# Table of Contents-Student Handouts

Name________________________________ Date______________ Hour_______

# Pre-Test: Biofuels Life Cycle Analysis (Energy)

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.

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

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

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

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

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

*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?

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

Name__________________________________ Date_______________ Hour_______

# 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.

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

3. Ethanol can only be produced from corn grain.

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

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

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

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

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.

## The Problem

You will be assuming the role of the farmer of a 240 hectare farm and President of your Farm Cooperative, a collective of ten farms in your area. You and your members currently grow corn grain, but are interested in converting your fields to biomass crops. Before the entire cooperative switches crops, they asked you to model some potential outcomes for different plants under different growing and processing conditions to determine the best option for all. The overall goal is to determine whether the farming cooperative should begin growing crops for cellulosic ethanol production. To help you accomplish this goal you must be prepared to answer the following questions using the quantitative models provided:

- Does cellulosic ethanol have the potential to provide us with a sustainable source of liquid fuel that has a net energy gain?
- Which production system provides the greatest reduction in greenhouse gas emissions compared to gasoline?
- Which feedstock holds the greatest potential for liquid fuel production?

# **Building a Model** - Life Cycle Assessment of Cellulosic Ethanol

Creating a model for the production of cellulosic ethanol requires a large amount of information. How much of a crop will a given amount of land produce? How much fuel is needed for tractors? How much ethanol can be produced from each kilogram of biomass? These and many other questions must be answered for each crop you wish to model and compare. This reading explains how some of these values can be determined. The model contains a particular amount of uncertainty, and a few of the assumptions behind this are described. Still, these types of models can be useful tools when planning efficient uses of agricultural land.

### Our Farm

Our model farm covers 240 hectares. A hectare (abbreviated *ha*) is an area a little more than two acres, about the same size as two American football fields. Most of the assumptions in our models are based on conditions particular to the Midwestern United States.

Diverse Prairie

Three different crops, or *feedstocks*, are considered: diverse prairie, switchgrass, and corn stover. *Diverse prairie* is a mixture of native plants like grasses, legumes and composite flowers. As a collection of native species, well-adapted to local growing conditions, a diverse prairie can be grown on poor or abandoned land that is being restored without large amounts of fertilizer or other chemicals. Diverse prairie could be grown on high quality soil with lots of added fertilizer, but this particular model assumes poor land quality and low fertilizer use. *Switchgrass* is a fast-growing native grass. Using a single, high-yielding perennial crop makes the process of converting biomass to ethanol easier than using diverse prairie. In this activity, switchgrass is given enough fertilizer and other chemicals to maximize biomass yield. *Corn stover* is the part of a corn plant (cobs, leaves and stalks) left in the field after corn

Switchgrass

Corn Stover

grain is harvested. Corn is already grown extensively across the Midwest and new plantings may not be necessary to create cellulosic ethanol with this feedstock. While a large amount of corn stover is normally left after harvest, not all of it can be harvested from the field without causing serious soil erosion and soil nutrient depletion.

**Crop Yield**

Each crop will produce a different *yield* on the same 240 ha farm. *Yield* is the amount of plant material we can actually harvest from the field. In our model we measure this in kilograms of biomass per hectare per year (kg/ha/yr). Crop yields can change significantly by location and weather conditions, which introduces a great deal of uncertainty into the model. Because of this, a range of possible yields for different locations or conditions is provided. Yields affect how much fuel is needed to harvest and transport a crop and is also connected to fertilizer inputs. All of these numbers are intertwined in the model. The corn stover yield provided with this model assumes that we leave 30% of the stover on the field. This percentage is still being researched and debated. Many feel the percent remaining on the field should be higher.

**Energy Content**

We grow crops for bioenergy because of their ability to take solar energy and transform it into chemical energy, which is stored in cellulose and other plant structures. Diverse prairie, switchgrass, and corn stover all contain the same cell wall components--cellulose, hemicellulose, and lignin--but because they are constructed in different proportions, their energy content varies. After harvest, the chemical energy from the plants is converted to chemical energy in the form of ethanol through a series of steps. Each liter of ethanol, the end product for this model, contains 21.1 Megajoules of fuel energy (written as 21.1 MJ/liter). For comparison, the energy content of gasoline is about 32 MJ/liter. There are slightly less than four liters (about 3.78 liters) in one gallon. In this model you are penalized for fossil fuel energy inputs (eg. coal or petroleum) but not for solar inputs (eg. photosynthesis).

