Quantitative Modeling of Biofuels Life Cycles

Overview: This activity allows students to compare the net energy and/or net greenhouse gases (GHG) emitted during the life cycle production of ethanol from switchgrass, diverse prairie and corn stover. Using Microsoft Excel spreadsheets, students model a range of scenarios, starting with data and assumptions provided in the package. This is a flexible quantitative model with many opportunities for modifications depending on the abilities and interests of the students.

Levels
9-Undergraduate

Subjects
Science, Environmental Studies, Engineering

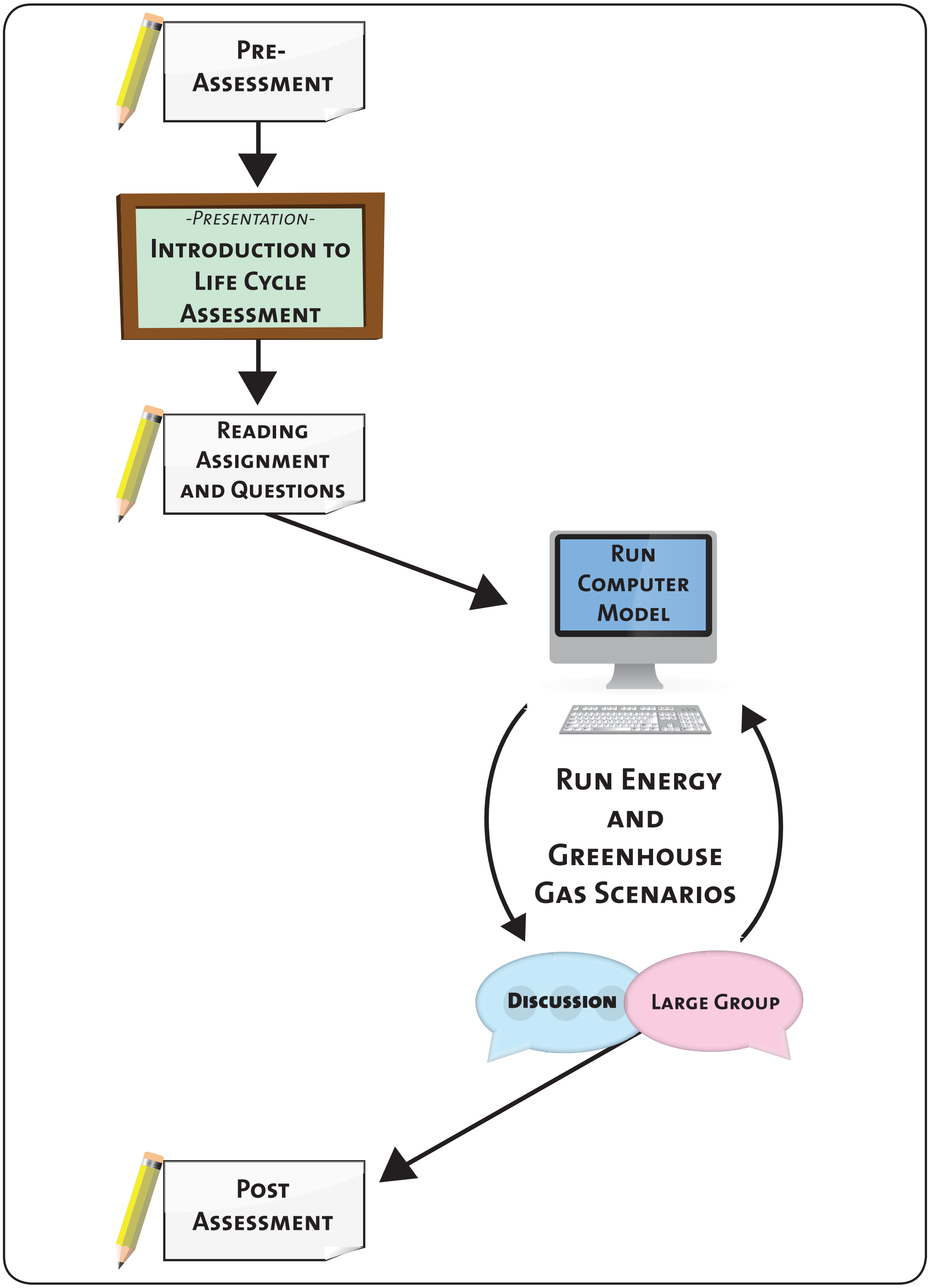
Objectives
- Compare energy requirements to create fuel from different energy crops.
- Use a spreadsheet to create a simple life cycle model for a process.
- Explore the concept of net energy and net GHG for a process.
- Identify opportunities for reducing net GHG emissions through agricultural practices.
- Others described on pg 2T

Materials
Quantitative Modeling of Biofuels Life Cycles Package

Activity Time
Variable: Five to six 50-minute class periods, fewer of only energy scenarios are completed

Standards
Next Generation Science Standards (2013)
- Scientific and Engineering Practices: asking questions and defining problems; developing and using models; analyzing and interpreting data; using mathematics and computational thinking; engaging in argument from evidence
- Disciplinary Core Ideas: matter and its interactions; ecosystems; earth and human activity; engineering design
- Crosscutting Concepts: systems and systems models; energy and matter
- Performance Expectations: See page 3 for details

NGSS Lead States. 2013. Next Generation Science Standards: For States by States. Washington DC: The National Academies Press



For Teachers - Quantitative Modeling of Biofuels Life Cycles

Overview:

This activity allows students to compare the net energy and/or net greenhouse gases (GHG) emitted during the life cycle production of ethanol from switchgrass, diverse prairie and corn stover. Using Microsoft Excel spreadsheets, students model a range of scenarios, starting with data and assumptions provided in the package. This is a flexible quantitative model with many opportunities for modifications depending on the abilities and interests of the students.

This activity is designed to run over the course of a minimum of five to six 50-minute class periods if both energy and GHG modeling is completed. Three to four is sufficient if only working with the energy model.

Learning Outcomes: Students will...

- Compare energy requirements to create fuel from different energy crops.
- Use a spreadsheet to create a simple life cycle model for a process.
- Explain the concepts of net energy and net GHG emissions for a process.
- Identify opportunities for reducing net GHG emissions through agricultural practices.
- Demonstrate competence in dimensional analysis.
- Describe the assumptions, boundaries and limitations of a life cycle model.
- Discuss the pros and cons of creating biofuels from different crops under different circumstances.

This lesson requires prior knowledge of energy units (J, kJ, MJ, GJ), and area units (particularly the hectare). Understanding of the causes of global climate change are helpful for the GHG portion. They should also be aware of reasons we are looking for alternative transportation fuels.

Standards

Next Generation Science Standards (2013)

Performance Expectations

Middle School:

- **MS-ETS1-1.** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

High School:

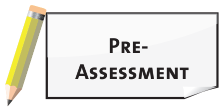
- **HS-PS1-7**. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
- **HS-LS2-7**. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.
- **HS-ESS3-2**. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.
- **HS-ESS3-3**. Create a computational simulation to illustrate the relationships among management of natural resources, the sustainability of human populations, and biodiversity.
- **HS-ESS3-4**. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.
- **HS-ETS1-1**. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- **HS-ETS1-4**. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to they problem.

