There's a lot of corn in the Midwest but can we use it to fly?

Grade Levels: 6-9
Lesson Length: Part I: 1-2 class periods, Part 2: 1-2 class periods, Part III: 1-2 class periods for a total of 3-6 class periods of 45 minutes each

Problem Challenge: There is a lot of corn in the Midwest but can we use it to fly?

An effect of global climate change is that the Midwest is now isolated from the rest of world. Your team of scientists needs to find a way to provide sustainable fuel sources for transportation because there is no more gasoline. Without fuel, there is no way to get water, food, and medical supplies around the region.

Fortunately, there is a lot of wind, a lot of good soil, plenty of sun in the summer, and big bodies of water. But is there anything that will power a car or an airplane? Is there anything that will move stuff? And will it do these things without producing the greenhouse gases (GHG) that make climate change even worse?

Lesson Overview

Part I Data Analysis and Discussion – This problem challenge is a contemporary real-world scenario that scientists at Argonne National Laboratory, in the airline industry, in agriculture, from government, and from not-for-profit energy organizations have been exploring for some time: how to reduce greenhouse gases (GHG) from ground and air transportation while meeting the needs of society.

From this collaborative work, two key resources have been developed: Argonne's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model https://greet.es.anl.gov/ and the Midwest Aviation Sustainable Biofuels Initiative (MASBI) report. Both are referenced in the lesson for students as they begin to form their own understanding, just as scientists and policy makers do.

Students are introduced to MASBI report data and to the Argonne GREET model. Here they learn first about the different sources used to make fuel and about their life cycles, including CO_2 emission rates. Through the data chart, students encounter terms that they will use as they explore biofuels.

Part II Making Biodiesel – After looking at and analyzing data, students review energy concepts as they prepare to use lab techniques to make biodiesel. While the chemical reaction is occurring, students might move ahead to testing fuels

(Part III) or use the time to record observations in their journals or on the student page provided in the lesson.

Part III Testing Biodiesel and Other Fuels – Students test the biodiesel they made and compare its properties with those of other fuels. Experimental data as well as information from the MASBI report or other sources will inform students as they work in teams or pairs to propose solutions to the Midwest's transportation problems.

Standards

NGSS-2013.MS-ETS1-1 and HS-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. (MS)
- Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. (HS)

Objectives

- Students will describe and interpret graphical information.
- Students will analyze characteristic properties of fuels.
- Students will synthesize data from different sources to reach conclusions.
- Students will recognize that plants can produce fuel.

PART I: DATA ANALYSIS AND DISCUSSION
Greenhouse Gas Emissions of Fuels

Materials for Part I

- A place to record ideas (i.e. chart paper, whiteboard, projector)
- Journal or lab notebook per student
- Copies of the Problem Challenge on p. 9 in the activity (1 per student to use for annotation and notes)
- An image of a tree, or a piece of firewood or a branch
- An image of corn in a field or on a cob, or an actual corn stalk or cob
- Copies of the MASBI graph p. 9 in the report and p. 8 in the activity (1 per student or pair of students) and to project

Teacher Preparation:

- Identify journal strategies you want students to use
- Per class, set up three large sheets of paper around the room and label them. They will be used to record:
    - Observations
    - New Terms and Ideas

  - Questions
- Make copies of the Problem Challenge (p. 9) per student
- Make copies of MASBI graph (p. 8) per student or group

Part I Activity - Introduction

Distribute the Problem Challenge and read it aloud the to the class. Brainstorm questions and ideas about the scenario. The teacher might want to ask for volunteers to record class suggestions. After a few minutes, when the lists seem complete for the moment, tell learners that they will come back to the notes later. Tell the students that this short description of the problem has terms and ideas they will want to return to later.

There are likely to be comments about unfamiliar vocabulary. Rather than defining each term, the teacher can tell students that they will address the vocabulary when it is relevant to research and discussion.

- Project or post an image of a tree, or point to one outdoors.
  - Ask: Is there a way to use this for fuel? How?
- Project or post an image of corn, either on the cob or in a field.
  - Ask: Is there a way to use this for fuel? How?
  - What do you know about biofuels?
  - Have you ever seen or used a biofuel?
  - What does “bio” mean?

Accessing Students’ Prior Knowledge

As learners talk about the tree and corn, lead them to see that plants can be fuel for heating and cooking. Ask if they think that plants can provide fuel for transportation. If they need to review energy, take a few minutes to be sure they understand that there is energy in trees and corn. There will be time to return to this concept later.

