How much gasoline does it take to run a bio-fueled engine?

Introduction:

Many AP Environmental Science teachers discuss the pros and cons of reducing our reliance on fossil fuels through the use of alternatives such as ethanol and biodiesel. What most students do not realize, however, is that fossil fuels are used in several of the processes required to grow the organisms that create fuels such as ethanol and biodiesel. This project is designed to provide a comparison of two different biofuel making organisms versus gasoline through a life cycle analysis to see what fuel source is the best choice for North Carolina. This lesson plan begins with a choice of growing labs for the oil-seed producing Camelina Sativa and/or the algae Dunaliella Salina. Students will record the amount of water, energy, fertilizer, and fossil fuels used to create the growing conditions in the classroom for these organisms and then scale some of those numbers to an acre of land to see how the total oil produced along with the possible emissions compare to the life cycle for gasoline. The final assessment for this lesson will be a board game style debate that will ask the students to research an alternative fuel and determine which one would be the best option for North Carolina in the future.

Learning Outcomes:

- Students will apply their knowledge of climate, biomes, net primary productivity, agricultural land use, fossil fuels, and the use of alternative energy through a life cycle analysis of biofuels.
- Students will learn to read scientific literature and compare their lab results with published standards.
- Students will determine which fuel choice is best for North Carolina.

Curriculum Alignment

AP Environmental Science Standards

I. Earth Systems and Resources (10-15%)
   a. Global Water Resources and Use
   b. Soil and Soil Dynamics

II. The Living World (10-15%)
   a. Ecosystem Structure
   b. Energy Flow
   c. Ecosystem Diversity

III. Population (10-15%)
   a. Population Biology Concepts
   b. Human Population
      Human population dynamics
   c. Population size
      (Strategies for sustainability; case studies; national policies)

IV. Land and Water Use (10-15%)
   a. Agriculture
      Feeding a Growing Population
   b. Controlling Pests

V. Energy Resources and Consumption (10-15%)
   a. Energy Concepts
   b. Energy Consumption
      History
   c. Present Global Energy Use
   d. Future Energy Needs
   e. Fossil Fuel Resources and Use
   f. Energy Efficiency; CAFÉ standards
   g. Renewable Energy

Materials:

Algae growing lab
Camelina growing lab
Digital Balance
Graduated cylinder
Calculator
Lab Notebook
Internet for research on fuels for post-lab debate

Teacher Preparation

The growing stations should be set up prior to the lesson. For the algae, an aquarium with a hood light is fine for creating the growth station, but you could add stronger lights if you would like to see more pronounced growth. I recommend putting white paper on the bottom and back of the aquarium for more reflectivity of light throughout the tank. For the Camelina, you will need at least four 40 Watt bulbs placed about 6 inches above the top of a four inch pot. The lighting should be able to be raised with the camelina as it grows to maturity. Our local nursery donated pots, soil, and stakes to assist with this lesson plan, and our local hardware store donated materials to build two 6'10" growing stations on wheels that the fluorescent fixtures were bolted to. We can move the stations into the elevator and to other classrooms so that multiple classes can grow these organisms at the same time.

Camelina Sativa will take four months from seed to harvest, so the pre and post labs can be completed using the teacher's discretion as to what topic this fits best with (energy, farming, genetically modified organisms, vehicle emissions, etc.) The Algae growing lab will only take 10 days from start to finish, and like the Camelina lab only takes a few minutes of time to maintain at the beginning of class. I recommend growing the Algae at the beginning of your alternative energy unit with the harvesting of the algae occurring towards the end and used as an addition to teaching about the future of biofuels.

Note: If you have chosen to use this curriculum to vertically align four of the core science classes, then you will not need to have the AP Environmental students grow the camelina or algae to do this lesson plan (although it makes it more fun!) They will just need to get the data from the Earth Science and Biology classes growing Camelina and algae respectively.