NGSS Standards, Continued

Scientific and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking questions and defining problems Developing and using models Analyzing and interpreting data Using mathematics and computational thinking Engaging in argument from evidence	**PS1**: Matter and its interactions **LS2**: Ecosystems: Interactions, energy, and dynamics **ESS3**: Earth and human activity **ETS1**: Engineering Design	Systems and system models Energy and matter: Flows, cycles, and conservation

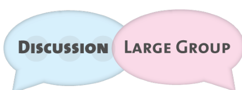
See Appendix for alignment with other standards.

Sequence:



Part 1. *Pre-Assessment & Background (pages 1-12) (1-2 50 min. periods)* Give the students the short pre-test on energy and/or greenhouse gases (GHG) and use this as a discussion starter. Depending upon the background knowledge of your students, you may spend more or less time with them in preparation for the activity. Students should be given an introduction to the steps involved in making ethanol from cellulosic sources and a basic description of the three feedstocks (plant types) they will be modeling. The *Introduction to Life Cycle Assessment (LCA) Modeling* PowerPoint provided in the supplementary materials folder of this package provides some images to help you introduce these concepts. There are more introductory activities on life cycle assessment suggested in Extensions and references provided in the Appendix of this document.

"Introduction to LCA Modeling Presentation"



Read *The Problem* worksheet together which introduces the context for the modeling activity. Next, introduce them to the model they will be using by projecting the blank LCA modeling spreadsheet on a screen, starting with the Energy sheet. Also hand out *Building a Model*, and accompanying discussion questions, which they will read and complete for homework. This reading provides a more detailed explanation of the steps necessary to create cellulosic ethanol and some of the variables that come into play when creating a quantitative model of the energy requirements for each step. When they return the next day, check for understanding of the reading and help clarify any necessary concepts before moving to the computers. Question 9, which addresses the difference in accounting for fossil fuels vs photosynthetic energy in the model, is particularly important to the results. An answer key is provided in this teacher document.

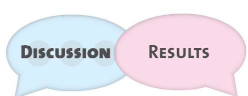
"LCA Modeling Spreadsheet"

Part 2. Running the initial model for Energy (pages 13-19), blank student LCA Modeling Spreadsheet) (50 min.) Use a projector to show students the blank LCA modeling spreadsheet for Energy. Show them the equations entered into some cells so they understand how the model works. Divide your class into teams of 3-6, and ask them to divide the work so that 1-2 people assess the net energy balance for each of the three feedstocks (diverse prairie, switchgrass or corn stover).

(Note: The spreadsheet provided already has formulae entered. If you would like students to determine how to make the calculations, unprotect the sheet and delete the formulae from the blank spreadsheets before giving them to the students. With pre-entered formulae, students can complete the spreadsheet very quickly.) Each group should use the *Student Handbook: Biofuels Life Cycle--Energy* to complete a spreadsheet for one biomass feedstock. If you or your students would like more information on the origin of these numbers, please refer to the *Technical Assumptions Guide* in the supplementary materials folder of this packet.

"Technical Assumptions Guide"

When they are done have each group complete *The LCA Bioenergy Model Analysis Questions for Energy* worksheet for their own data. They should share their data with the rest of their team and then answer the remaining questions on the page.



"Energy Model Answer Key"

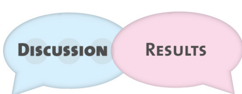
Bring the class together to compare results. Be sure that groups with the same feedstock have the same results for the initial run (pages 16T - 22T have a summary of answers, and the full *Energy Model Answer Key,* including comparative graphs, is found in the supplementary materials folder). Conduct a comparison of group results:

- Does producing liquid fuels from biomass provide a net energy gain? Where did that energy come from? (sun)
- What ethanol production steps require large energy inputs? Which do not?
- How does fuel production from biomass change if different crops are used?
- Which feedstock seems to be the best choice at this time?
- Where do they think it would be worth putting research efforts into finding efficiencies in the system? Where would we get the most benefit?

Part 3. Run alternative scenarios for energy. (pages 20-21) (LCA modeling spreadsheets) (50 min.),
By now, students should be challenging the model and asking *what if* questions such as, "What if we didn't have ideal growing conditions?" "What if I wanted to use fewer chemicals to reduce pollution or cut my costs?" Evaluate which questions can and cannot be answered with this particular

model. Return the groups to their spreadsheets using either the *Alternative Energy Scenarios* provided in this package or some of your own. Students should prepare a second summary of their new scenario and compare it to their initial one. They should calculate the percent change caused with their scenario so different teams can easily compare results (formula for percent change is on the *Analysis Questions* worksheet).

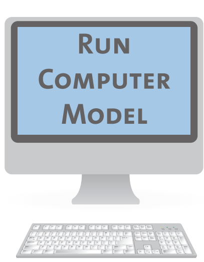
Differentiation note: students doing the alternative diverse prairie and corn stover scenarios provided in this package will need to calculate ratios before they enter data into the spreadsheet with the given scenarios.



"Energy Model Answer Key"

Bring the class together to discuss the new scenario results. Also show the corn grain ethanol data from the *Energy Model Answer Key* provided as a basis to compare what is happening today (pages 16T - 22T have a summary of answers). Farmers who grow corn have the option to sell the biomass to make ethanol from both corn grain and the stover. The graphs on each spreadsheet page in the *Model Answer Key* are linked to part of the spreadsheet and will change as you manipulate numbers allowing you to do quick visual comparisons.

Discuss the strengths and limitations of this model. Consider concerns other than energy, such as biodiversity, water use, greenhouse gas emissions, or farmer's profitability.

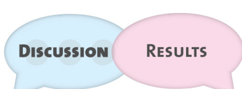


"LCA Modeling Spreadsheet"

Part 4. Run the initial model for Greenhouse Gases (GHG) (pages 22-31, blank student LCA Modeling Spreadsheet GHG page, access to internet required) (two 50 min. periods)

In light of the previous discussion, refocus the students' attention on running an LCA for GHG. Two pages of background information on GHG and LCA are provided in the student pages to introduce the measurement system used in this portion of the LCA and how GHG accounting is done by engineers working in this field. Read this together or assign it as homework before class. Make sure students understand the concept of kgCO_2eq before you move on.

They will use data from the energy model to start the GHG model and will then add data from an online source described in the instructions. The three goals of this section focus on the difference in GHG emissions between feedstocks, the effect of farming techniques used (till vs no till), and on understanding how the model itself was constructed. *The Student Handbook: Biofuels Life Cycle Assessment--Greenhouse Gas Model* takes students through the process of creating equations for this part of the model. Depending on your students' comfort with dimensional analysis (unit conversion) you may want to go through the first page as a class. It may also be useful to demonstrate how to work with the online US Cropland GHG Calculator they will use in this portion of the activity. You could work through the switchgrass model together and send students to the computer to work on diverse prairie and the two corn stover scenarios. Once students understand how to use the online and GHG excel model, they will be able to calculate results in 10-15 minutes. Students should record their answers on the *The LCA Bioenergy Model Analysis Questions for GHG* worksheet.



Bring the class together to discuss the results of this model. Discuss the benefits and limitations of this model and its link to the energy model data they collected previously. Decide if you would like them to run alternative scenarios for GHG and/or energy at this time. Use the *Discussion Questions* handout as a guide for analyzing the overall results.

Part 5. Final Assessment (page 32) (30+ min.)
Hand out the *Final Assessment* worksheet. Ask students to write an essay considering why cellulosic ethanol is being considered as a transportation fuel and an explanation of which feedstock(s) they believe is (are) the best choice. The second portion should be supported with both data from the activity, and specific information on what assumptions they are making about growing and processing methods in the model (fertilize or not? Remove 30 or 70% of stover?, etc). They can discuss these essays in groups, or as a class.