Brainstorm all the different kinds of fuel sources they have heard of or use at home.
Possible Prompts:

- What kinds of fuel do you use or your family use?
- Think of all the items at home that require fuel–what kind of fuel do they use?

Possible answers are kerosene, gas, ethanol, petroleum, biofuels, used vegetable oil.

Student Conceptions: Many students will only be aware of electricity and may not have used or seen any other kind of energy. They also may not know that electricity in their daily lives comes from some fuel source. A purpose of this exercise is to find out what you might need to teach in order to move ahead with the problem challenge. Learners need not have a deep understanding of energy and fuel to grasp the issues and develop creative solutions.

Use additional questions to elicit ideas about different kinds of fuel that come from various sources. For example, fossil fuels (or petroleum based fuels) come from decayed living matter (plants and animals) found deep in the ground in the form of coal or oil. And biofuels are fuels generated from living organisms–mainly plants or waste from living organisms, such as corn or algae.

This is a good place to check in with learners on their understanding of energy, using questions such as:

- How do we use fuels? (*heating, cooking, transportation, making electricity*)
- What do fuels have in them that lets us use them for these purposes? (*energy*)
- Do plants have energy? (*yes*)
- Where does it come from? (*the sun, photosynthesis*)

What the teacher is aiming at is to review student knowledge about energy, plants, and photosynthesis. Because the problem challenge is to develop a fuel that doesn't add to Greenhouse Gases (GHG), it's important to link photosynthesis to carbon and oxygen. Depending on where students are in understanding the chemistry of photosynthesis, at least state and post that plants take in carbon dioxide (CO_2) in this process, use the elements to make food for themselves (and animals and us), then release CO_2 when burned for fuel. Writing out the equation for photosynthesis in a simple form is best for younger learners:

$$CO_2 + H_2O + \text{sunlight} \rightarrow CH_2O + O_2$$

carbon dioxide + water + sunlight → carbohydrate + oxygen

Data Analysis and Discussion

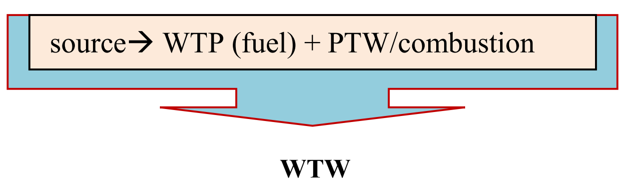
Remind students that they are exploring a real-world problem that scientists, aviation industry experts, and policy makers are currently studying.

Emphasize that a data table in the MASBI report will help learners as they look for solutions to the problem challenge. Pass out Exhibit 1- *Well-to-Wake GHG Emissions by Alternative Jet Fuels Production Pathways*. Direct students to explore this table using the What do you see? What do you think? What do you wonder? teaching strategy. There may be questions about terms. Assure learners that they will find out more about the vocabulary, abbreviations, and units soon enough.

Teaching Strategy: What do you see? What do you think? What do you wonder?
This strategy helps students break down a complex image, chart or table. Ask the students to first focus on what they see or notice (e.g. I see the x-axis label is fuel sources. I see a dark blue color, a light blue color and a green color on the chart.) Then take ideas or even guesses about what those elements might mean (i.e. I think the dark blue represents the Well-to-Pump, the light blue means *Pump-to-Wake* and the green stands for *Well-to-Wake*). Ask others if they agree with this guess or assumption. After there is a group/class consensus, move the class to state an 'I wonder' (i.e. I wonder if there is a relationship between the Well-to-Pump, Pump-to-Wake or Well-to-Wake categories). Open it up to discussion to see if others have thoughts. Run through the series of questions until you have exhausted all the 'seeing, thinking, and wondering'.

After learners have broken down the chart, explain to them that the life cycle of emissions for any fuel will progress through these stages:
Well-to-Pump (WTP), Pump-to-Wake (PTW), and Well-to-Wake (WTW).

a. WTP – a series of steps (pathway) that begins with the source of energy (oil in the ground) and progresses to a final fuel and its distribution end point (conventional JetA at the airport fuel pump).
b. PTW – a single step that involves the combustion of the fuel in specific type of vehicle/aircraft and engine.
c. WTW – is the total life cycle: WTP + PTW = WTW



Ask students to focus their attention on what is actually being compared on this chart. Possible prompts:

- What is the label on the *x-axis*? What is the *y-axis* label?
- What does *GHG* stand for?
- What do the different colored bars mean?
- Which fuel produces the most GHG emissions? How do you know?
- Do you see any patterns on this chart? Describe the patterns.