**Crop Production Energy Inputs**

For the crops studied in this model, energy inputs used to grow the crops are grouped into five major categories: Planting, Chemical Production/Application, Harvesting, Equipment Production, and Transportation. Read the following sections to get an idea of how the energy inputs vary from between crops for each category.

***Planting***

Even before planting, it takes energy to grow the seeds themselves. Roughly 4,000 MJ goes into producing each hectare's worth of diverse prairie seed, but the prairie has a long life span (our model assumes 30 years) and will not need to be replanted every year. For comparison purposes, the initial energy investment is spread out over thirty years to equal about 134 MJ/ha per year. The energy to prepare land and plant seeds during the first year is also spread out over thirty years to 37.2 MJ/ha/yr. Therefore, the total energy used for planting diverse prairie is counted as 171 MJ/ha.

Unlike diverse prairie, which is a mixture of seeds, switchgrass consists of only one seed type and, on average, takes less energy to produce and plant, even though it is sometimes replanted every ten years. The total energy per year for switchgrass seeds and planting is 138 MJ for each hectare. Corn stover does not need to be planted separately from corn grain, so there is no extra energy needed to plant or produce seed and the energy is counted as zero MJ per hectare each year.

***Chemical Production/Application***

Once established, diverse prairie needs little fertilizer, herbicide, or pesticide to maintain. Most of the chemical inputs are required to establish the prairie in the first year, which is averaged over a 30-year time frame for our model. As a perennial, many of the inputs for switchgrass are also in the first year of establishment. Many models for switchgrass, however, include larger amounts of fertilizer, pesticides, and herbicides in order to maximize yields. Establishing corn stover generally does not require extra fertilizer inputs or other chemicals since these are already provided for the corn grain. However, removing corn stover from the field for fuel also removes the nutrients that would otherwise return to the soil, meaning some energy is needed to produce the fertilizers to replace these nutrients.

***Harvesting***

Most harvesting equipment uses diesel fuel. The amount of fuel burned depends on the feedstock yield. Since switchgrass yields are normally higher than diverse prairie, we expect a larger energy input for this step in the model. Separate equipment will be used to harvest corn stover from the grain itself, so additional energy inputs are required here.

*Equipment Production*

Our model also includes the energy needed to manufacture the equipment used in the fields to plant, apply chemicals, and harvest our crops. Diverse prairie and switchgrass use similar equipment and we assume that the equipment will last for 30 years. No separate equipment is needed to plant corn stover or apply chemicals, but it will take some specialized equipment to collect the corn stover from the field, and this equipment is not already needed to produce corn grain.

*Transportation*

Energy is needed to fuel trucks that take the biomass from the field to the processing plant. This number is based on the amount of material harvested from each hectare of land and the need to move it an average distance of 40 km from the field to the refinery. Switchgrass requires more energy to transport because of the higher yield, requiring more truckloads of material to be moved to the processing plant.

**Biomass Processing Energy Inputs**

Once the crop is transported to the refinery, a series of processing steps occur to transform the biomass into ethanol and co-products: pretreatment, enzyme hydrolysis, fermentation, and ethanol separation.

*Conversion Rate*

Each kilogram of biomass can be expected to produce a certain volume of liquid ethanol. As technology improves, the amount of ethanol produced from each kilogram of biomass will increase. Right now, about 250 milliliters of ethanol (0.25 liters, or about one cup) is produced for each kilogram of cellulosic biomass, regardless of species. For comparison, the conversion rate of corn grain is 0.419 l/kg.

*Pretreatment*

Biomass needs to be broken down in order to make the cellulose inside accessible for ethanol production. This currently involves chopping the plant matter into smaller pieces and treating it with chemicals (pretreatment). Some components of the plant (lignin) cannot be converted to ethanol, but this material can be burned in the refinery to produce heat and power. In this way, only the energy needed to make chemicals for pre-treatment needs to come from outside the refinery. This is a small amount, less than 0.20 MJ per kilogram, and is similar for all of the biomass crops.