This is the fourth lesson plan associated with the vertical alignment of your science department. I have used Biofuels as an example of a topic that could connect Earth Science, Biology, Chemistry, and AP Environmental Science together. The hope is to provide your students with a broad science theme that shows them how each of the sciences are related to each other to create bridges between the traditional science islands that we have taught on over the years. If the students are shown all of the ways they can build on their prior knowledge, then you can provide a deeper connection to the materials and topics that you present them with. Freshman Earth Science students will grow Camelina Sativa to get an understanding of why we are looking at biofuels to replace fossil fuels. Freshman/Sophomore Biology students will grow salt water algae to utilize their understanding of cell parts and plant cell function to learn why algae make fatty acids that can be made into a biodiesel. Chemistry students will show their understanding of molar solutions by making the media that the Biology classes will use to grow the algae in. The Advanced Placement Environmental students can utilize all of the knowledge gained from these other classes to dive more deeply and determine which alternative fuel would be the best choice for North Carolina.

Author Information

Mark Townley is a 14 year National Board Certified Teacher and Kenan Fellow working as an AP Environmental/Earth Science teacher at Holly Springs High School in Wake County. He has a degree in Geology from North Carolina State University and is General Science Certified. In 2009, Mark was a finalist for the Wake County Teacher of the Year, and was named as the N.C. Outstanding Science Teacher of the Year for District 3 by the N.C. Science Teacher Association in 2011. He has assisted with the development and implementation of multiple state-wide curricula including two from the N.C. Environmental Education Fund titled "It's Our Water!" and "It's Our Air!," and was an original member of the NSF funded EarthView program back in 2000 when Earth Science became a graduation requirement.

Acknowledgement

Lesson developed through the Flight Fellowships: STEM in Aerospace Science and Aeronautics, a program of the Kenan Fellows Program and the North Carolina Science, Mathematics and Technology Education Center.

Funding provided for the Flight Fellowships by NASA K-12 Cooperative Agreement #NNX10AU89A.

