Name_____ Date_____ Hour_____

Thinking About Plants as Transportation Fuel

What have you heard about biofuels, like ethanol, for cars -- are they a good alternative?

Which is a better fuel -- gasoline or ethanol? For each of the criteria below, put a check under what you believe is the best answer.

	Gasoline	**Ethanol**
Energy per gallon/Miles per gallon		
Energy required to produce a gallon		
Carbon dioxide (CO_2) emissions		
For the environment		
Amount available		

To create ethanol, sugars in plant biomass (the leaves, stems, and other plant parts) are harvested and converted into fuel (C_2H_5OH).

Based on what you know, check the statement(s) with which you agree.

CO_2 is released when ethanol is produced from plant biomass.
Creating ethanol from plant biomass is carbon neutral*.
Creating ethanol from plant biomass contributes to climate change.

Create a drawing or cycle that explains the production of ethanol from plant biomass. Show the movement of carbon or carbon dioxide from location to location as best you can.

** Carbon-neutral implies that the amount of carbon dioxide released into the atmosphere equals the amount taken up by plants during photosynthesis.*

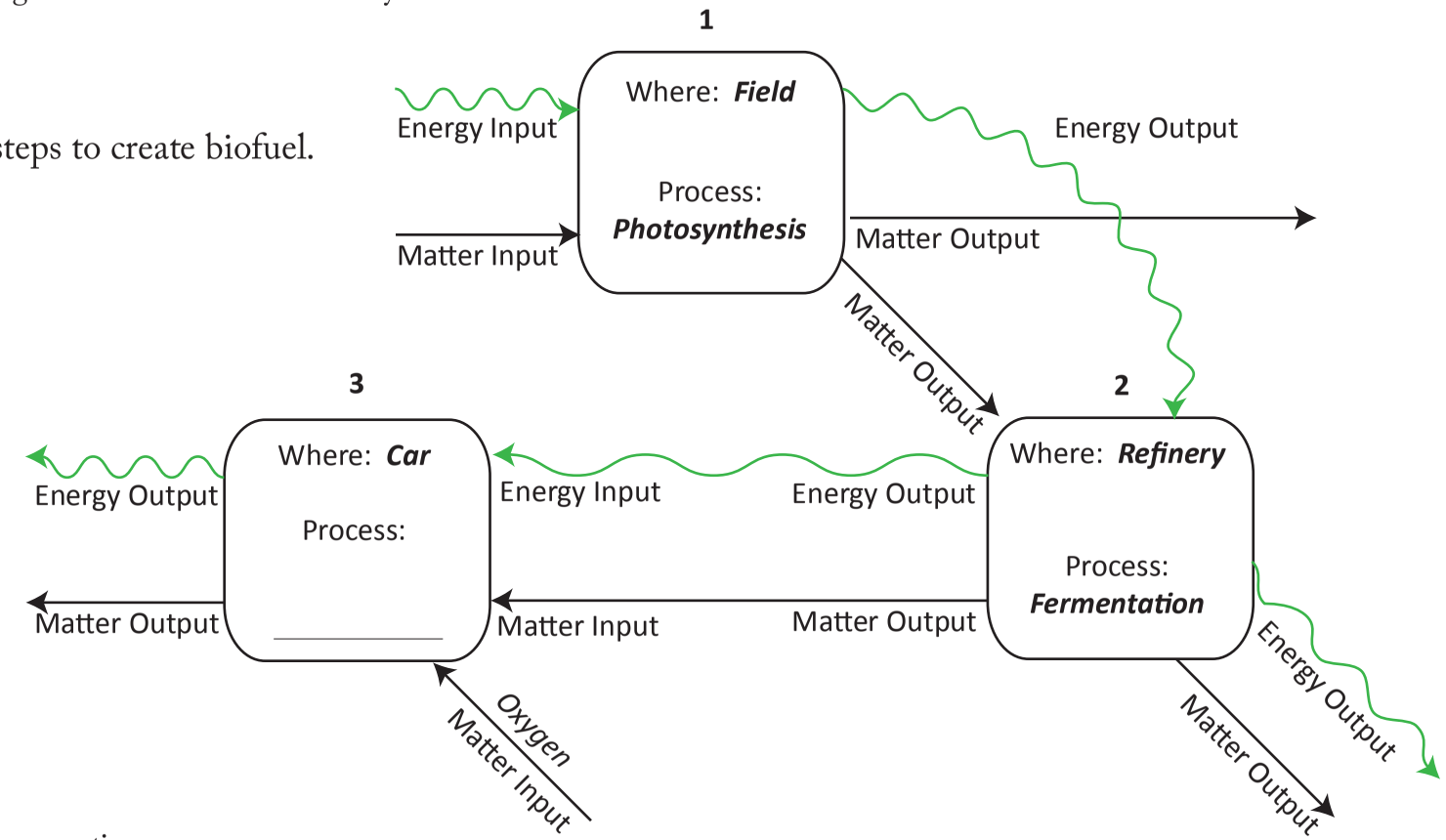
Discuss your answers with others. Were there any questions that were hard to answer? Why? What additional information would you need to decide? Take notes on agreements, disagreements and questions that remain after your discussion.