***Enzymes and fermentation***

Certain protein molecules, called enzymes, are needed to break the cellulose freed by pretreatment into simple sugars that can be converted into ethanol. Making enzymes adds a small energy cost. Heat and electricity are also needed in this stage, but, as with pretreatment, these requirements can be met by burning non-convertible plant material.

***Ethanol Separation***

At the end of the fermentation process, the ethanol sits in a mixture of water, yeast, plant parts and other materials. The ethanol must be distilled, dehydrated and denatured before it can be used as fuel. This stage requires large amounts of heat and electricity, however, just as in the last two steps, this energy can come from burning left-over biomass, requiring no external energy inputs and no energy accounting.

***Co-Products***

Burning the portion of the biomass that cannot be made into ethanol provides enough heat and electricity to run the processing facility and even produces excess electricity, which can be sold. Before ethanol is made, high-protein portions of the biomass can also be extracted for animal feed. The electricity and animal feed, which are produced in addition to ethanol, have added-value and are called *co-products*. Since making them in another way would require additional energy, these products save energy and act as energy credits for cellulosic ethanol production.

Name________________________________ Date______________ Hour_______

## 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?

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

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

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

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

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.

7. What is a conversion rate?

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

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

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

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

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

# Student Handbook: Biofuels Life Cycle Assessment Model of *Energy*

## Introduction

As human populations and use of resources continue to expand there has been growing concern about environmental damage caused by producing and burning gasoline and diesel fuel. Important political issues are also created when countries import large amounts of petroleum to produce fuels, and global supplies of petroleum, a nonrenewable resource, continue to decrease. As a result, ethanol is being produced from biomass crops to replace gasoline and diesel, with most of the ethanol in the U.S. produced from corn grain.

Some scientists argue that producing ethanol from corn grain is an inefficient process that requires large amounts of fossil fuels (including gasoline and diesel fuel) and causes additional environmental damage. An alternative to producing ethanol from corn grain is the production of ethanol from plant materials such as wood, leaves, and stems; such materials are called cellulosic biomass. Ethanol produced from these materials is the same as ethanol made in other ways, but is called cellulosic ethanol because of its starting material.

Producing ethanol from cellulosic biomass is challenging and, like corn grain ethanol, requires resources and has environmental impacts. The goal of this activity is to investigate the energy inputs of cellulosic ethanol production and the pollution that results to see if producing ethanol creates an overall benefit to society. Three different starting materials (often called "feedstocks") are considered in this model: diverse prairie grasses, switchgrass, and corn stover (leaves, stalks and cobs).

## Directions

There are many choices to make when considering cellulosic ethanol. What biomass source will be used as the feedstock? How and where will this biomass be grown? How will it be processed? The following steps help create a simple model for cellulosic ethanol production for a particular biomass feedstock and production conditions. Follow the steps in this handout to create an energy life cycle analysis model for one of the crops in this activity.

**Farm and Crop Characteristics**

1. Open the excel file "Student Energy LCA of Cellulosic Ethanol." (Use the zoom tool to increase the size of the numbers if necessary.)

2. Choose diverse prairie, switchgrass, or corn stover as a biomass material for ethanol production and enter then name of that material in cell B-2. From this point forward, select values for that specific crop for your model.

3. Choose the typical yield for your biomass crop (see below) and enter that value in cell E-2.

| Crop | Typical Yield (kg/ha) | Yield Range (kg/ha) |
|---|---|---|
| diverse prairie | 3860 | 3860 - 6000 |
| switchgrass | 11200 | 4500 - 23000 |
| corn stover | 5830 | 3330 - 5830 |

4. For the feedstock you have chosen, enter the appropriate level in cell C-2 of the spreadsheet.

| Crop | Energy Content |
|---|---|
| diverse prairie | 18.5 |
| switchgrass | 16.7 |
| corn stover | 18.0 |

5. The energy content of ethanol is 21.1 MJ/liter. Enter this value in cell C-24.

6. Continue to complete the model by adding values in column C for crop production and processing. The next section gives all needed values for the cells C-6 to C-10 and C-16 to C-18.

**Stage 1 Inputs- Crop Production**

In this section, enter the energy inputs needed to grow and harvest the crop you have selected. In this activity, these inputs are divided into five major categories: Planting, Chemical Application, Harvesting, Equipment Production and Transportation.

