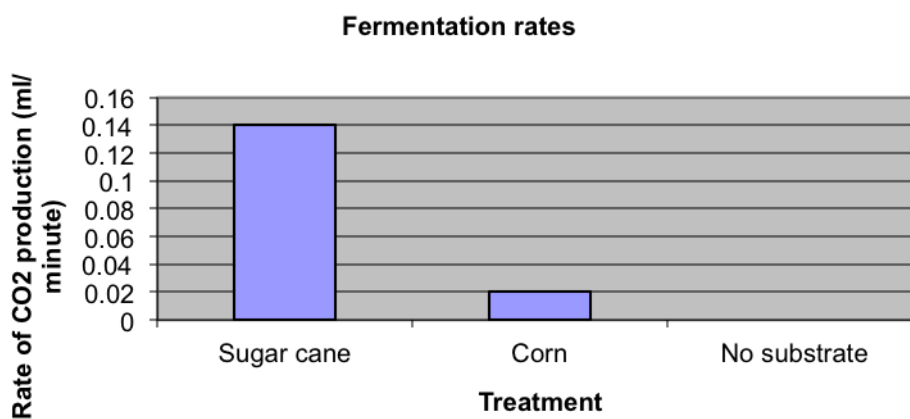
We required each student to write an individual report on this experiment in scientific paper format. In the Discussion section for the report, students were asked to consider not only their group’s results in relation to their research hypothesis, but also their results in the broader context of the future of ethanol as fuel. We asked the students to address the questions for discussion listed at toward the end of the student handout in the discussion section of their reports.

### Examples of Results

See Figures 2 and 3 for examples of student data.



**Figure 2.** Example graph of volume of carbon dioxide (mean +/- standard deviation in ml for two replicates) produced over fifteen minutes.



**Figure 3.** Example bar graph depicting rate of fermentation for two test materials and the negative control (no added substrate).

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## About the Authors

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Dr. Robert Letovsky is Professor and Chair of Business Administration & Accounting at Saint Michael's College in Colchester, VT. His research interests center on case writing, focusing on issues pertaining to business-government relations and sustainability. His cases have appeared in *The Case Research Journal*, the Pew collection at Georgetown University, Annual Advances in Case Research and the University of San Francisco Nonprofit Case Collection, as well as in various textbooks, including *Case Studies in Sustainability Management and Strategy: The Oikos Collection* and *Strategic Management: Formulation, Implementation and Control*. Dr. Letovsky's teaching focuses on strategic management, business/public policy, and international marketing. In addition to his teaching duties at Saint Michael's,

Dr. Letovsky has served as a visiting instructor at American University of Afghanistan (AUAF), and is a regular adjunct instructor for the Universidad Catolica de El Salvador (UNICAES) in Santa Ana, El Salvador.

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