	Agreements, Disagreements, and Questions
Energy per gallon/Miles per gallon	
Energy Required to produce a gallon	
Carbon dioxide emissions	
For environment	
Amount available	
Creating ethanol from plant biomass is carbon neutral	
Creating ethanol from plant biomass contributes to global warming	
CO_2 is released to produce ethanol from plants	

Life Cycle Assessment Process Tool

Demonstrate the flow of energy and matter through this system to make ethanol. Enter the correct energy input and output above the wavy lines and matter input and output above the straight lines. Pay attention to stages with more arrows than the others. Determine which inputs and outputs stay in the system and which "escape." The first page follows the energy from the field to the refinery to your car. The second page shows additional inputs needed to create the fuel. Fill in the "process" occurring at any stage where it is not filled in for you.

Primary steps to create biofuel.



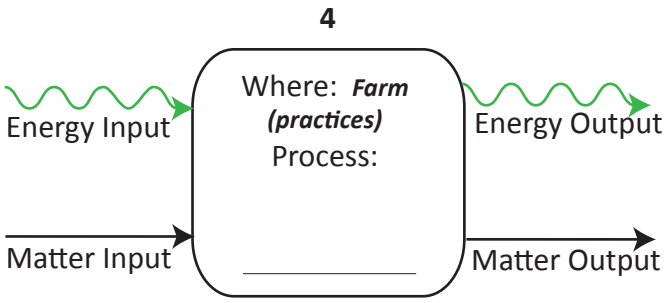
Follow-up questions:

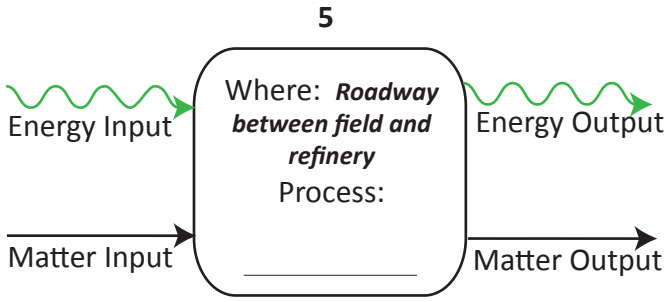
1. What is the relationship between the matter output from #3 to the matter input in #1?

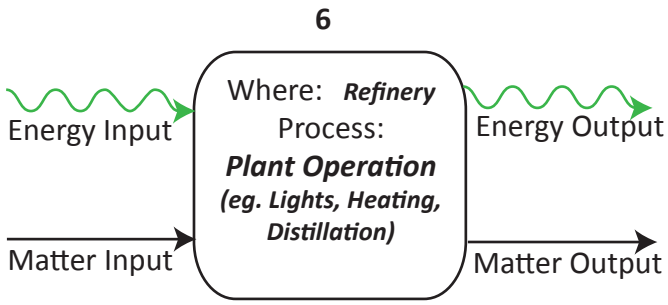
2. Does all energy put into #1 make it to the energy output stage of #3? Why or why not?

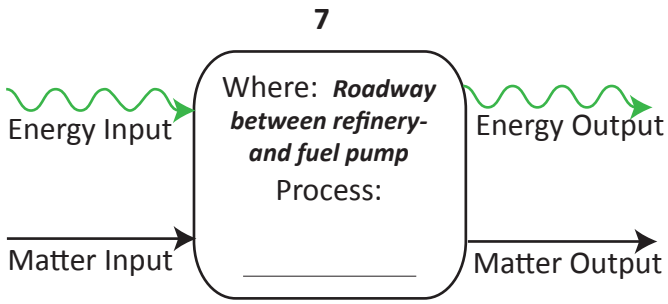
3. If we are conducting a life cycle assessment for energy or greenhouse gases, like carbon dioxide, why can't we stop at stages 1-3? Why do we need to include stages 4-7 as well?