**7. Planting:** (C-6)

Energy is needed to run equipment that prepares the soil and plants seed, but the seed also requires energy to produce.

| Crop | Energy Content for Planting and Seeds (MJ/ha) |
|---|---|
| diverse prairie | 171 |
| switchgrass | 138 |
| corn stover | 0 |

**8. Chemical Application:** (C-7)

Energy is needed to produce, transport, and apply fertilizer and pesticides.

| Crop | Energy Input for Chemicals (MJ/ha) |
|---|---|
| diverse prairie | 103 |
| switchgrass | 7010 |
| corn stover | 1660 |

**9. Harvesting:** (C-8)

Energy is needed to provide fuel to power equipment used for harvesting.

| Crop | Energy Input for Harvest (MJ/ha) |
|---|---|
| diverse prairie | 1380 |
| switchgrass | 3250 |
| corn stover | 1700 |

**10. Farm Equipment:** (C-9)

Not only is energy needed to operate equipment, but energy is also needed to make equipment.

| Crop | Energy Input for Equipment (MJ/ha) |
|---|---|
| diverse prairie | 188 |
| switchgrass | 182 |
| corn stover | 56 |

**11. Transportation:** (C-10)

Once a crop is grown and harvested, energy is still needed to transport it to a processing plant.

| Crop | Energy Input for Transportation (MJ/ha) |
|---|---|
| diverse prairie | 293 |
| switchgrass | 850 |
| corn stover | 444 |

**Stage 2 Inputs- Biomass Processing**

Processing biomass into ethanol also involves energy inputs, and they are grouped here into three different categories: Pretreatment, Hydrolysis/Fermentation, Ethanol Recovery.

**12. Conversion Rate:** (F-16)

Conversion rate is the amount of ethanol that is produced for each kilogram of biomass. Select a conversion rate for your feedstock from the table and enter it in cell F-16.

| Crop | Conversion (liters/kg) |
|---|---|
| diverse prairie | 0.255 |
| switchgrass | 0.250 |
| corn stover | 0.255 |

**13. Pretreatment:** (C-16)

Pretreatment is the process of breaking biomass into small pieces and exposing the cellulose so it can be converted to ethanol. Pretreatment requires heat, electricity, and chemicals. Since the heat and electricity can be produced by burning what is left of the biomass at the end of the process, the inputs for pretreatment are small.

| Crop | Energy Input for Pretreatment (MJ/kg) |
|---|---|
| diverse prairie | 0.189 |
| switchgrass | 0.189 |
| corn stover | 0.10 |

**14. Hydrolysis / Fermentation:** (C-17)
Hydrolysis is the breaking apart of cellulose into different types of sugar molecules and fermentation is the biochemical processing of those sugars into ethanol. Heat and electricity are provided by burning biomass residue, but energy is needed to make enzymes for this step.

| Crop | Energy Input for Hydrolysis/Fermentation (MJ/kg) |
|---|---|
| diverse prairie | 0.364 |
| switchgrass | 0.364 |
| corn stover | 0.364 |

**15. Ethanol Separation:** (C-18)
In ethanol from corn grain ethanol, energy for distillation of ethanol is a very large input. In the cellulosic ethanol plant, like the one modeled in this activity, the heat and power produced from burning the remains of the biomass after processing provide all of the energy needed for distillation. As a result, the value for C-18 is 0 MJ/kg.

**16. Co-Products:** (C-26)
Some of the material left after processing biomass into ethanol is burned to produce heat and electricity. Other parts of the left over material have other uses. These materials are called co-products and act as energy credits since they would take energy to make if they were not produced as part of the biomass grown for the cellulosic ethanol plant.

| Crop | Energy Output for Co-Products (MJ/kg) |
|---|---|
| diverse prairie | 0.484 |
| switchgrass | 1.73 |
| corn stover | 1.17 |

**17. Optional**
If you want to run a second scenario, we recommend you use a new spreadsheet in the same file. Double click on the tab at the bottom of the spreadsheet that says "Sheet 1" to name it. Then click the "+" sign in the tab to the right. Name the tab as well. Copy and paste your first spreadsheet into the new sheet. Delete and replace numbers as necessary on the second sheet to complete your new scenario. Flip back and forth between the two spreadsheets to make comparisons.