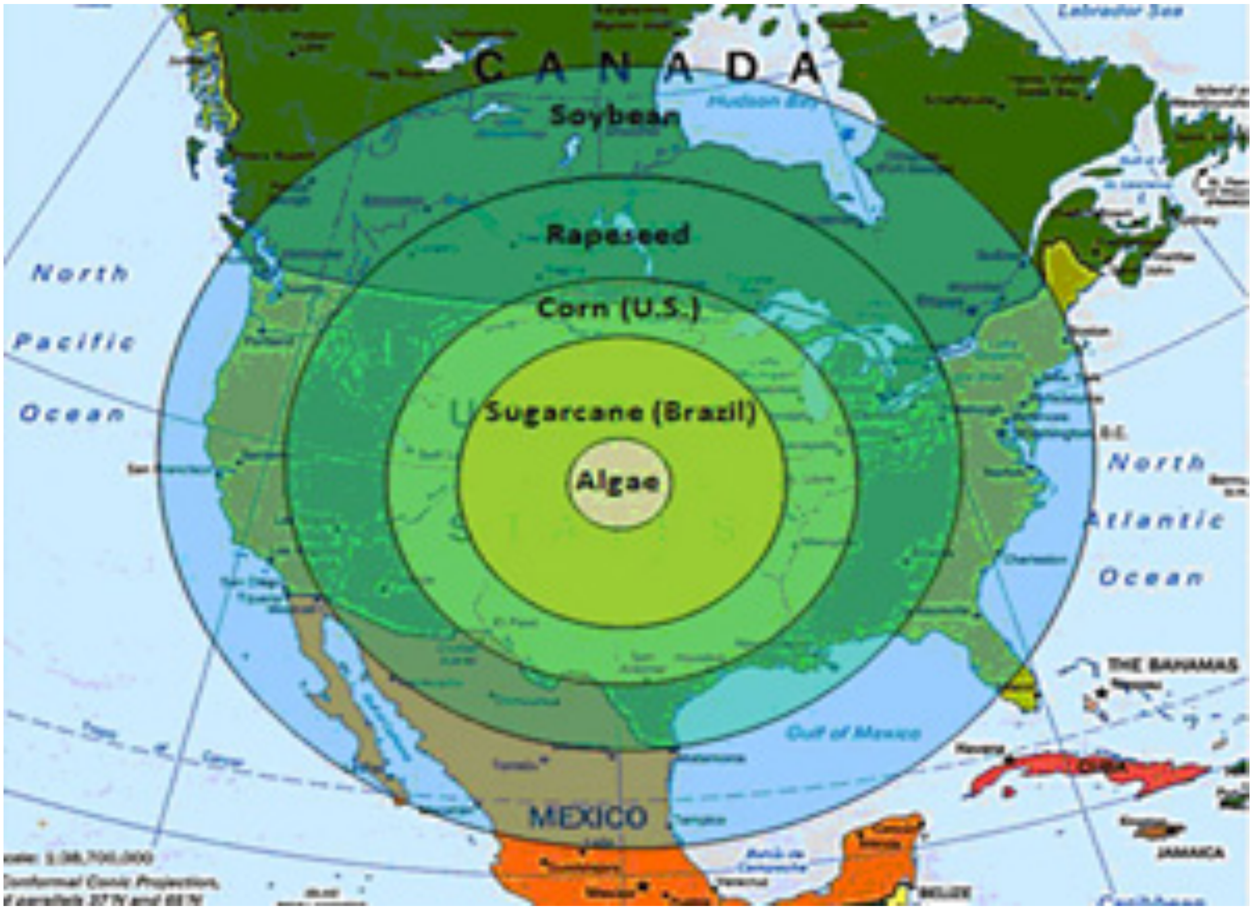
KENAN FELLOWS PROGRAM

SMT
North Carolina Science,
Mathematics, and Technology
Education Center

Pre-lab Student Worksheet for How Much Gasoline Does it Take to Run a Bio-fueled Engine?

Over the last few decades, most of us have heard about the concerns over the depletion of fossil fuels such as oil or petroleum. Many have also seen the push by many universities, global organizations and corporations to find an alternative fuel source to replace those fossil fuels. There seems to be a variety of options available to replace gasoline and diesel, but many of those fuel sources are not available yet for public consumption. The picture in figure 1 shows the amount of land that would be required to grow enough crops to meet the fuel demands in the U.S.

Part 1: Look at figure 1 below and answer the following questions.



Picture by George Santana, Greener Dawn

Figure 1: Land use required to grow enough crop to meet the fuel demand in the U.S.

1.) Based on this picture, what do you think is the key characteristic of algae that allows it to require so much less land than soybean to provide us with enough oil to meet the U.S. fuel demand?

2.) With the exception of Algae which can grow anywhere, where do you think the best place to grow most of these crops is in the U.S?

3.) Name at least two advantages and disadvantages that you can see with using crops like these to make Biofuels.

4.) Camelina (Rapeseed) is mostly grown in northern latitude climates. Sugarcane grows better in more tropical regions. What is one thing that scientists could possibly do to allow us to reduce the amount of land needed to grow these crops OR to allow us to grow them in any climate in the U.S.?

5.) Based on this picture, what is one major reason we have not switched from gasoline or diesel to a biofuel source?

Part 2: Look at figure 2 below and answer the following questions.

Year: 2010 **BTUs or grams per mmBtu**	**Camelina-based BD20**	**Algae-based BD20**	**Baseline Conventional Gasoline**	**Baseline Conventional and LS Diesel**
Total Energy	366,954	611,748	225,759	200,231
WTP Efficiency	73.2%	62.0%	81.6%	83.3%
Fossil Fuels	214,941	266,599	205,559	197,068
Coal	14,422	45,723	16,054	14,480
Natural Gas	124,924	138,893	117,278	110,921
Petroleum	75,596	81,983	72,227	71,667
CO2 (w/ C in VOC & CO)	1,694	3,378	15,500	16,321
CH4 (methane)	132.494	225.725	143.895	142.110
N2O	5.990	3.855	1.123	0.220
GHGs (greenhouse gases)	6,791	10,170	19,432	19,939
VOC: Total (volatile organic compounds)	17.931	9.702	27.365	8.108
CO: Total	15.662	17.679	12.229	11.796
NOx: Total (nitrogen oxides)	53.575	66.590	47.629	46.200
PM10: Total (particulate matter smaller than 10 micrometers)	7.175	12.880	7.485	6.851
PM2.5: Total (particulate matter smaller than 2.5 micrometers)	4.223	5.882	4.030	3.827
SOx: Total (sulfur oxides)	31.530	23.996	26.907	25.713

