Analyzing Fuel Carbon Footprints: Gasoline, Ethanol and Electricity

Teacher Pages

Overview: Burning gasoline, a fossil fuel, in cars produces the greenhouse gas, carbon dioxide. Carbon dioxide contributes to global climate change. We have several options besides gasoline for powering our cars – electricity and biofuels like ethanol. In this data dive, students interpret and analyze data on the greenhouse gas emissions from producing and using different fuels for vehicles. In the process, they apply the concept of a life cycle assessment to tally environmental impacts for each step of fuel production and use. Based upon this analysis, students develop an argument based on evidence for the fuel that is most environmentally sustainable.

Target Grade Levels: 7 - 12

Time needed: 2 50-minute class periods

Learning Objectives

Students will be able to:

- Describe how Life Cycle Analyses are used to compare complex processes.
- Evaluate data on competing choices for fueling cars.
- Make arguments based on evidence about which choice for fueling cars is least harmful to the environment.

NGSS Standards

MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.

HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.

Suggested background knowledge

Students will need to know that the basic cause of global climate change is human use of fossil fuels which moves carbon from underground pools of fossil fuels to carbon dioxide in the atmosphere. This activity does not require an understanding of the mechanism of the greenhouse effect. Students will also need to know something about the life cycles of liquid fuels made from fossil fuels, biofuels, and electricity made from fossil fuels. The following resources can be used to develop students' understanding of these fuels:

- https://vimeo.com/166055834 - 8 minute video on the carbon cycling associated with fossil fuels and biofuels.
- Fuel life cycle illustrations: Use the illustrations in the presentation included with this activity to help students track how carbon moves with the steps of production and use for gas, biofuels and electricity.
- Investigating Fuel Sustainability Lesson - https://www.glbrc.org/education/classroom-materials/investigating-fuel-sustainability; Activity 2 scaffolds students' investigation of the processes involved in the production and use of different fuels.

Related activities from GLBRC

Available at https://www.glbrc.org/education/classroom-materials/

- Life Cycle Assessment of Biofuels 101
- Quantitative Modeling of Biofuels Life Cycles

Introduction and Initial Discussion

Have students read the one-page introduction. Use the designated discussion questions to engage students and elicit their ideas. Students are likely guessing initially, but have them try to come up with reasons that support their ideas.

For the second discussion question, collect students' responses in some way so that they are visible to all. Once you have collected the class's ideas, show the PowerPoint slides to help them visualize the process of making fuels and see how we can break this process into three stages. Give students Page 2 of the Student Pages which tells them that analysts think of the life cycle of fuels in three broad stages: ground or field to processor, processing to fuel or electricity, and operation of the vehicle. Have them sort the steps that they identified into these categories and add whatever additional steps the categories bring to mind. (If you would like to have your students research the steps of production, use *Presentation 2: Where do fuels come from*? in the from the Investigating Fuel Sustainability Activity Package).

Possible Answers for Page 2

	Ground/field to processor	Processing fuel/electricity	Vehicle Operation
Gasoline (100% gasoline)	*Drilling for crude oil* *Pumping crude oil out of the ground* *Transporting crude oil to refinery*	*Refining crude oil – separating mixture into constituent molecules including gasoline*	*Transportation of gasoline to gas stations* *Burning gasoline in car*

Cellulosic Ethanol (E100) made from switchgrass	*Harvesting switchgrass* *Transporting switchgrass to processing plant*	*Processing switchgrass biomass to make and purify ethanol*	*Transportation of ethanol to gas stations* *Burning ethanol in car*
Electricity made from coal	*Mining coal* *Transporting coal to power plant*	*Burning coal in power plant to generate electricity*	*Transmission of electricity to homes & charging stations* *Operation of vehicle*
Electricity made from natural gas	*Removing natural gas from ground* *Transporting natural gas to power plant*	*Burning natural gas in power plant to generate electricity*	*Transmission of electricity to homes & charging stations* *Operation of vehicle*

Making Sense

Have students work in groups to answer the questions on Page 3 of the Student Pages. Possible answers are listed below.

1. The first column of data shows the CO_2 equivalents produced when the fossil fuels are removed from the ground and transported to refineries or power plants. For cellulosic ethanol, it shows the CO_2 equivalents produced from the vehicles that plant, fertilize, harvest and transport the switchgrass, plus greenhouse gases produced by the soil. There is another piece of data associated with this stage of cellulosic ethanol production – the bioenergy credit. This number is negative, meaning that CO2 or other greenhouse gases are removed from the atmosphere. Explain how this happens.

   The growing plants use photosynthesis to make the molecules they need for growth and to store energy. Photosynthesis pulls carbon dioxide OUT of the atmosphere rather than putting carbon dioxide into the atmosphere. Plants remove more carbon dioxide than what is put in the atmosphere by farm equipment or transportation, so the net transfer of carbon dioxide is out of the atmosphere.

   Note to teacher: switchgrass puts as much of the carbon it fixes during photosynthesis into root material as into other plant materials. Thus this grass sequesters carbon, pulling it out of the atmosphere and transferring it to the soil where it remains for a long time. For more on carbon sequestration by plants, see GLBRC Root Depth Model.