**Results**
Using the summary and conversion tables at the bottom of the spreadsheet, prepare a summary of your model according to directions by your instructor.

Name____________________ Date____________ Hour________

## 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/ha | Biomass Energy (MJ) | % to fuel | % to fuel + coproduct | Net Energy Gain per ha (MJ/ha) |
|---|---|---|---|---|---|---|
| Diverse Prairie | | | | | | |
| Switchgrass | | | | | | |
| Corn Stover | | | | | | |

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

   Diverse Prairie ____________________

   Switchgrass ____________________

   Corn Stover ____________________

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

   Diverse Prairie ____________________

   Switchgrass ____________________

   Corn Stover ____________________

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

   Diverse Prairie ____________________

   Switchgrass ____________________

   Corn Stover ____________________

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

6. How is net energy gain determined? Write the equation and explain what this means in your own words.

7. Identify the most efficient feedstock at producing ethanol according to the model. Provide data to support your answer.

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:

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).

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

# Alternative Energy Scenarios

Rainfall amount, timing of rainfall, temperatures, and other factors can affect the amount of biomass that grows during a given year. It is likely that different types of biomass would be affected in different ways. Find the biomass crop that you selected before, and make the adjustments that are described below.

**Diverse Prairie**

The yield used for diverse prairie in the original model is at the bottom of the range given. Suppose that in a given year the yield is actually 30% higher than that value, which is more in the middle of the range. If the energy needed for transportation also increased by 30%, how do the final results compare to the original model?

Suppose in a different year it is very dry early in the growing season and the tall grasses of the diverse prairie do not grow as large as they normally would. If this reduces the yield to 3200 kg/ha, how are the final results different? Use a reduced transportation energy of 243 MJ/ha. What other factors in the model might change if the yield is smaller than what was used in the original model?

**Switchgrass**

The table below gives switchgrass yields for three years from three different locations. Choose two different yields from one of these locations to investigate in your spreadsheet model. What would these yields mean from a farmer's perspective?

***Switchgrass yields, 2 years after planting, in kg/ha***

| Location | Year 3 | Year 4 | Year 5 | Mean |
|---|---|---|---|---|
| Douglas, NE | 3900 | 8800 | 7500 | 6700 |
| Huron, SD | 6600 | 10500 | 5500 | 7500 |
| Highmore, SD | 8400 | 8300 | 3700 | 6800 |

**Corn Stover**

Leaving additional stover behind prevents erosion, returns nutrients to the soil, enriches soil carbon and reduces the need for fertilizers. In the original scenario, 70% of the 8330 kg/ha of corn stover on the field was harvested. Calculate how the results would change if only 50% were harvested. Less fertilizer will be needed to replace nutrients if less stover is taken, so you should reduce the energy needed for chemicals in your model.

Compare changing the amount of corn stover removed with a reduced yield due to weather conditions. Suppose that in a year where it is extremely dry early in the growing season the amount of corn stover in the field before harvest is only 6200 kg/ha instead of the average 8330 kg/ha. Calculate the harvested yield (E-2) if we take 70% of the standing crop and see how the results of the model are affected.

## Background on Greenhouse Gases and Life Cycle Assessment

The combustion of gasoline creates large amounts of carbon dioxide ($CO_2$), leading to higher concentrations of this greenhouse gas (GHG) in the atmosphere and thus contributing to global warming and climate change. While $CO_2$ is the most commonly discussed GHG, other gases contribute to natural warming of the Earth's atmosphere including methane ($CH_4$), and nitrous oxide ($N_2O$). GHGs vary in their abilities to trap heat and therefore have different "warming potentials." To aid in the comparison across processes where different GHG are released, all of the GHG warming potentials have been set relative to carbon dioxide. These units are called "carbon dioxide equivalents" ($CO_2$eq). For example, because methane has 24 times the global warming potential of carbon dioxide, one kg of methane would have a value of 24 kg$CO_2$eq. Nitrous oxide has a global warming potential of 298.

| Greenhouse Gas | Global Warming Potential |
|---|---|
| *Carbon Dioxide ($CO_2$)* | 1 |
| *Methane ($CH_4$)* | 24 |
| *Nitrous Oxide ($N_2O$)* | 298 |