Upon completion of the the full activity students should be able to discuss the following questions:

- What are the steps of cellulosic energy production?
- What forms of energy are used at each step?
- What are the different GHG emissions given off during the different production steps in the creation of cellulosic ethanol and by what processes are these GHGs emitted?
- How do land use practices affect greenhouse gas exchange between the soil and the atmosphere in the production of corn stover?
- How do scientists derive the formulas found in a quantitative model?
- What are the benefits and limitations of using quantitative models in understanding a system?

Extensions

1. Create graphs comparing scenarios or comparing feedstocks (Sample graphs are provided in the teacher answer key spreadsheet).
2. Research the latest numbers in the literature for various parts of the model and revise your numbers.
3. Use the Life Cycle Assessment of Biofuels 101 activity (available from the GLBRC website) as an introduction to this activity. This includes video interviews with scientists who conduct LCA of biofuels (also available directly in the Multimedia section of the GLBRC education website).
4. Alternatively, the supplementary materials in this package contain an activity called *Building a Biofuels System-flow Diagram* which asks students to build a flow diagram of the biofuels process and then determine the fossil fuel inputs within the provided system. Once they understand the basic system, they work their way backwards to expand the system boundaries to show additional inputs (such as adding the source material for steel to build a tractor) to make a full "cradle to grave" diagram.

"Building a Biofuels System-flow Diagram"

Pre-Test: Biofuels Life Cycle Analysis (Energy)

Pre-Assessment

Answer the following questions as either true or false based on your ideas before starting this activity. If false, please explain what is incorrect about the statement.

1. Most of the gasoline used in the United States is produced from oil that is imported from other countries.

   True (we import over half of our petroleum from foreign countries).

2. Ethanol is a liquid fuel that can be mixed with gasoline and used in cars with normal engines.

   True, E10, which is 10% ethanol, 90% gasoline works in normal gasoline engines. False, if you use E85, you need a special engine. Ethanol does not work in diesel engines.

3. Most of the ethanol used in the United States is made from corn grain.

   True, we import some ethanol made from sugar cane and are just beginning to make ethanol from cellulosic sources.

4. Ethanol cannot be made from plant material such as grasses or wood.

   False. Ethanol can be made from any plant material. We're just more efficient at making ethanol from simple sugars and starches.

5. Corn grain, corn stalks, and grasses all contain considerable amounts of stored chemical energy.

   True. Plants store solar energy from photosynthesis in carbohydrates in the plant (starch, sugar, cellulose, hemicellulose).

6. It takes more fossil fuel energy to make ethanol than you get from the ethanol itself.

   False. Using modern methods, we can create a net energy gain making ethanol from corn grain, switchgrass, corn stover and other feedstocks.

Please answer the following questions to the best of your ability.

7. What are some of the ways in which growing and processing crops for fuel would require inputs of energy?

   Planting, making and adding fertilizer, harvesting, transporting biomass, pretreatment, enzyme, fermentation heat, distillation.

8. How could we improve the efficiency of the processes of growing crops and converting them to fuel?

   Choose perennials that only need to be planted once every 10 years, reduce distance feedstocks need to be transported from the field to the refinery, capture excess heat when producing electricity to heat fermenters, create more efficient vehicle engines, etc.

Pre-Assessment

Pre-Test: Biofuels Life Cycle Analysis (GHGs)

Answer the following questions as either true or false based on your ideas before starting this activity. If false, please explain what is incorrect about the statement.

1. Gasoline used by automobiles in the United States is a renewable resource.

   False, gasoline is refined from crude oil, a fossil fuel that forms over millions of years. The rate at which we use gasoline is many orders of magnitude higher that the rate crude oil is being formed geologically. There is also a limited supply of oil on the Earth.

2. Ethanol is a fuel additive to gasoline and represents a potentially renewable source of energy.

   True. Ethanol was first used as an oxygenate to make gasoline burn more completely with fewer emissions.

3. Ethanol can only be produced from corn grain.

   False, sugar cane is an excellent source of biomass used for creating ethanol. Ethanol can also be created from any part of the plant that contains carbohydrates. Improvements in current cellulosic ethanol technology could create a large source of biomass for creating ethanol.

4. Carbon dioxide is the only GHG contributing to global climate change.

   False, there are several GHGs that trap heat energy radiated from the Earth. The five other main GHGs are water vapor, methane, nitrous oxide, tropospheric ozone, and HFCs and CFCs.

5. The process of photosynthesis adds CO_2 to the atmosphere while the processes of decomposition and respiration removes CO_2 from the atmosphere.

   False, the opposite is true. Photosynthesis uses carbon dioxide from the atmosphere and converts it to glucose and oxygen gas. Respiration and decomposition convert sugars back into carbon dioxide and water.

6. Agricultural practices such as plowing and fertilizing have little impact on GHGs emitted from soils.

   False, adding nitrogen fertilizers to soils causes bacteria to form more nitrous oxide, which outgases from the soil to the atmosphere. Also, heavy tillage of fields increases decomposition rates, releasing more carbon dioxide into the atmosphere.

7. Scientific models represent approximations of physical, chemical, and/or biological systems based on fairly well understood scientific principles.

   True. Although models can change as we learn more.

8. List as many ways as possible that fossil or anthropogenic GHGs could be emitted during the growing and processing of crops grown for biofuel.

   Energy is needed to create chemicals, fertilizers, fuels, and seed. This energy often comes from burning fossil fuels which releases carbon dioxide. The combustion of diesel from planting, harvesting, and transporting crops releases carbon dioxide. Nitrous oxide outgases from the soil due to nitrogen fertilizer use. Methane also can outgas from soils if the field is flooded for a significant amount of time.

Background

Building a Model Discussion Questions

1. 240 hectares is equivalent to roughly one square mile. Use a map to locate an area near you that is approximately the same size. Location: ______________________ How big is the location you found? How is the land used?

   Answers will vary.

2. Why are the three crops given different amounts of fertilizer? How are the assumptions in the model different for the three crops?

   The crops are grown with different strategies. Our goal for diverse prairie is to grow well-adapted, native plants with few chemical inputs. This is grown as a supplement perhaps to a food crop on a part of the land where the soil is poor and the food crop won't grow well. For switchgrass we are growing this as a primary crop and trying to produce as much biomass as possible, requiring fertilizer inputs. Corn stover is a secondary crop after grain is harvested so most of the fertilizer applied was with grain in mind, not the stover.

3. Why does corn stover require additional fertilizer if some is already applied to grow the corn grain taken from the same field?

   Corn stover contains nutrients, such as nitrogen and phosphorus, that would normally be returned to the soil as the corn stover decomposes. When some of the corn stover is removed, the nutrients in the material that is removed are not returned to the soil and need to be replaced.

4. What potential values does corn stover have to a farmer other than harvesting it for bioenergy?

   Prevent erosion, return nutrients to soil, animal bedding, made into silage for animal feed.

5. What factors affect crop yield? Why might these factors, for example a drought, affect one crop differently from another?

   Crop yield could be affected by amount of rainfall, timing of rainfall, soil type, plant disease, insect herbivory, temperatures, timing of frost, amount of fertilizer and other factors. Deep roots may help perennials weather droughts, while corn, with its shallow roots will not survive without irrigation. Crops are also often affected by timing of a drought—for example when flowering vs. fruiting occurs. In corn, for example, early season rain may lead to large amounts of corn stover but little corn grain whereas later rainfall may lead to the opposite. High switchgrass yields depend on early season rainfall. See "Technical Assumptions" in supplementary materials for further discussion associated with the Alternative Scenarios.