Teacher Background Knowledge: Spend some time understanding the data in the bar graph. Point out the difference between a *pollutant* and a *greenhouse gas (GHG)*. Pollutants are solids, liquids, or gases that are harmful to plant or animal life, causing disease or even death. Students probably know about acid rain and particulates that cause respiratory diseases, and may think GHG include them. Greenhouse gases are gases that cause the temperature of Earth's atmosphere to increase. GHGs have global effects that are stressful to life, but do not produce cancer or other diseases.

WTW accounts for all net carbon dioxide (CO_2) emissons in a fuel life cycle. How can we express this in terms of the amount of fuel? We could use gCO_2 (grams of CO_2) per gallon of fuel, or gCO_2 per lb of fuel. Another way is to express this in gCO_2/energy unit → gCO_2/megajoule of fuel. For purposes of this activity, it is sufficient that students know a megajoule is a unit of energy.

It is important to know what information is available in a table and what is not there. Use of GREET in this lesson will be limited to the carbon-based greenhouse gas, CO_2. Carbon dioxide is an abundant GHG. Water vapor is another very important GHG but it is not part of the discussion.

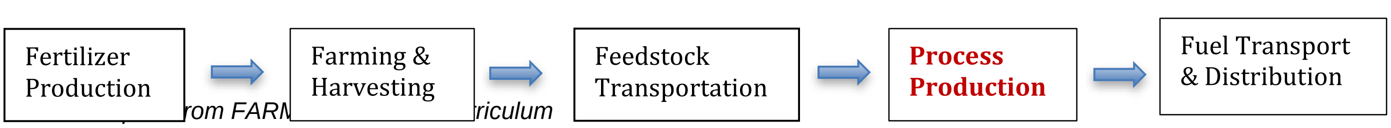
Reinforce for students the connection between fuels and GHG emissions. State that the important GHGs are carbon gases, in particular, carbon dioxide. Ask where students think the CO_2 came from. They should reason that it must be in the fuels. Remind them that the fuels are made of plants, either recently or millions of years ago. Ask for an explanation for how the CO_2 got into the plants. (*photosynthesis*). Now students are ready to talk about biofuels.

Looking at Biofuels

At this time, the class may or may not have identified which of the fuels are biofuels. It is important to tease out for the students which of the fuels listed are derived from a biological source and which are derived from fossil fuels.
Ask the students:

- What do you think biofuels are? (*fuels that used to be living things*)
- What are biofuels made of? (*carbon, hydrogen, oxygen*)
- What is the difference between biofuels and fossil fuels? (*time since they were alive*)
- Which of the fuels listed in the chart are fossil fuels and which are biofuels? (*biofuels–biomass, soybeans, algae; fossil fuels–crude, oil sands, crude mix, natural gas, various kinds of coal*)

Explain to students that the WTP stage for biofuels will have a modified pathway that is shown below in generic form:



Teacher Background Knowledge: Emphasize that every type of energy used for making fuel typically has emissions associated with it. All energy inputs must be tracked and added. When plants use photosynthesis to fix CO_2, that gas will be removed from the atmosphere and placed in a feedstock that can be converted to a fuel. When plants (future *feedstocks* which are plant materials that are used as fuel) do this, WTP emissions drop and typically go negative. The concept of Life-Cycle Modeling estimates the emissions needed to make and consume the fuel for one cycle.

Ask the students:

- How can the WTP bars be tagged with emissions? (*every box above uses energy*)
- How can a bar show negative emissions? (*when plants use photosynthesis to make biomass, CO_2 is removed from the atmosphere*)
- Which kind of fuel can be negative?
- What is the significance of a short Well-to-Wake bar? (*take answers, but don't acknowledge that any are correct*)