The main functional unit in this model is kilogram carbon dioxide equivalents per liter of cellulosic ethanol (kg$CO_2$eq/L). Because our model is measuring a replacement for gasoline, we need to know the kg$CO_2$eq/L for gasoline as our baseline for comparison. The *production* of one liter of gasoline contributes another 0.57 kg$CO_2$eq/L. *Burning* one liter of gasoline emits 2.31 kg$CO_2$eq/L. Summing these two values we find that the life cycle emissions for the production of gasoline is approximately 2.9 kg$CO_2$eq/L per liter of gasoline. If we are concerned about global climate change, we want to find an alternative fuel that results in reduced GHG emissions throughout its life cycle.

| Fuel | Life Cycle $CO_2$ equivalents (kg$CO_2$/L) |
|---|---|
| Gasoline | 2.9 |
| Corn Grain Ethanol (in WI) | 1.04 |
| Cellulosic Ethanol | *For you to determine!* |

One potential alternative to gasoline is ethanol, a liquid fuel created from the fermentation of plant material. In the United States today we primarily use corn grain to make ethanol. However, the energy stored in the corn kernel represents only a fraction of the potential energy stored in a corn plant. The leaves, stem, and corncobs all contain a variety of carbohydrates that could be converted into fuel. If we are able to convert this stored energy into ethanol, any plant in the world could potentially be used for biofuel. Whether this can be done efficiently and with fewer GHG emissions is under investigation.

## GHG Accounting in the Life Cycle Assessment (LCA) Model

Growing crops for energy production allows us to eliminate the use of some fossil fuels, thus reducing the total amount of GHG building up in the atmosphere. Although burning plant material creates $CO_2$, those emissions are considered "neutral" as they are balanced by the uptake of $CO_2$ from the plants themselves as they build more leaf and stem material. In the life cycle accounting of GHGs for crop and ethanol production, carbon trapped in the plant or carbon converted into ethanol and later burned is not counted in the LCA. The carbon came from the atmosphere and will be returned to the atmosphere either through the decomposition of the plant biomass, through fermentation, or during the combustion of ethanol.

Land use practices involved in plowing and fertilizing can have a significant impact on the out-gassing of GHGs from farm soils. Nitrogen fertilizer use can result in the formation of large amounts of nitrous oxide. Plowing cuts furrows into the soil allowing for oxygen to mix into the soil, speeding decomposition rates of organic matter, leading to the release of $CO_2$.

Accounting for what happens underground in the soil is more difficult. Although many believe that growing perennial crops with deep root systems is preferable to annual crops, it is common practice in LCA GHG modeling of biofuels not to count the carbon assimilated into root biomass as "sequestered," or stored. There is much debate in the scientific community over how long carbon in these root systems must remain underground in order for it to be considered truly sequestered for modeling purposes.

In our model, GHG emitted from burning fossil fuels count as positive GHG emissions. However, inputs from plant materials which displace GHG emissions that normally would have arisen from burning fossil fuels (for example burning plant biomass instead of coal to produce electricity at the refinery) receive a negative value for GHG emissions.

Name__________________________________ Date_______________ Hour_______

## Student Handbook: Biofuels Life Cycle Assessment *Greenhouse Gas Model*

1. Open the excel file "Student Energy LCA of Cellulosic Ethanol."
2. Enter the yield/ha you used in the LCA Energy model in the proper cells in column D.
3. In order to create models, researchers go through the painstaking process of researching conversion values for various processes in the production of cellulosic ethanol. Researchers must be able to use scientific reasoning and mathematical logic in order to create the model. To understand how the model was created you will be asked to utilize several useful pieces of quantitative information to help you create the missing portion of the model.

For example, let's look at how the cell E50 is calculated. This formula in this cell allows the model to determine our ethanol production rates from switchgrass automatically as our yields change.

We know from research that it is possible to get 250 liters of ethanol (EtOH) from one Megagram (Mg) of switchgrass (SG). Because your model works in kilograms (kg) we have to convert Mg to kg. There are 1000 kg per Mg.

$$\frac{250 \text{ L EtOH}}{1 \text{ Mg dry SG}} \times \frac{1 \text{ Mg}}{1000 \text{ kg}} = \frac{0.250 \text{ L}}{\text{EtOH}}$$

This conversion rate can now be used to calculate the amount of ethanol produced per hectare from the yields on our fields.