Chart from GREET software created by the Argonne National Laboratory and the U.S. Department of Energy

Figure 2: Chart comparing emissions from Camelina Sativa, Algae, Conventional Gasoline and Low Sulfur Conventional Diesel

1.) Why do you think Camelina (a member of the same family as rapeseed) and algae use more fossil fuels than gasoline and diesel?

2.) Between the fossil fuels (gas and diesel) and the biofuels (Camelina and Algae), which ones have the highest greenhouse gas (GHG) emissions?

3.) Which of type of fuel uses the most energy?

4.) Which fuel choice has the highest total engine emissions when you add CO2 down to total Sulfur Oxides? Which one has the lowest total emissions? Write the totals of both answers in grams/mmBtu.

5.) Based on this chart, what is another major reason besides your answer in Part 1 why we have not switched from gasoline and diesel to biofuels?

Part 3: Answer the following questions.

1.) When you compare algae and camelina (rapeseed) using land requirements and emissions, which one do you think is the better choice? Explain your answer using both figures.

2.) What are some things that could be done to improve the possibility of switching to biofuels?

Answers to Pre-Lab Questions for "How Much Gasoline Does it Take to Run a Bio-fueled Engine?"

Part 1:

1.) Algae produce significantly more oil per acre than any of the other biofuel options. They can also be put under increased stress conditions to reliably create more oil without any genetic modification required.

2.) Answers will vary, but the majority of these crops (particularly corn) can be successfully grown in the Great Plains or the Mid-West area of the U.S. west of the Mississippi River and East of the Rockies. More specifically, Rapeseed (Camelina) prefers northern latitudes while sugarcane is grown successfully in warmer climates. Algae can be grown anywhere.

3.) Advantages could be the possible reduction of greenhouse gases and other pollutants in our atmosphere such as nitrogen oxides, volatile organic compounds (VOCs), sulfur oxides, and particulate matter depending on the fuel source; less of a reliance on foreign oil; the transition from a non-renewable source to a renewable source.

    The biggest disadvantage would be the loss of a feedstock from that crop if that much land is required just for fuel stock; more land than is available in the U.S. would be required for soybeans, rapeseed, and possibly corn; raise in prices of the crops.

4.) Scientists could genetically modify the crop to be able to produce more oil per acre, or they could genetically modify the crop to be able to withstand a variety of climactic conditions.

5.) All of these crops are currently grown as a feedstock for humans, livestock, or fisheries. If the land that is currently being used to grow food is converted to a fuel stock then there will be economic repercussions. With the exception of algae, there is not enough land in the U.S. to meet our feedstock needs and our fuel needs unless the crops are genetically modified to produce significantly more oil per acre of land. Based on this picture, we would still be heavily reliant on foreign countries to assist us with meeting our food and fuel needs.

Part 2:

1.) Camelina and algae use more fossil fuels than gasoline and diesel because of the fossil fuels required to grow the crops through the production of fertilizer and herbicides at the factory, the transportation of the fertilizers and herbicides to the store and the farm, the gas and diesel used in the tractors and farm equipment, and the fossil fuels required to make the plastics used in any part of the growth process such as the photo-bioreactors that the algae may grow in.

2.) Gasoline and Diesel have the highest emissions with 19,432 BTUs and 19,939 BTUs respectively.

3.) Algae uses the most energy with 611,748 BTUs

4.) Low Sulfur Diesel has the highest emissions with 36,504.825 g/mmBtus. Gasoline emits 35,202.663 g/mmBtus, algae emits 13,914.309 g/mmBtus, and Camelina has the lowest total emissions with 8,753.58 g/mmBtus.