6. Would the energy inputs for the diverse prairie model change if the prairie grasses grew better in one year compared to another? Explain your answer.

   Yes- it takes more energy to harvest and transport a higher yield than a smaller yield. Energy for processing is counted per kg, so with a higher yield, more energy would be required overall to convert to fuel.

7. What is a conversion rate?

   A conversion rate gives the amount of ethanol than can be produced from a certain amount of biomass material. In this activity, the conversion rate is given as the number of liters of ethanol that could be produced from each kilogram of biomass. Conversion rates can be used to estimate how much ethanol would be produced from a given area of cropland if the biomass yield is known.

8. Why do you think the conversion rate for corn grain is higher than the rate for cellulosic feedstocks, like corn stover?

   Corn grain contains a high percentage of readily accessible, easily *fermentable starch, unlike corn stover. With currently technologies, we are unable to access all of the available carbohydrates (cellulose and hemicellulose) and efficiently convert it to ethanol. (As pretreatment and hydrolysis technologies improve, conversion rates will rise).*

9. How are fossil fuels and energy inputs from plants accounted for differently in this model? Why do you think that decision was made?

Fossil fuels add to the overall energy inputs in the model. Solar energy inputs (photosynthesis) provide "free energy" and are part of the energy output in the model (the ethanol). If we burn biomass during processing, such as during refining, to produce heat and electricity, it is not accounted for as an input. This part of the biomass cannot become ethanol, but the stored energy can serve as a substitute for other energy inputs. This type of accounting favors non-polluting renewable energy sources. The US Government is trying to reduce greenhouse gas emissions from transportation fuel production. Burning fossil fuels, like coal or petroleum, puts ancient stored carbon back into the atmosphere. By burning plant material that quickly recycles and re-sequesters the CO_2 *emitted during burning, there is no net carbon dioxide emissions gain in the atmosphere.*

10. What is an enzyme? Do enzymes convert the entire plant into sugars to be converted to ethanol? Explain.

An enzyme is a specific molecule that helps certain chemical reactions happen more easily, a catalyst. Enzymes are used in biomass processing to break cellulose into sugar molecules that can be converted to ethanol. Not all plant material can be broken into sugars that are able to be processed into ethanol. Only cellulose and hemicellulose are carbohydrates that can be converted. Lignin cannot. This remaining plant material (residue) can still be used, though, and, as described in the last question, can be burned to generate heat and electricity.

11. Does separating ethanol from the other results of processing take a small or large amount of energy? Explain your answer.

Separating ethanol requires a lot of energy, but the energy can be obtained by burning biomass residue so it does not necessarily require large external energy inputs accounted for in this model. Look at the corn grain *ethanol spreadsheet to get actual numbers for comparison.*

12. List two other products that can be produced at the same time ethanol is made. How would these products normally be produced?

Animal protein and electricity are end products that can be produced during the ethanol production process. Animal protein might normally be produced by growing crops that have a high protein value. Growing and processing these crops requires additional fossil fuel inputs. Electricity in the United States is mostly generated by burning fossil fuels to produce heat to drive generators, although some electricity is generated using nuclear energy, hydroelectric dams, or other sources. Fossil fuels, such as coal, come from ancient plant sources, whereas biomass crops, are regenerated on a short time scale. If our energy to produce these co-products is more efficient and comes from renewable energy sources we come out ahead.

LCA Bioenergy Model Analysis Questions for *Energy*

Use your calculations from the LCA Energy model to answer the following questions.

1. Fill in the following table with the information from the model.

Feed Stock	Fuel (MJ)	Liters of fuel per ha	Biomass Energy (MJ)	Percent to fuel	% to fuel + coproduct	Net Energy Gain per ha (MJ/ha)
Diverse Prairie	*4987795*	*984*	*17138400*	*29.1*	*31.7*	*18367*
Switchgrass	*14179200*	*2800*	*44889600*	*31.6*	*34.5*	*46877*
Corn Stover	*7528396*	*1487*	*25185600*	*29.9*	*36.4*	*31624*

2. Identify the most energy intensive process associated with **crop production**.

Diverse Prairie	*harvesting*
Switchgrass	*chemical application*
Corn Stover	*harvesting*

3. For each process identified from #2 identify the source(s) of energy (example: coal is combusted to produce electricity).

Diverse Prairie	*Diesel for tractors, machinery*
Switchgrass	*Coal, Natural Gas to make fertilizer, Diesel for tractors to apply fertilizer*
Corn Stover	*Diesel for tractors, machinery*

4. Identify the most energy intensive process associated with **fuel production**.

Diverse Prairie	*Hydrolysis/fermentation*
Switchgrass	*Hydrolysis/fermentation*
Corn Stover	*Hydrolysis/fermentation*

5. Using the table in question 1, identify the feedstock that:
    a. Produces the most biomass energy: *switchgrass*
    b. Has the greatest percent of biomass converted to ethanol (with and without coproduct): *corn stover (with), switchgrass (without)*
    c. Has the largest net energy gain per hectare: *switchgrass*

6. How is net energy gain determined? Write the equation and explain what this means in your own words.
= B31 + (D26) – B29, meaning total energy in ethanol plus the energy value saved by avoiding production of the coproduct another way minus the fossil energy used throughout the process of crop and fuel production. Or, the energy gained from capturing solar energy as chemical energy in plants minus the fossil fuel inputs needed to create ethanol.

7. Identify the most efficient feedstock at producing ethanol according to the model. Provide data to support your answer.
Varies, switchgrass comes out best in the initial model for most values. However, if you show data for corn grain included in the teacher instructions, students may decide that they want to add corn grain and corn stover values, making it more efficient.

8. What assumptions were made in this model? Is this realistic year after year? Make a change to the starting values and return to the model to see what effect it has on the outcome. (Note: if you need to change formulae in the model, you will need to unprotect the sheet first. This function is in the drop-down menu bar "Tools > Protection > Unprotect Sheet". Reprotect the sheet when you are done.)

    Your hypothesis and results: *answers will vary*

9. Calculate the percent change in the starting and ending values so you can compare your results to other class members (the whole class should choose the same ending value to compare, for example percent change in net energy).

$$\text{Percent change} = \frac{\text{new value - old value}}{\text{old value}} \times 100$$

answers will vary

Results summary for all energy scenarios:

Base Results for Diverse Prairie:

SUMMARY	
Total Energy Input (MJ)	*1,024,699*
Total Ethanol Produced (liters)	*236,232*
Total Fuel Energy (MJ)	*4,984,495*
Fuel + Coproduct Energy (MJ)	*5,432,873*
Net Energy Gain (MJ)	*4,408,174*
Net Energy Gain per ha (MJ/ha)	*18,367*
liters of fuel per ha (liters/ha)	*984*

Conversion Results for Diverse Prairie:

CONVERSION	
Biomass Energy (MJ)	*17,138,400*
Fuel (MJ)	*4,984,495*
Percent to Fuel	*29.1*
Fuel + Coproduct Energy (MJ)	*5,432,873*
% Fuel + Co Products	*31.7*

Base Results for Corn Stover:

SUMMARY	
Total Energy Input (MJ)	*1,575,629*
Total Ethanol Produced (liters)	*356,796*
Total Fuel Energy (MJ)	*7,528,396*
Fuel + Coproduct Energy (MJ)	*9,165,460*
Net Energy Gain (MJ)	*7,589,831*
Net Energy Gain per ha (MJ/ha)	*31,624*
liters of fuel per ha (liters/ha)	*1,487*