Additional inputs to create biofuel.









Follow-up questions:

1. Describe how you would determine the net energy gain or loss for ethanol production. Write an equation using only the relevant steps. You can abbreviate EI for Energy Input and EO for Energy Output (eg. EI #1 - EO #7=).

2. How do you think you could best improve the energy efficiency of this process? Reduce the carbon footprint?

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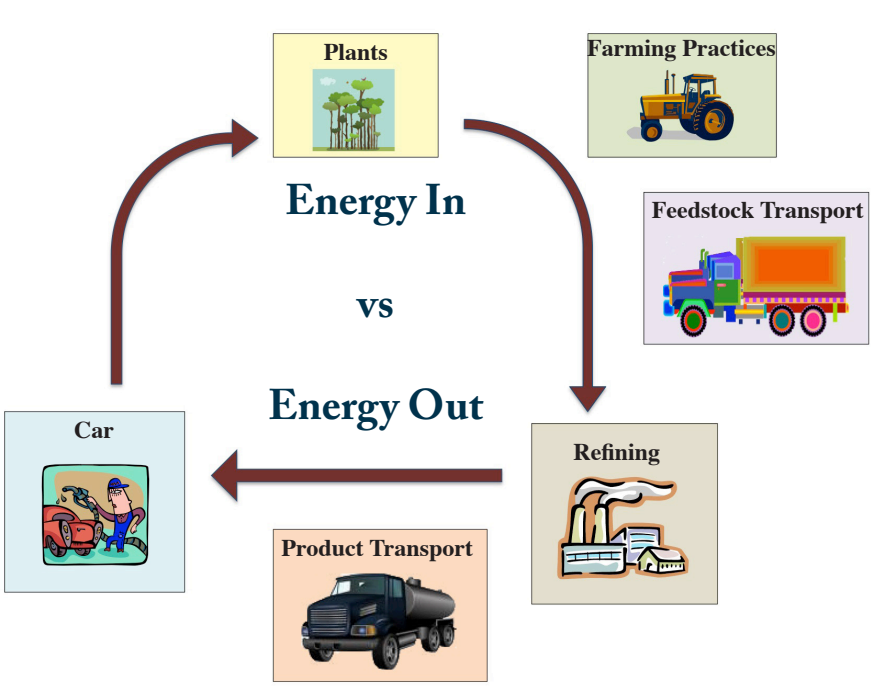
Life Cycle Assessment

In order to compare the environmental consequences from using different fuels, scientists conduct what is called a life cycle assessment (LCA). In a bioenergy LCA they look at all of the steps along the way--from planting a crop, to harvesting, to transporting it, to refining to vehicle use. One measurement in an LCA determines the amount of energy used or produced at each step (Figure 1). They also calculate greenhouse gas emissions through the cycle to see, for example, where carbon dioxide is taken in by plants or emitted from combustion (Figure 2).

Figure 1—Life Cycle Assessment of Energy for Ethanol Production and Consumption.



Where is the energy put into this cycle?

In what form?

How is energy used in the cycle?