5.) Even though the emissions would be lower for the biofuels versus the fossil fuels throughout the life cycle of the fuel choices, we would actually be more reliant on fossil fuels with our current production methods than we would if we just kept using fossil fuels.

Part 3:

1.) Opinions will vary. Camelina has fewer total emissions than algae (8,753.58 g/mmBtu for Camelina vs. 13,914.309g/mmBtu for Algae) but would take up considerably more land than is available to meet fuel demands in the U.S. Algae have higher emissions than camelina, but can be grown anywhere in the U.S. with significantly less land required. Both fuels could be used as an additive to diesel.

2.) Multiple answers possible. Both fuels could be genetically modified to produce more oil per acre, we could use more alternative energies and fuels in the growing process of these organisms, we could utilize the oils from the crop that grows best in each area to reduce transportation emissions, we could use Integrated Pest Management to reduce the amount of pesticides used.

Activities

As the students grow the two different organisms, have them keep track of the amount of water and fertilizer used to grow them.

Growing the salt water algae Dunaliella Salina as a biofuel source

Use the Biology based algae growing lab attached to this curriculum.

Background

The algae used in the figures in the pre-lab activities were fresh water algae. That means that all of the emissions throughout the life cycle of the algae were based upon the need to add nutrients, flocculants, and chemicals in order to grow, harvest, and convert the algae to diesel. The algae that you will be growing is a marine algae that utilizes nutrients added through wastewater. Adding salt to the wastewater gives you a glimpse at two different options that can be used to dramatically reduce the footprint of algae as a biofuel.

The first option suggested by this lab is the use of wastewater treatment plants as the fresh water source for growing algae. This option would allow the algae to absorb the nutrients and other impurities to provide extra filtration for the treated wastewater before it is returned to the river or other body of water. The disadvantage of using this effluent is that you would still need to add nutrients and other chemicals to grow enough algae to harvest, although it would be less than fresh water taken straight from a pristine water source. Flocculent would also need to be added to make the algae clump for harvesting.

The second option is to grow marine algae in salt water. There are multiple advantages associated with this option. The salt water would need to go through a minor purification process, but if used on land there are very few micro-organisms away from the ocean that can grow in salt water. So using ocean water would reduce contamination of the algae making for an easier harvest. Another advantage is that salt water is naturally high in positive Magnesium ions which have been proven to help cause the algae to naturally flocculate when the pH of the water gets above 10. When harvesting these unicellular algae, all you have to do is add a very small amount of freshwater and the salt water algae cells explode due to pressure differences allowing the lipids to float to the top and the starches to sink to the bottom. The lipids are the fatty acids that will be converted into biodiesel, so using salt water could save millions of dollars in flocculants and harvesting chemicals. This would also significantly reduce the life cycle emissions caused by algae as a biofuel. The major disadvantage of using salt water would be the cost of transporting the ocean water uphill to the growing stations. This could be significant depending on the amount of ocean water needed to grow enough algae to meet our fuel demands. (3)

Growing Camelina Sativa as a biofuel source

Use the Earth Science Based Camelina Sativa growing lab attached to this curriculum.

Background

Camelina Sativa is a member of the family Brassicaceae along with mustard, rapeseed, cabbage, and broccoli. It is a northern latitude plant that does not require much nitrogen and is very drought tolerant. Other advantages of Camelina are that this oil seed plant grows to maturity in 120 days which makes it an excellent short season crop that can be planted between other growing seasons. Camelina can be grown before most of the spring weeds start to appear which means that it can be grown with significantly less herbicide than many other biofuel options. No insects have been found to cause economic damage to Camelina, so no insecticide is required. The disadvantage of Camelina is that because it is a northern latitude plant, growing in warmer climates would require some adjustments to planting schedules or some genetic modification. (2)