Conversion Results for Corn Stover:

CONVERSION	
Biomass Energy (MJ)	*25,185,600*
Fuel (MJ)	*7,528,396*
Percent to Fuel	*29.9*
Fuel + Coproduct Energy (MJ)	*9,165,460*
% Fuel + Co Products	*36.4*

Base Results for Switchgrass:

SUMMARY	
Total Energy Input (MJ)	*4,229,664*
Total Ethanol Produced (liters)	*672,000*
Total Fuel Energy (MJ)	*14,179,200*
Fuel + Coproduct Energy (MJ)	*18,829,440*
Net Energy Gain (MJ)	*14,599,776*
Net Energy Gain per ha (MJ/ha)	*60,832*
liters of fuel per ha (liters/ha)	*2,800*

Conversion Results for Switchgrass:

CONVERSION	
Biomass Energy (MJ)	*44,889,600*
Fuel (MJ)	*14,179,200*
Percent to Fuel	*31.6*
Fuel + Coproduct Energy (MJ)	*18,829,440*
% Fuel + Co Products	*41.9*

Base Results for Corn Grain Ethanol:

SUMMARY	
Total Energy Input (MJ)	*13,117,920*
Total Ethanol Produced (liters)	*962,359*
Total Fuel Energy (MJ)	*20,305,779*
Fuel + Coproduct Energy (MJ)	*22,593,392*
Net Energy Gain (MJ)	*9,475,472*
Net Energy Gain per ha (MJ/ha)	*39,481*
liters of fuel per ha (liters/ha)	*4,010*

Conversion Results for Corn Grain Ethanol:

CONVERSION	
Biomass Energy (MJ)	*40,423,680*
Fuel (MJ)	*20,305,779*
Percent to Fuel	*50.2*
Fuel + Coproduct Energy (MJ)	*22,593,392*
% Fuel + Co Products	*55.9*

Results for alternative scenarios:

Diverse Prairie, 30% yield increase

SUMMARY	
Total Energy Input (MJ)	*1,178,389*
Total Ethanol Produced (liters)	*307,102*
Total Fuel Energy (MJ)	*6,479,844*
Fuel + Coproduct Energy (MJ)	*7,062,735*
Net Energy Gain (MJ)	*5,884,346*
Net Energy Gain per ha (MJ/ha)	*24,518*
liters of fuel per ha (liters/ha)	*1,280*

Diverse Prairie, dry conditions reduced yield

SUMMARY	
Total Energy Input (MJ)	*937,104*
Total Ethanol Produced (liters)	*195,840*
Total Fuel Energy (MJ)	*4,132,224*
Fuel + Coproduct Energy (MJ)	*4,503,936*
Net Energy Gain (MJ)	*3,566,832*
Net Energy Gain per ha (MJ/ha)	*14,862*
liters of fuel per ha (liters/ha)	*816*

Switchgrass, Douglas, year 3

SUMMARY	
Total Energy Input (MJ)	*3,260,808*
Total Ethanol Produced (liters)	*234,000*
Total Fuel Energy (MJ)	*4,937,400*
Fuel + Coproduct Energy (MJ)	*6,556,680*
Net Energy Gain (MJ)	*3,295,872*
Net Energy Gain per ha (MJ/ha)	*13,733*
liters of fuel per ha (liters/ha)	*975*

Switchgrass, Douglas, year 4

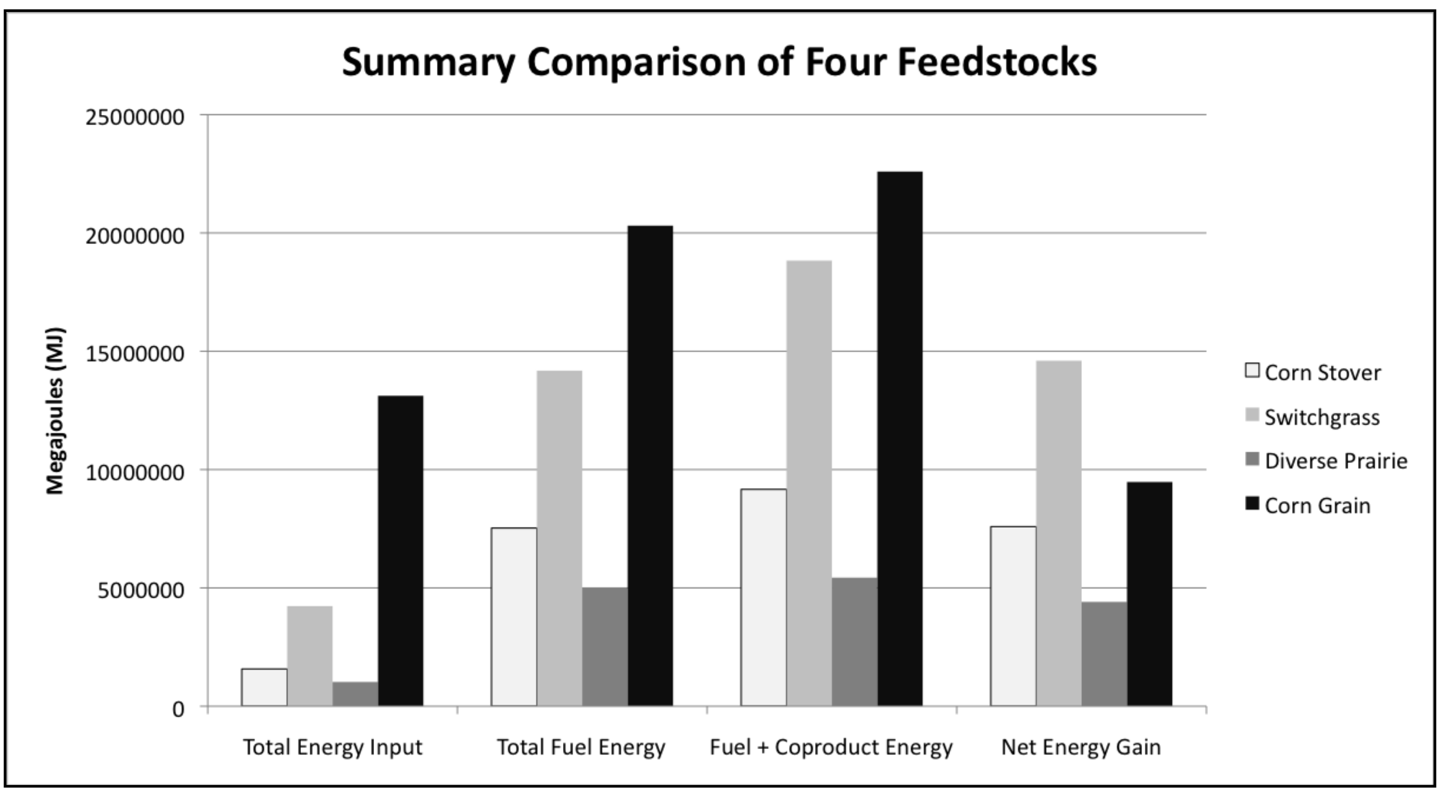
SUMMARY	
Total Energy Input (MJ)	*3,911,136*
Total Ethanol Produced (liters)	*528,000*
Total Fuel Energy (MJ)	*11,140,800*
Fuel + Coproduct Energy (MJ)	*14,794,560*
Net Energy Gain (MJ)	*10,883,424*
Net Energy Gain per ha (MJ/ha)	*45,348*
liters of fuel per ha (liters/ha)	*2,200*