Glossary of select terms for Life Cycle Assessment

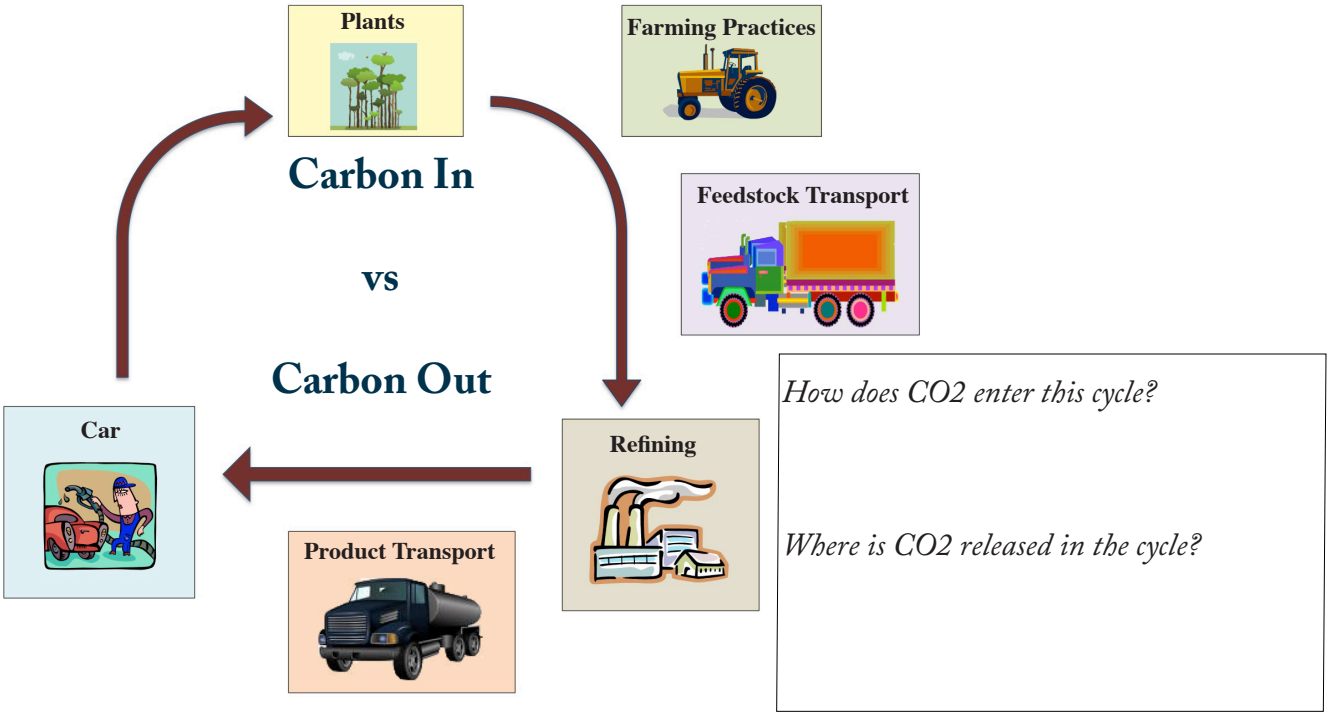
Feedstock—the plants or waste products (corn grain, corn stover, switchgrass, sugar cane, wood chips, etc) used to create biofuels such as ethanol, or other industrial chemicals.

Refining—the process of transforming the plant material into fuel. This may include physical and chemical changes to the plant material, fermentation and distillation.

Sequester—to remove gases from the atmosphere (in our case carbon dioxide) and transform it via photosynthesis in the plant into carbohydrates, which can be stored.

Transport—moving raw materials or finished products from point to point

Figure 2--Life Cycle Assessment of Carbon Dioxide for Ethanol Production and Consumption.



1. ***Try your own life cycle assessment.***
   Calculating these amounts can be very tricky. There are many steps along the way to measure and/or estimate what is happening. For the chart below, consider only carbon dioxide. Work through the qualitative steps of a life cycle assessment, beginning with planting the crop. Decide if CO2 is sequestered or released in each of these steps. Explain how or why for each step (photosynthesis, cellular respiration, combustion).

Steps:	**Carbon Sequestered or Released?**	**Form of carbon (from__ to__)**	**How or why? (Photosynthesis, cellular respiration, combustion)**
Planting crop	*Released*	*Gasoline to CO_2*	*Combustion*

2. In order for ethanol production to be carbon neutral, what would need to happen?

3. Where along the way could you modify the system to reduce the total amount of carbon dioxide released into the atmosphere? What other measurements should be made in a bioenergy life cycle assessment? Are there other choices that could be made that would make the system less damaging to the environment?

Name_____ Date_____ Hour_____

Collecting evidence to support your opinions...

It takes energy to convert fuels to a usable form. The Life Cycle Assessment gives you an idea of the full spectrum of energy inputs needed to make ethanol. The same assessments are done for gasoline and other fuels. In this section, you will estimate the quantity of energy needed to produce gasoline, corn ethanol, and cellulosic ethanol and then look at one set of results calculated by engineers who work in this field.

1. Why would you need to use fossil fuels to create gasoline and ethanol? Think of at least 3 examples for each fuel (remember fossil fuels include petroleum, coal and natural gas).