One of Camelina Sativa's closest relatives is Arabidopsis Thaliana. Arabidopsis was the first plant to have its entire genome sequenced and mapped and has been studied by plant biologists for years. This gives Camelina an advantage as it is the best biofuel option available for genetic modification due to its significant similarities to Arabidopsis. The Plant Biology Department at North Carolina State University has been tasked with looking at genetic modifications for Camelina that include making it more tolerant of warmer climates so that it can be grown anywhere, and with finding ways to increase the oil production per seed and per acre. (3)

Camelina has been grown for the last 3,000 years to make vegetable oil and animal feed. The seeds are 40% oil, which is double the amount of oil produced by soybeans. Camelina oil is extremely high in Omega-3 fatty acids which are helpful with several different aspects of human health including metabolism, blood pressure, and decreased risk of stroke. The oil in the seed is also high in vitamin E and is used as cooking oil which has an almond-like flavor and smell. (1)

References:

1. Hunter, Joel and Greg Roth 2010. Camelina Production and Potential in Pennsylvania, Agronomy Facts 72. College of Agricultural Sciences, Crop and Soil Sciences, Pennsylvania State University.
2. Ehrensing, D. T. and Guy, S. O. 2008. Camelina. EM 8953-E. Oregon State University Extension Service, Corvallis, OR, USA.
3. Sederoff, Heike and Dums, Jacob. Personal interview. 5 July 2012.

Post-Lab for How Much Gasoline Does it Take to Run a Bio-Fueled Engine

Part 1: Answer the following questions.

1. A typical square foot in a field of Camelina can successfully germinate up to 80 plants.
   a. Calculate the amount of fertilizer that your class used per square foot. Increase your total to match the 80 plant sq. ft.
   b. Osmocote uses 19% nitrogen in the form of Ammonium nitrate. There are 857.5 grams of Carbon dioxide emitted per Kilogram of Nitrogen produced. Using your answer from part A, determine the metric tons of CO2 emitted per acre of land. There are 43,560 square feet in an acre and 1000 kg per metric ton.
2. An acre of Camelina Sativa is estimated to be able to produce around 100 gallons of oil per year. If the mass of a typical Camelina Seed is approximately 50% oil, mass your seeds to determine how many gallons of oil you would produce per acre (There are 3.785 liters/gallon, 1000 cm^3/liter, and 0.75g/cm^3.) Assume 80 plants per square foot. Does your growth data agree with this? What are two reasons why your data reflects or disproves this statement?
3. The amount of oil required to produce, ship, and store the water bottle that you used as a photobioreactor would fill about one third of a 500mL bottle. The Pacific Institute claimed that there were 29 billion water bottles sold in 2012. How much oil was used to create those water bottles? Research greener ways we could reduce the amount of plastics required to grow algae as a biofuel.
4. Using the Background information on Algae, do you think the focus should be on salt water or fresh water algae? Why?

Part 2: Debate for Best Fuel Choice in North Carolina.

Assign eight groups of 3 to 5 students a fuel to research from the list below. Each group should research their fuel with the focus on why their fuel would be the best choice for North Carolina.

Fuel list:

1. ***Hybrid***
2. ***Full Electric***
3. ***Camelina or Rapeseed***
4. ***Algae***
5. ***Corn Ethanol***
6. ***Soybeans***
7. ***Switchgrass***
8. ***Hydrogen fuel cells***

Research your fuel using the following suggestions:

1. What air/water/land pollutants are produced by this fuel?
2. Is there infrastructure in place to fuel vehicles? (gas stations, etc.)
3. Can your fuel be used as a feedstock and how might this conflict with using this crop as a fuel?
4. How much land do you need to grow this fuel?
5. Where is the best place to grow your fuel and how might genetic modification help?

Procedure:

After the students have completed their research, randomly choose one student from each group to be a part of a panel of judges for a debate. Waiting until after the research has been completed insures that the judges are knowledgeable enough to assist each other with their decisions if needed. On the board in front of the classroom, draw a game board like the one shown below.