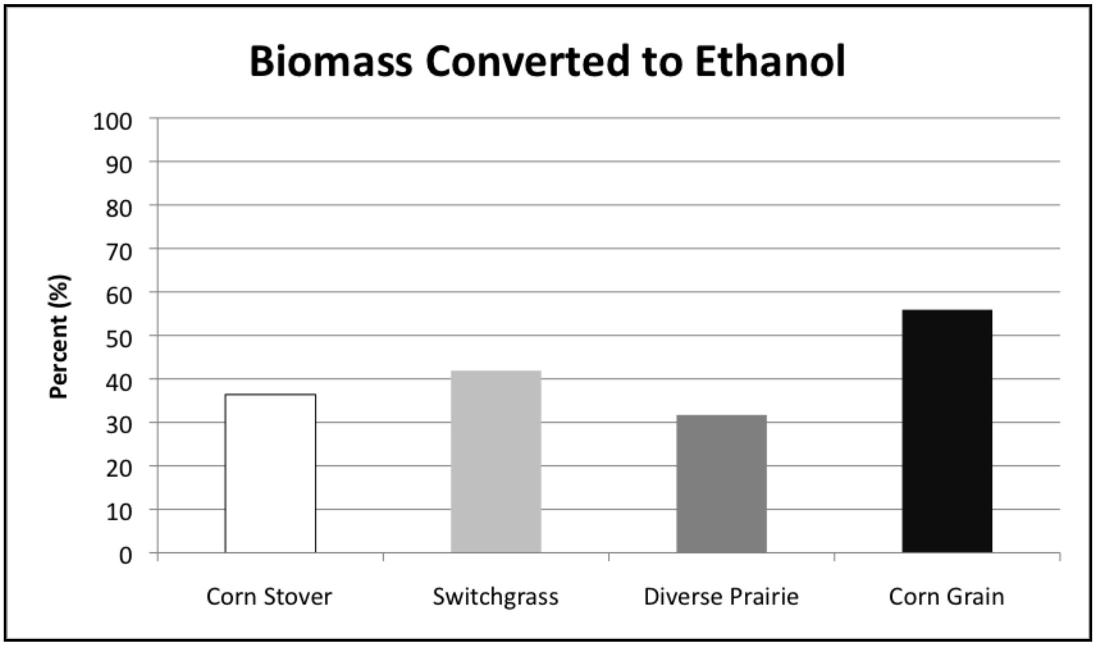
Corn Stover, 50% removal

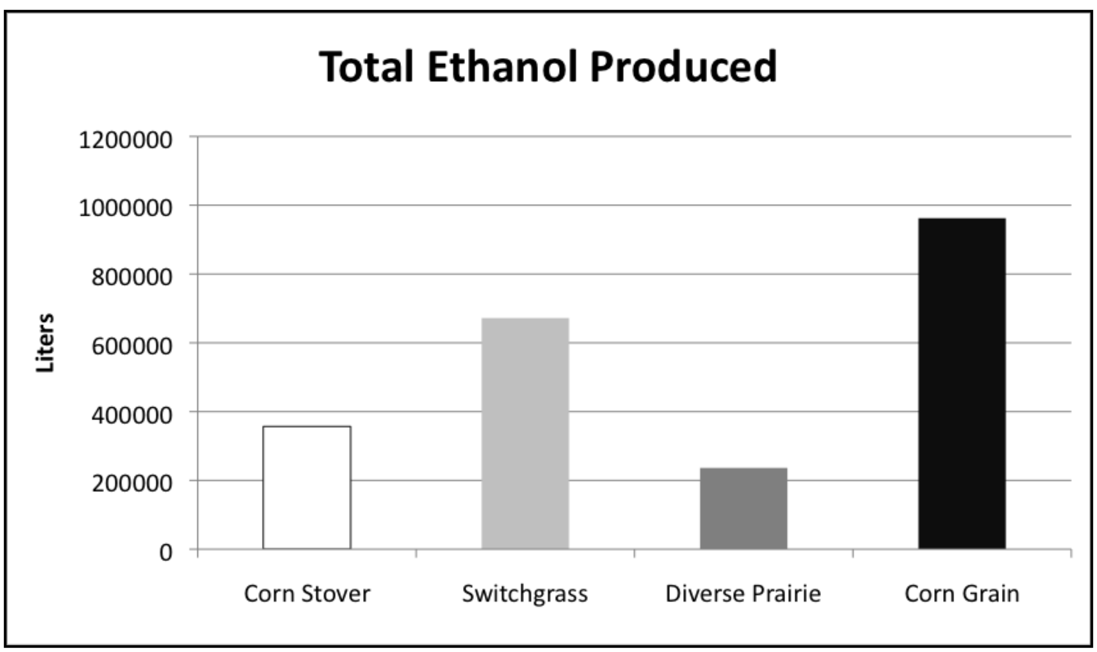
SUMMARY	
Total Energy Input (MJ)	*1,276,454*
Total Ethanol Produced (liters)	*254,898*
Total Fuel Energy (MJ)	*5,378,348*
Fuel + Coproduct Energy (MJ)	*6,547,880*
Net Energy Gain (MJ)	*5,271,425*
Net Energy Gain per ha (MJ/ha)	*21,964*
liters of fuel per ha (liters/ha)	*1,062*

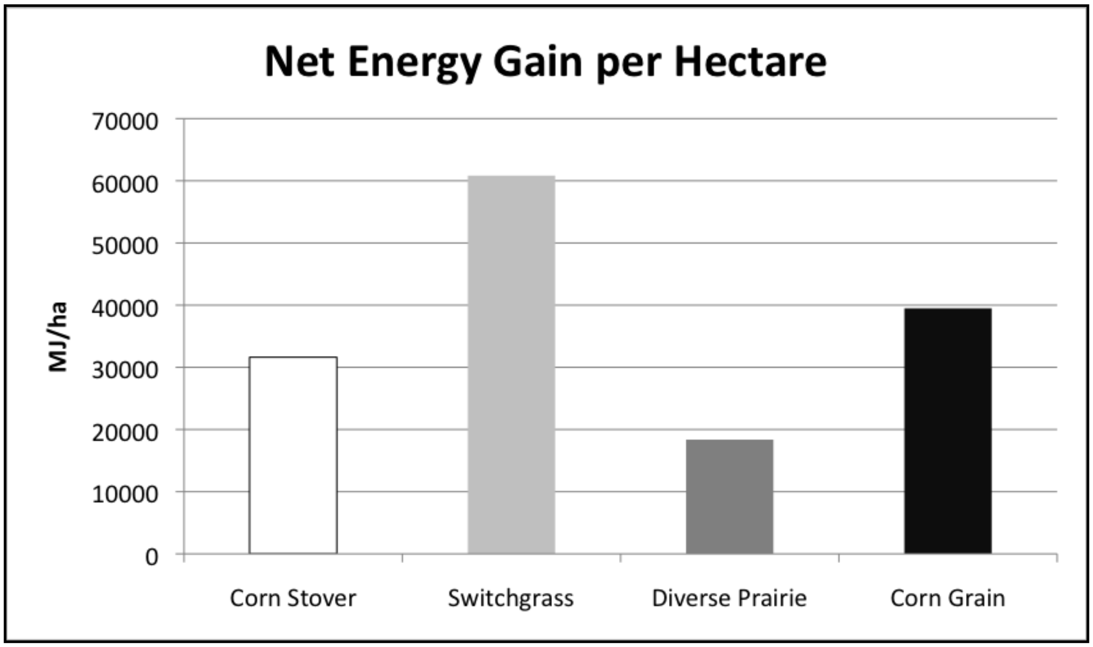
Corn Stover, dry conditions reduced yield