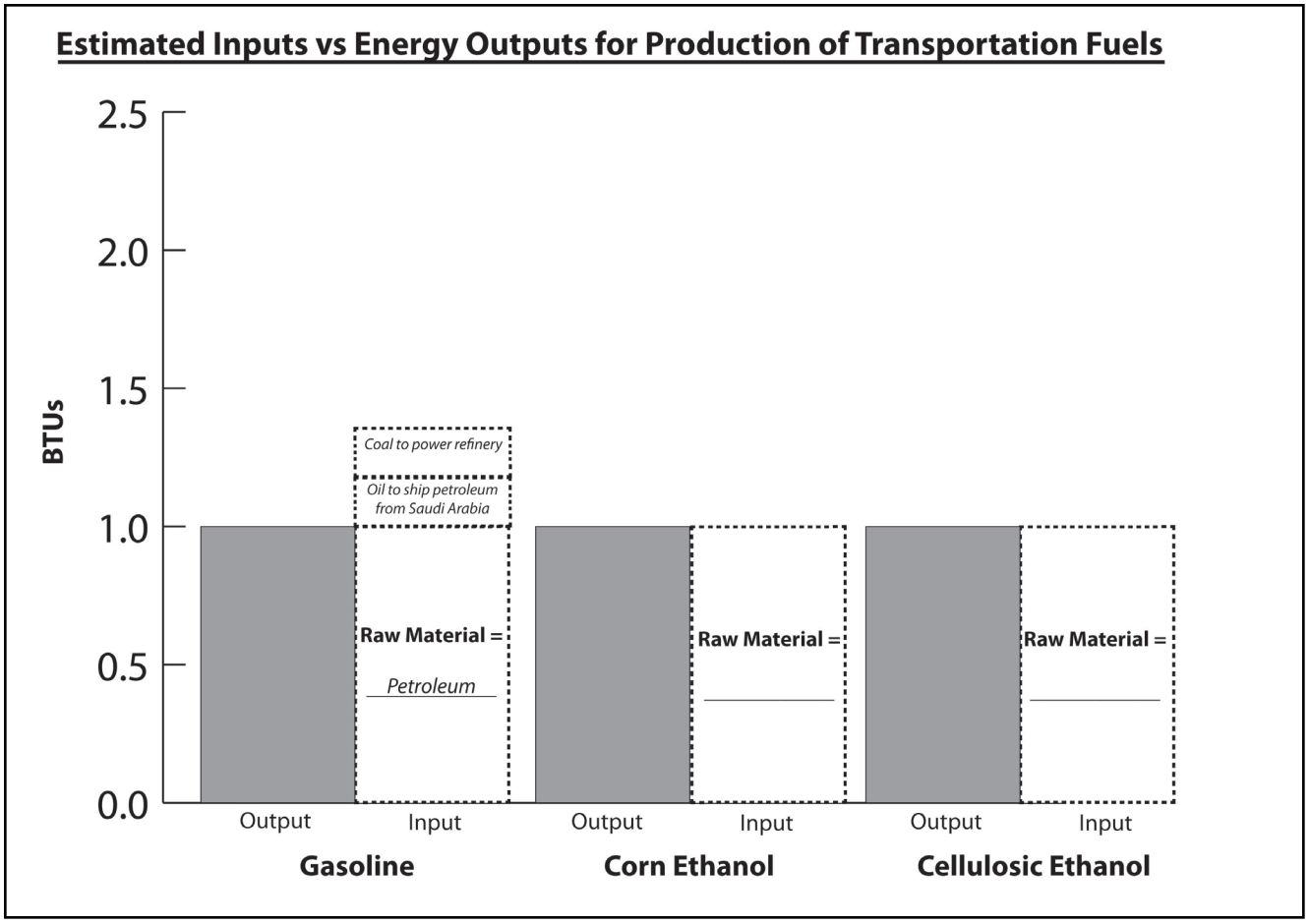
2. Estimating energy inputs. The graph on the next page (figure 3) is incomplete. The solid bars show the energy output (useable fuel) obtained from 1 BTU of gasoline, corn ethanol and cellulosic ethanol. (Btu is a British Thermal Unit = amount of heat energy needed to raise the temperature of one pound of water by one degree F.) To the right of each energy output measurement is an incomplete bar, showing the energy inputs needed to produce that fuel.

Name_____ Date_____ Hour_____

Complete the graph.

- First, fill in the blank dashed input bars with the raw material needed to create one BTU of each fuel.
- Second, stack additional energy inputs above the raw material to indicate the energy needs to produce each fuel. Use your list from question 1 for ideas and estimate the amount of energy needed from each source as you add it to the stack. Gasoline is started for you.