Fuel type	←	Advantages	←	Start	→	Disadvantages	→
Hybrid cars							
Full Electric							
Camelina							
Algae							
Corn							
Soybeans							
Switchgrass							
Hydrogen Fuel Cells							

1.) Move the judges to the front of the room and give each judge a two-sided card that clearly says YES on one side and NO on the other.
2.) Start the debate by having each group give a brief introduction to their fuel.
3.) Decide on the order that the groups will go for each round. When it is their turn, each group will have the option to either say an advantage for their fuel as the best choice for North Carolina, or they can give a disadvantage of using one of the other fuel choices in this State.
4.) If the group chooses to give an advantage of their own fuel, then the judges can vote yes or no with the majority deciding. If they say yes, then you can move that group's magnet from the starting position to the left towards the fuel name. If the judges say no, then the game piece stays.
5.) If the group chooses to give a disadvantage of another fuel, then the fuel the group is targeting will get a chance for a rebuttal before the judges decide yes for the attacking fuel or no for the defending fuel. If the judges say yes, the game piece for the attacking fuel moves to the left and the defending fuel moves to the right. If the judges say no, then the game pieces of both fuels stay in the same place.
6.) Play four rounds or until one of the fuels reaches their name on the game board. The winner should be based upon what that class thinks is the best fuel choice for North Carolina.

Answers to the Post Lab Questions:

Part 1:

1. a. Example Answer for Part A: One pot has 5 grams of Osmocote and there are eight pots for the class with 40 plants total. The fertilizer used would be 40 grams multiplied by 2 to get enough for eighty plants for a total of 80 grams of fertilizer per square foot.

   b. Using the example from part a.
   80 grams of Osmocote per square foot
   80 grams Osmocote X 0.19(19% of Osmocote is Nitrogen)=15.2 grams N/sq. ft.
   Convert to kg: 15.2 grams N/sq.ft. X 1kg/1000g =0.0152 kg N/sq. ft.
   43,560 sq. ft. per acre X 0.0152kg N/sq. ft. = 662.11 kg N/ acre
   857.5 g of CO2 emitted per 1 kg of Nitrogen X 662.11 kg N/acre = 567,759.32 g of CO2/acre
   567,759.32 g divided by 1000 g per kg=567.75 kg CO2/acre divided by 1000kg per metric ton
   =0.568 metric tons CO2/acre

2. Using the same total of plants from number 1 you would need to multiply times 2 to get to 80 plants per square foot. So if you ended with 3 grams of seeds, then you would have 1.5 grams of oil times 2 for 3 grams of oil per square foot (which would be a very good harvest.)
   1 cm^3/0.75 grams X 3 grams/1 square foot=4cm^3
   4cm^3/1 sq. ft. X 43,560 sq. ft./1 acre=696,960cm^3/acre
   696,960cm^3/acre X 1 liter/1000cm^3=696.96 liters/acre
   696.96 liters/acre X 1 gallon/3.785 liters
   =184.14 gallons/acre
   This answer would exceed the estimates by a considerable amount. Reasons for this could include aspects of the growing conditions the plants were placed under or the volume of oil per seed could vary.

3. 1/3 X 500 mL = 166.66mL
   166.66mL X 29 Billion bottles =**4.8 X 10 ^12 or 4,833,140,000,000mL or 4,833,140,000 L or 1,247,261,935 gal of oil**
   Research will provide several answers. Some ways that we could reduce the amount of plastics would be to utilize old Wastewater treatment ponds instead of using bioreactors, or we could use recycled plastics.

4. Answers will vary. Both choices are logical and have a high potential for success.

Part 2: Helpful Hints

1. Students enjoy the debates when there is more back and forth allowed. Give the attacking group and the defending group a couple of opportunities to debate the original statement before the judges decide.
2. Choose the judges randomly on the day of the debate from each group to make sure that the judges have each researched one of the fuels. If you tell them ahead of time that they will be judging, then the student might not learn enough about the fuel to provide proper judgments.
3. Take notes during the debate so that once the class decides the winner you can give suggestions on how the students could have improved their arguments. You can also provide some insight as to any facts the class might not have included when determining the outcome.