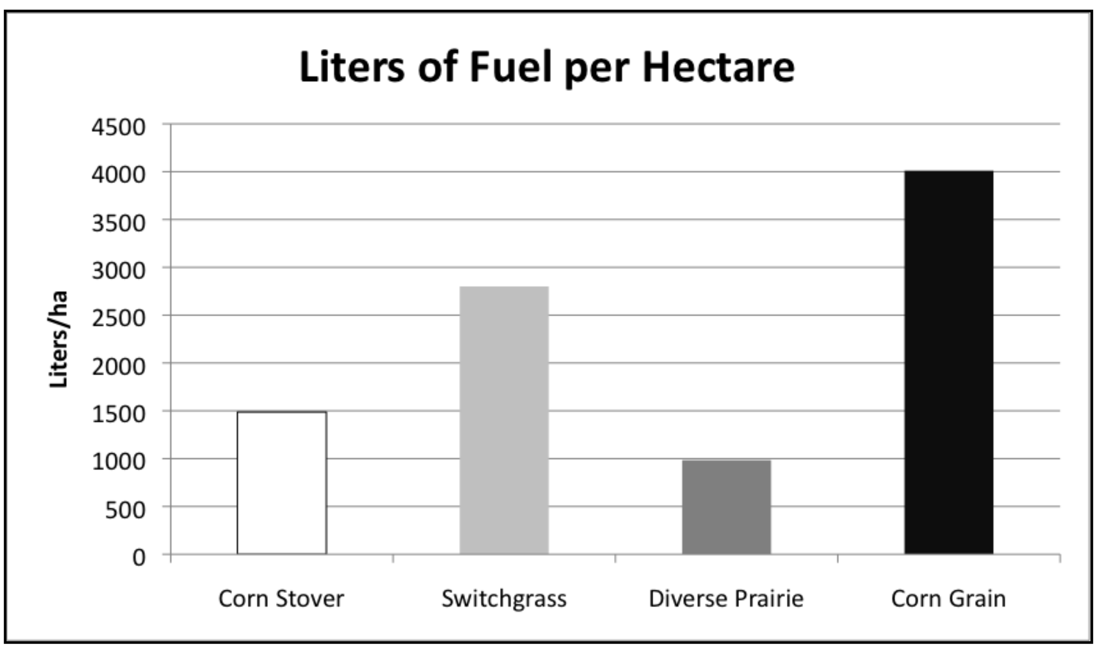
SUMMARY	
Total Energy Input (MJ)	*1,409,702*
Total Ethanol Produced (liters)	*265,608*
Total Fuel Energy (MJ)	*5,604,329*
Fuel + Coproduct Energy (MJ)	*6,823,001*
Net Energy Gain (MJ)	*5,413,298*
Net Energy Gain per ha (MJ/ha)	*22,555*
liters of fuel per ha (liters/ha)	*1,107*




Biomass Converted to Ethanol
Percent (%)
100
90
80
70
60
50
40
30
20
10
0
Corn Stover
Switchgrass
Diverse Prairie
Corn Grain


Total Ethanol Produced
Liters
1200000
1000000
800000
600000
400000
200000
0
Corn Stover
Switchgrass
Diverse Prairie
Corn Grain


Net Energy Gain per Hectare
MJ/ha
70000
60000
50000
40000
30000
20000
10000
0
Corn Stover
Switchgrass
Diverse Prairie
Corn Grain


Liters of Fuel per Hectare
Liters/ha
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Corn Stover
Switchgrass
Diverse Prairie
Corn Grain

Student Handbook: Greenhouse Gases

Answers given use Dane County, WI with the US Cropland Calculator.

4. Write down what should be calculated in cells cell D27 and E 27, including the final units needed.

   Cell D27 *soil outgassing for cornstover in kg/CO_2eq/ha*

   Cell E 27 *soil outgassing for cornstover in kg/CO_2eq/ha*

10. After you have entered the correct values, look at the greenhouse gas costs on the right side of the page. We are using this model to extract only values for SOIL. Write down the Annual Average SOIL value as well as the units.

    Annual Average Soil value: *0.37 MtCO_2eq/ha/yr*

12. Setting up the equation...

$$\left(\frac{0.37\ \cancel{\text{Mt}}\ \text{CO}_2\text{eq/ha/yr}}{10\ \cancel{\text{Mt SG/yr}}}\right)\left(\frac{1000\ \text{kg}\cancel{\text{CO}_2}}{1\ \cancel{\text{MtCO}_2}}\right)\left(\frac{1\ \cancel{\text{MtSG}}}{1000\ \text{kgSG}}\right) = \frac{0.037\ \text{kg CO}_2\text{eq/ha/yr}}{\text{kgSG}}$$

13. Enter this equation into cell E27 as: *D3 * 0.037*

Scenario 1 for Corn Stover: Conventional Tillage

3. Once you have done this look at the average value for MtCO_2eq under Soil.

   Annual Average Soil CO_2 equivalents = *0.09 MtCO_2eq/ha/yr*

4. Silage is composed of approximately 50% grain by weight. Because our LCA model is only for stover, not the grain, we must reduce the crop yield value in the US Cropland model by 50%. Look at the "yield" in the yellow column. Calculate 50% of that annual value and write it in the blank below.

   Yield _(42.5 Mt/ha) 50% = 21.3_ MT/ha

5. Use the same conversion method you did for switchgrass to create the formula for Cell D27 $\frac{0.09}{21.3}$

   = D2 * 0.0042

Scenario 2 for corn stover: No till

3. Follow the same steps:

   Annual Average Soil CO_2 equivalents = _0.01 $MtCO_2eq/ha/yr$_

   Yield = _21.3_ MT/ha

   Formula for D27 = D2 * 0.000486

LCA Bioenergy Model Analysis Questions for *Greenhouse Gases*

Use your calculations from the LCA GHG model to answer the following questions.

1. Fill in the following table with the information from the model.
   Answers given use Dane County, WI with the US Cropland Calculator. Only diverse prairie will be the same for all locations.

Feed Stock	Total GHGs emitted by the farm ($kgCO_2eq$)	Net GHG emissions per liter of ethanol ($kgCO_2eq$/L EtOH)	Net GHG emissions per liter of ethanol without electricity coproduct ($kgCO_2eq$/L EtOH)
Diverse Prairie	*-1,482,866*	*-6.04603*	*0.6682*
Switchgrass	*-3,648,002*	*-5.42857*	*1.2857*
Corn Stover (conventional tillage)	*-2,035,641*	*-5.70534*	*1.0089*
Corn Stover (no-till)	*-2,040,863*	*-5.71997*	*0.9943*

2. Identify the process that produces the greatest amount of GHG equivalents during **crop production**.

Diverse Prairie	*Transportation combustion*
Switchgrass	*Soil outgassing N_2O*
Corn Stover	*Transportation combustion*

3. For each process identified from #2 identify the source(s) of GHGs (example: coal is combusted and produces CO_2).

Diverse Prairie	*Diesel combustion – CO_2*
Switchgrass	*N fertilizer application turns into NO_2*
Corn Stover	*Diesel combustion – CO_2*

4. Identify the process that produces the greatest amount of GHG equivalents during **fuel production**.

Diverse Prairie	*LPG–production for pretreatment*
Switchgrass	*LPG–production for pretreatment*

Corn Stover	*LPG-production for pretreatment*

5. Using the table in question 1, identify the feedstock that:
   a. offsets the most GHGs on a per liter of ethanol during a typical growing season: *diverse prairie*
   b. offsets the most GHGs total for the farm: *switchgrass*

This is a good place to discuss the difference between these two measurements. Although prairie looks better on a per liter basis, switchgrass is better overall because of its high yield.