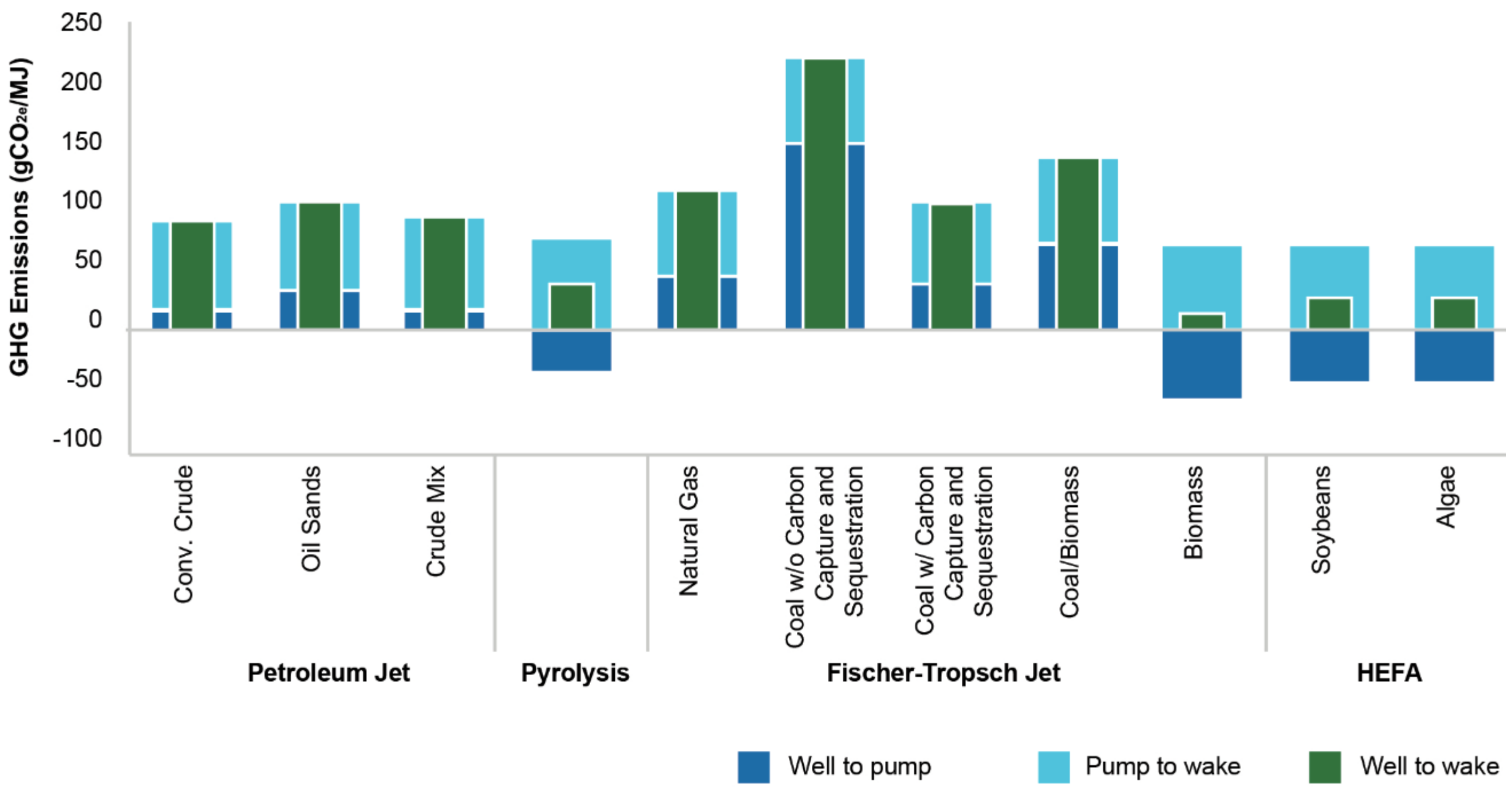
Debrief, Making Sense, Assessment

Ask what big science ideas or themes are contained in this lesson. Record student contributions, being aware that later you can cut redundant ideas or those that are too specific. Students will eventually see that a principle is broad in scope and applies across the sciences, though perhaps not in the context of just this lesson. Some principles or big science ideas that might be on the list are:

- When carbon-based fuels burn, carbon dioxide is released into the atmosphere
- Biofuels and fossil fuels are made of carbon
- Biofuels use up carbon dioxide during their growth period

A formative assessment for this lesson could be to ask students to create a simplified Carbon Cycle sketch or diagram that includes plants, animals, the sun, air, land, and human-made manufacturing or heating or transporting (factories, cars or planes).

EXHIBIT 1: WELL TO WAKE GHG EMISSIONS BY ALTERNATIVE JET FUELS PRODUCTION PATHWAYS



Note: gCO_{2e}/MJ equals units of greenhouse gas per units of energy.

Source: "Life-cycle Analysis of Alternative Aviation Fuels in GREET," A. Elgowainy 1, J. Han 1, M. Wang 1, N. Carter 2, R. Stratton 2, J. Hielman 3, A Malwitz 4, S. Balasubramaian 4; 1-Energy Systems Division, Argonne National Laboratory, 2-Massachusetts Institute of Technology, 3-Massachusetts Institute of Technology; currently with the FAA, 4-John A. Volpe National Transportation Systems Center.

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