Figure 3

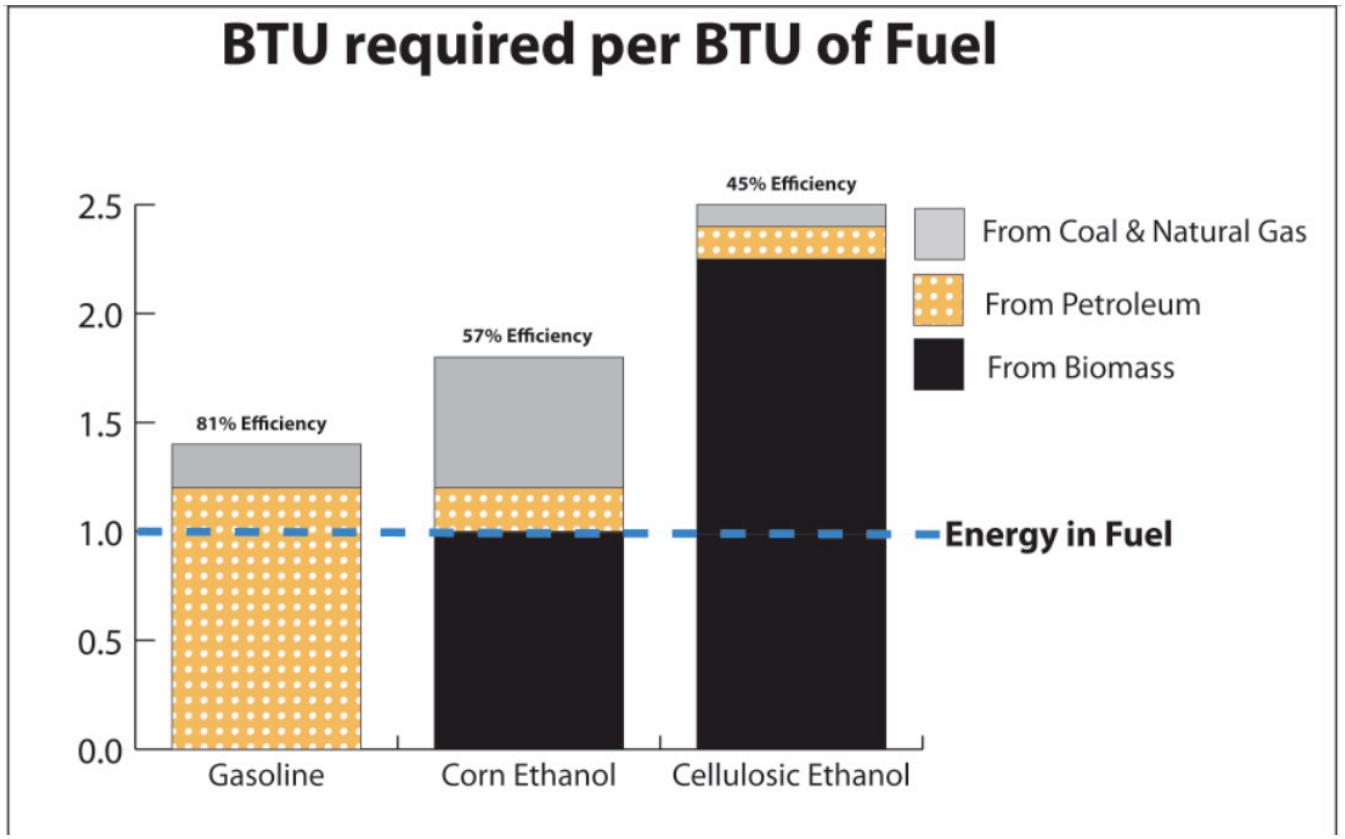


3. Which fuel do you think will require the greatest amount of energy to manufacture? Why?

4. Why is the output bar for one fuel source always lower than the input?

Compare your graph to Figure 4, which was taken from a document from the National Renewable Energy Lab. Take some time to interpret this graph.