6. Look at the land management practices of conventional and no-till agriculture for corn stover to determine which practice reduces GHG emission the most. Explain the reason why this management technique reduces GHG emissions more than the other.

No till reduces GHG the most. Tilling mixes plant residues and oxygen into the soil, speeding up the rate of decomposition of plant residues by soil microbes. Decomposition release CO_2 into the atmosphere. No till planting causes little soil disturbance and therefore little GHG release.

7. Although the difference between conventional and no-till agriculture may appear small, in the future payments could be paid to farmers who offset GHG emissions through the production of biofuels. As the president of your farm cooperative identify two ways the farmers you represent could reduce their GHG emissions without compromising yield. How might this increase profits? (note: in January 2011 carbon credits in Europe sold for $20/ metric ton CO_2eq*)

To reduce GHG: 1. Use no till vs conventional till agriculture. 2. Reduce fertilizer use. 3. Increase fuel efficiency of farm machinery. 4. Create a one-pass harvesting system instead of the two-pass system assumed in the model (see technical assumptions for more details). 5. Other options are possible.

Profits: Assuming the answers in #1, approximately 5000 kgCO_2 eq are saved using no till. This is 5 metric tons or $100 per farmer. Given that this is a cooperative, those savings could be pooled for use towards a common goal/purpose.

* Source: http://www.bloomberg.com/news/2011-01-10/un-carbon-credit-premiums-for-2011-evaporates-as-supply-of-offsets-advance.html

Discussion Results

Discussion Questions: GHGs

1. Explain the concept of greenhouse gas carbon dioxide equivalents ($kgCO_2eq$ in our model).

   The GHG warming potentials of all greenhouse gases have been set relative to carbon dioxide. This way we can use one measure to determine the total effect of multiple gases that may come from one production system compared to another one.

2. How do your results compare to the current liquid transportation fuels below? (note that different researchers determined the system boundaries and assumptions behind these numbers)
   - Gasoline= 2.9 $kgCO_2eq/L$
   - Corn grain ethanol (in WI) = 1.04 $kgCO_2eq/L$, 0.9 $kgCO_2eq/L$ with co-product

   Results are more favorable for all cellulosic fuels, especially when co-products are considered. Switchgrass is the only exception w/o co-product.

3. With your limited experience working with and creating a small portion of a model:
   a. Discuss the benefits of using models as predictors of the real world by reflecting on your experiences using the Energy and GHG models

   Allows us to try scenarios at little or no expense to us in terms of time, money or the environment; uses best available data to make predictions; allows us to consider the logical system boudaries for comparison; allows for side by side comparisons.

   b. Discuss the limitations of using models as predictors of the real world. How might you modify this model to make it better?

The real world is variable and more unpredicatable than this model allows. Natural systems are more complex than we may be able to model--unintended consequences are likely to arise in the real world. This model is limited to only GHG and energy, other factors such as economics, social issues are also important to making decisions.

To improve the model, increase the number of links between cells (ie. connect fertilizer use and yield). Find data specific to our situation, not generalized numbers from the United States or Midwest. Find the latest data on processing techniques and upgrade categories.

Appendix:

Area Units for Comparison:

Area Unit	Length (m)	Width (m)	Area (m2)
hectare (ha)	100	100	10,000
acre	63.6	63.6	4,047
square mile	1609	1609	2,590,000
American football	91.4 (300 ft)	48.8 (160 ft)	4,460
International A Soccer	105	68	7.140

One hectare = 2.57 acres

Video Resources:

What is cellulose and how is it used to make ethanol? (Also accessible from the educational materials page on our website.) - A basic, three-minute video that explains the physical properties of cellulose and how it is broken down into smaller molecules of glucose, which can be fermented into ethanol.
http://www.vimeo.com/10378252

Converting Biomass to Liquid Fuels - Excellent 5 minute summary of difference between corn and cellulosic ethanol and process currently used to make cellulosic ethanol. Be aware the process discussed here is evolving and may vary from other information sources you read.
http://www.nrel.gov/learning/re_biofuels.html

Fields of Energy - From the Minnesota Department of Agriculture, a free DVD with student hosts. Two short segments show how corn ethanol is made and the research into cellulosic ethanol. These two segments are currently available online.
http://www.mda.state.mn.us/kids/

Life Cycle of Fuels - An eight-minute video that serves as a primer to some of the climate change impacts and sustainability issues associated with producing and using biofuels and fossil fuels. *https://vimeo.com/166055834*

Text Resources:

Why is it so difficult to make cellulosic ethanol? GLBRC. 2008. - A short handout that discusses the difficulties in creating cellulosic ethanol. Appropriate for high school and college students. *http://glbrc.org/sites/default/files/Cellulosic_Ethanol.pdf*

Biofuels: An important part of a low-carbon diet. November 2007. P Monahan, Union of Concerned Scientists "Catalyst" publication. Vol 7(2). - Nice overview comparing the carbon contributions of gasoline, ethanol and other possible transportation fuels. Introduces the concept of a life cycle assessment.
http://www.ucsusa.org/clean-vehicles/better-biofuels/biofuels-low-carbon-diet#.V1GS_ucrKX0

Growing Fuel: the Wrong Way, the Right Way. National Geographic. October 2007 212(4) pg 38-59. - Provides an overview of different ways to make ethanol and provides some life cycle assessment data. Be aware the results of life cycle analyses varies by methodology. The data provided in this article is older than that from the classroom activity, but the fundamentals still apply.
http://ngm.nationalgeographic.com/2007/10/biofuels/biofuels-text

"Life cycle assessment." Encyclopedia of Earth. 2010. Eds. Cutler J. Cleveland (Washington, D.C.Finnveden, G. (Lead Author);and A. Bledzki (Topic Editor), Environmental Information Coalition, National Council for Science and the Environment). First published in the Encyclopedia of Earth - A good overview description for educators or undergraduates of a life cycle assessment, including the phases and uses.
http://www.eoearth.org/article/Life_cycle_assessment

A complete set of references used to create the model can be found in the Technical Assumptions file in the Supplementary Materials folder.

Standards:

AAAS PROJECT 2061 (1993):

3C - The Nature of Technology: Issues in Technology
4D - The Physical Setting: Structure and Matter
4E - The Physical Setting: Energy Transformations
5E - The Living Environment: Flow of Matter and Energy
8A - The Designed World: Agriculture
8C - The Designed World: Energy Sources and Use
11A - Common Themes: Systems
11B - Common Themes: Models

Activity developed by James Reichling of Madison East High School, Madison, WI (energy portion) and Scott Kloehn of Sun Prairie High School, Sun Prairie, WI (GHG portion) with Dr. Paul Meier and Julie Sinistore at University of Wisconsin-Madison with funding and other support from the Great Lakes Bioenergy Research Center

GREAT LAKES BIOENERGY RESEARCH CENTER

DOE Bioenergy Research Centers

www.glbrc.org/education
education@glbrc.wisc.edu

U.S. DEPARTMENT OF ENERGY