2. Like gasoline, cellulosic ethanol produces CO_2 when burned in a car engine. You can see this because both fuels have virtually the same CO_2 equivalents when the car is operated. So why is cellulosic ethanol a better option than gasoline? Answering this question requires that you trace the carbon that comes out of the tail pipe of a car burning ethanol back to its source.

   The processing of switchgrass to produce ethanol requires energy – mostly electrical – that has a carbon footprint. However the actual fuel itself does not, because the carbon in the ethanol came from the atmosphere. It's not "new" carbon moving into the atmosphere. Therefore, the net carbon footprint of ethanol is less than that of gasoline.

3. For each fuel source, which stage has the largest carbon footprint?

   For gasoline and ethanol, the stage with the largest carbon footprint is when the fuel is burned in the car. When the fuel is combusted in the car engine, essentially all of the carbon in it is converted to CO_2. For cars run on electricity made from coal or natural gas, the stage with the largest carbon footprint is the production of electricity at the power plant. Again, the process is combustion and essentially all of the carbon in the fuel is converted to CO_2.

4. Looking at the number of total CO_2 equivalents produced for each fuel source, organize the fuel sources from smallest to biggest carbon footprint.

   cellulosic ethanol made from switch grass< electricity made from natural gas< electricity made from coal < gasoline

5. Cellulosic ethanol made from plants such as switch grass is just now becoming available in a few areas. The next best choice is electricity made from natural gas. Use this site to determine where the electricity in your state comes from. http://www.eia.gov/state/

Looking to the future

6. The carbon in ethanol is recycled. It came from the atmosphere. The switchgrass used it. The switchgrass material was converted ethanol. The ethanol was burned releasing CO_2 back into the atmosphere. Unfortunately some of the benefits of this are offset by the carbon footprint from processing the switchgrass material to make ethanol. Using electricity in a car has no carbon footprint, but the production of electricity using fossil fuels does. How could we combine the best parts of these two ways of powering a car (switch grass and electric cars) into a method for moving cars with a very low carbon foot print?

   The switchgrass material could be burned in a power plant to produce electricity that in turn could be used to power a car.

7. Sometimes the expense and/or the inconvenience keep us from making the best choices for the environment. In the table below, write any extra expenses or inconveniences associated with the two most environmentally-friendly was of powering cars.

	Extra expense	Inconvenience
Ethanol (E85) Cellulosic (100% switchgrass)	*Cellulosic ethanol costs more than gasoline.*	*Not much*
Electricity from Natural Gas	*Electric cars are more expensive*	*Battery limits number of miles you can drive. Recharging battery take time and special stations.*

8. What technology improvements would make the best environmental choices cheaper and more convenient?

   Less expensive ways of processing switchgrass material into ethanol would lower the price of ethanol compared to gasoline. Batteries are the main cost and inconvenience with electrical cars, so better battery technology (lighter, cheaper batteries that would allow you to drive more miles without recharging) would lead to cheaper cars and more convenient driving.

How Life Cycle Analyses Work

9. Explain how Life Cycle Analyses give us meaningful data for comparison of complex processes.

   Life cycle analyses define one metric that is a measure of the environmental impact of all of the processes. In this case it was the CO2 equivalents. Then, for every stage of each process, data are gathered to help estimate that metric for that stage. Finally the impact from all of the stages are summed. This works because, even though the processes are different, they are compared based on the same metric.

A Guide to the Numbers for Teachers

A lot goes into the data presented in this data dive. Here are some notes that might help answer students' questions about the meaning of the numbers.

	Ground/field to processor	Bioenergy credit	Processing to Fuel/electricity	Vehicle Operation	Total CO_2 eq (kg/mi)
Gasoline (100% gasoline)	0.0295		0.0597	0.3443	0.4335
Cellulosic Ethanol (E100) made from switchgrass	0.0781[1]	-0.3126 [2]	-0.0007[3]	0.3248	0.0896
Electricity made from coal	0.0227		0.3688	0	0.3915
Electricity made from natural gas	0.0306		0.1651	0	0.1957[4]

[1]The field-to-processor number for switchgrass includes the carbon emissions from planting, application of fertilizer and herbicide, harvesting, other field processes, and drying. The switchgrass lifetime is assumed to be 10 years, with planting occurring in Year 1 and harvesting occurring each of the 10 years. The field-to-processor number represents one average year of switchgrass production.

[2]The bioenergy credit applies only to ethanol made from switchgrass, because this is the only option listed where part of the process (growing switchgrass) removed carbon from the atmosphere as the grass did photosynthesis.

[3]The processing-to-fuel number for switchgrass is based on the assumption that one of the products of switchgrass processing, lignin, is burned in order to provide heat for the production and purification of ethanol. This is the current practice. This reduces the use of less fossil fuels or electricity.

[4]Both natural gas and coal are fossil fuels. However, the carbon footprint of using natural gas to make electricity is much lower than the footprint of coal. This is because coal is primarily made of carbon atoms, which when burned produce CO_2. Natural gas contains approximately 4 hydrogen atoms for each carbon atom (CH_4). When burned, the carbon ends up in CO_2 while the hydrogen ends up in water vapor. The water vapor is also a greenhouse gas, but it doesn't persist in the atmosphere for very long. The average half-life of water in the atmosphere is 9 days as opposed to ~27 years for CO_2.