Liters of ethanol produced/ha = yield of SG in kg/ha * conversion rate from above

Cell D3 is where "yield of SG in kg/ha" is found.

So, the formula to calculate liters of ethanol produced/ha becomes: =D3*0. 250
Click on cell E50 and you should see this formula.

$$\text{D3} \times 0.250 = \frac{\text{dry kg SG}}{\text{ha}} \times \frac{0.250 \text{ L}}{\text{EtOH}}$$

dry kg SG cancel out and we are left with units of L EtOH/ha

4. A portion of the LCA GHG model, highlighted in blue (cells D27 and E27), has been left intentionally blank. We will have you calculate the values and formulas for "soil outgassing of $CO_2$." This will help you understand how the model was created and functions. To complete the missing parts of the puzzle you must use dimensional analysis as well as another model created by researchers at Michigan State University.

   What are the units of measure for cells D27 and E27?

   ______________________

   It is important that as you do your calculations in the steps that follow, you end up with these units.

5. To find the data necessary to create this formula, we will use an online modeling program that farmers use to calculate greenhouse gas emissions from their fields. Navigate to the "US Cropland Greenhouse Gas Calculator" model. *http://www.kbs.msu.edu/ghgcalculator/*

6. Select the county in the state where you live from the map (or another county if directed).

7. Look at the bottom of the screen. Change the "Units" from Imperial to **METRIC**.

8. In order to determine $CO_2$ emissions from the soil, you will need to input the farming practices relevant to our biofuel crops.

We will calculate information for cell E27 for switchgrass first. Establishing switchgrass requires that corn be grown the year before. Growing an annual crop such as corn reduces the amount of weed species and also removes large amounts of nitrogen from the soil. Weed species thrive in high nitrogen soil environments as they are highly opportunistic and reproduce quickly. As a result, no nitrogen is added to the soil as switchgrass establishes itself. The switchgrass yields and fertilizer amounts you will enter for years 4-13 come from average research values.

9. Change the base scenario online to match the following table. You will need to use the button "add another year to the rotation" to get to 13 years.

| Year | Crop | Tillage | Yield (MT/ha) | N fertilizer (kg/ha) |
|---|---|---|---|---|
| $Y_1$ | Corn | Conventional | default value | default value |
| $Y_2$ | SG | NA | 0 | 0 |
| $Y_3$ | SG | NA | 0 | 0 |
| $Y_4$ | SG | NA | 10 | 117 |
| $Y_5$ | SG | NA | 10 | 117 |
| $Y_6$ | SG | NA | 10 | 117 |
| $Y_7$ | SG | NA | 10 | 117 |
| $Y_8$ | SG | NA | 10 | 117 |
| $Y_9$ | SG | NA | 10 | 117 |
| $Y_{10}$ | SG | NA | 10 | 117 |
| $Y_{11}$ | SG | NA | 10 | 117 |
| $Y_{12}$ | SG | NA | 10 | 117 |
| $Y_{13}$ | SG | NA | 10 | 117 |

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: ______________________________

11. We must also note the yield used in the calculator: __*in this case **10 MT/ha***__

**12. Setting up the equation:** The units on the US Cropland Calculator are in MT/ha/year, but our LCA model is in kg. We need to convert the units before we can use them.

To calculate the equation and convert to the correct units that should be typed into cell E27, the following information must be used:

$$1 \text{ MtCO2eq} = 1000 \text{ kgCO}_2\text{eq}$$

$$1 \text{ Mt of SG} = 1000 \text{ kg of SG}$$

Determine the conversion factor for converting the yield into kg$CO_2$eq/ha. This will be the ratio of $CO_2$eq per unit SG yield from the US Cropland Calculator: $\frac{\textit{value from \#10}}{\textit{value from \#11}}$

13. Enter this equation into cell E27 as: *=D3*your answer from #12*

**Calculating the equation for the outgassing of $CO_2$ from growing corn stover**

Corn can be grown several different ways. Tilling practices used by the farm can affect the greenhouse gas emissions from the soil. Conventional till agriculture utilizes a plow that turns over the soil up to nine inches deep. This helps eliminate weeds and makes it easy to plant crops. No-till agriculture drills seeds directly into the soil using heavy machinery and does not break-up and turn over the soil. It is used to reduce soil erosion because it leaves residuals from previous crops on the field.