Figure 4

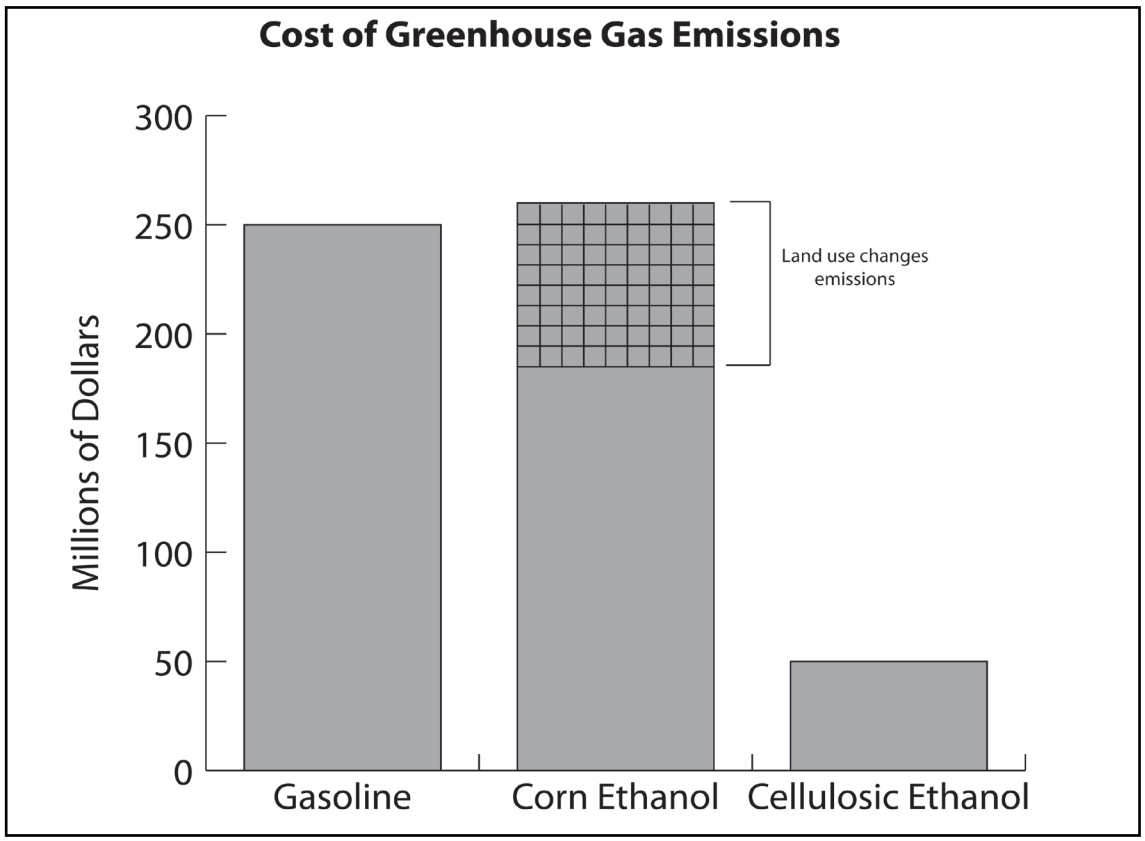


Adapted from NREL 2006. Biomass to biofuels.

1. The dashed line is equivalent to what on figure 3? _____
2. Do the vertical bars represent energy inputs or outputs? _____
3. Which fuel currently requires the most BTUs to produce? _____
4. Which fuel requires the least amount of fossil fuels to produce? _____
5. The efficiency above each bar refers to the amount of energy needed to produce the transportation fuel. Which fuel is most efficient? _____ What percent? _____
6. If gasoline is most efficient, why would we even consider making ethanol from corn or cellulosic biomass?

Now take a look at some results of a life cycle assessment of greenhouse gases. Note that estimates of emissions from both corn and cellulosic ethanol are highly variable depending upon where and how the crop is grown, as well as the crop choice for cellulosic ethanol.

Figure 5



Adapted from Hill et al. 2009. PNAS. Production estimate per one billion gallons of fuel to meet US demand. Corn ethanol refinery uses natural gas. Boxed area on corn ethanol indicates emissions estimate if previously unfarmed land is plowed to grow more corn. Cellulosic ethanol refinery uses switchgrass. Dollar amounts were calculated from prices from carbon mitigation costs, carbon market, and social costs.

7. Why is the measurement for corn ethanol almost the same as gasoline?

8. The bar for corn ethanol includes possible changes in land use to grow additional acres of corn. Is this land use change inevitable? Are there alternatives the United States could consider to prevent land use changes?

9. Revisit your choices on page one. Do you still hold the same opinion? Explain which transportation fuel you think is most sustainable. What have you learned in this activity to either change your mind or support your original position? (Write your answer on the back of this page.)