You will calculate the greenhouse gas emissions for both planting methods to determine their impact on our GHG model. This is only relevant for annual crops such as corn stover.

***Scenario 1 for Corn Stover: Conventional Tillage***

1. Using the same county as you did for switchgrass, return to the US Cropland GHG Calculator. Make sure your units are still metric. *http://www.kbs.msu.edu/ghgcalculator/*

2. In the US Crop Calculator "silage" is equivalent to corn stover. Change the base scenario to match the following table. Hit "recalculate" to be sure the calculation is correct when you are finished.

| Year | Crop | Tillage | Yield | N fertilizer (kg) |
|---|---|---|---|---|
| $Y_1$ | Silage | Conventional | Use default | Use default |
| $Y_2$ | Silage | Conventional | Use default | Use default |
| $Y_3$ | Silage | Conventional | Use default | Use default |
| $Y_4$ | Silage | Conventional | Use default | Use default |

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

   Annual Average Soil $CO_2$ equivalents = ______________________________

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 ________________________ MT/ha

5. Use the same conversion method you did for switchgrass to create the formula for Cell D27.

   ______________________________

***Scenario 2 for corn stover: No till***

1. Enter the following scenario into US Cropland GHG Calculator. Make sure your units are still metric. *http://www.kbs.msu.edu/ghgcalculator/*

2. Use the same yield and fertilizer values from the previous scenario but choose NO-TILL for tillage for all four years.

3. Follow the same steps:

   Annual Average Soil $CO_2$ equivalents = ______________________________

   Yield = ________________________ MT/ha

   Formula for D27 = _________________________________

4. Compare the values from conventional till and no till agriculture using your LCA model. Enter the formulae you created into the proper cells in the LCA model and record the resulting values.

Name____________________ Date__________ Hour______

## 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.

| 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 | | | |
| Switchgrass | | | |
| Corn Stover (conventional tillage) | | | |
| Corn Stover (no-till) | | | |

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

   Diverse Prairie ____________________

   Switchgrass ____________________

   Corn Stover ____________________

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

   Diverse Prairie ____________________

   Switchgrass ____________________

   Corn Stover ____________________

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

   Diverse Prairie ____________________

   Switchgrass ____________________

Corn Stover ____________________________________________

5. Using the table in question 1, identify the feedstock that:

   a. offsets the most GHGs per liter of ethanol produced: ______________________

   b. offsets the most GHGs total for the farm: ______________________

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.

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 $CO_2$eq*)

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

Name________________________________ Date______________ Hour_______

# Discussion Questions: GHGs

1. Explain the concept of greenhouse gas carbon dioxide equivalents (kg$CO_2$eq in our model).

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 kg$CO_2$eq/L
   - Corn grain ethanol (in WI) = 1.04 kg$CO_2$eq/L, 0.9 kg$CO_2$eq/L with 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

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

## Final Assessment:

Return to the role of the farmer of a 240 ha farm and President of your ten farm cooperative. Write a summary report to the cooperative members which informs them about the feasibility of growing crops for cellulosic ethanol production. The report must include:

1. Summary of findings:
    a. Net energy produced from each feedstock
        - Discuss the processes that utilize the largest amounts of energy and identify the energy input for each process.
        - Discuss ways in which your large energy inputs could be reduced.

    b. Net GHG emissions produced from each feedstock
        - Discuss the processes that release the largest amounts of GHGs and identify which GHGs are emitted by the process.
        - Discuss ways in which the processes that contribute large GHG emissions could be reduced.

2. Discussion of additional ecological implications of choosing certain crops over others (Consider diverse prairie, switchgrass and corn stover).

3. Make a final recommendation to your cooperative that discusses whether they should begin planting and harvesting crops for use in producing cellulosic ethanol. Use data from the model to back up your recommendations. If you are for conversion, which feedstock(s) would you recommend and how you would sustainably manage a 240 ha farm or cooperative of farms for cellulosic ethanol production? If you are against it, explain why you do not think any of the three feedstocks tested are feasible.