FUTURE U.

Sustainable Aviation Fuels

Objectives

Students will:

- **Compare** and **contrast** sustainable aviation fuels with petroleum-based fuels
- **Research** an SAF feedstock and analyze its benefits and considerations
- **Choose** one SAF that they believe is best and **develop** a claim supported by evidence that **defends** this position

Overview

As members of Boeing's Sustainability Research team, students will receive their first assignment: to help Boeing decide how to move forward as it expands its use of sustainable aviation fuels (SAF). After watching a video that introduces the concept, the class will work together to define the term "sustainable aviation fuels" and compare and contrast sustainable aviation fuels with fossil fuels. Students will then break into smaller research teams that each focus on a different SAF feedstock. Team members will collaborate as they research their fuel source, its environmental benefits and/or risks, its social benefits and/or risks, and its potential sustainability. After sharing their findings with the class, students will write independent claims that identify the one SAF source they believe Boeing should focus on moving forward. The class will ultimately vote to determine the top SAF source for Boeing's aircraft.

This lesson focuses on

Engineering Design Process

- Defining the problem
- Designing solutions
- Communicating results

21st-Century Skills

- Communication
- Collaboration
- Critical thinking
- Creativity

Timing

Three 50- to 60-minute class periods

Materials

DAY 1

- Computer or device with the ability to project, one for the instructor

- Energy Options handout (half sheet), one per student
- *Biofuels: Renewable Jet Fuel* video, to project
- Research Suggestions handout (cut in strips in advance), six copies
- Sustainable Aviation Fuel Research Notes, one per student
- Devices with Internet access, enough for at least half the class

DAY 2

- Devices with Internet access, enough for at least half the class
- Completed Sustainable Aviation Fuel Research Notes, from Day 1
- Research Suggestions strips, from Day 1
- Blank, lined paper, one per student

DAY 3

- Sustainable Aviation Fuels: Presentation Notes handout, one per student
- Completed student work (collected during Day 2)
- Looking Forward handout, one per student

Have you ever wondered…

What exactly are sustainable aviation fuels?

Though some may be more familiar with the term biofuels, sustainable aviation fuels are different in that they can be produced from not only biological resources but also a variety of other, nonbiological sources. For this reason, the term "sustainable aviation fuels," or "SAF," is used by the aviation industry. The International Civil Aviation Organization, a United Nations agency, defines SAF as “any fuel that has the potential to generate lower carbon emissions than conventional kerosene on a life-cycle basis.” These alternative fuels are able to accomplish lower carbon emissions by shifting from traditional fossil fuel sources like coal, oil, and natural gas to sources (or feedstock) that range from used cooking oil to municipal waste, wood, plants, and algae—to name just a few. When conventional fossil-based fuel is blended with this alternative fuel, it becomes SAF and can be used without any aircraft modifcations.[1]

What are the benefits of sustainable aviation fuel?

Among the most important benefits of SAF are its positive environmental effects. As its name implies, SAF is produced sustainably and meets “sustainability criteria such as life-cycle carbon emissions reduction, limited fresh-water requirements, no competition with needed food production and no deforestation.” When SAF is made with biological products, the carbon dioxide absorbed by plants during their growth is about the same as the amount of CO_2 that is produced when the fuel is used. Though CO_2 is emitted when SAF is produced, the overall reduction in CO_2 emissions when compared to fossil fuels can be as much as 80 percent. In addition, SAF has economic and social benefits. SAF offers a reprieve from the frequent price fluctuations of a single oil source. SAF could also provide increased job opportunities for countries that are able to grow crops as feedstock. It may also help control waste in developing countries around the world, as some of this waste can be turned into fuel.[1]

Make Connections

How does this connect to students?

Around the world, the average person is responsible for 5.3 tons of carbon dioxide emissions from fossil fuels each year. The average American, on the other hand, is responsible for more than 3.5 times this amount.[2]

The effects of these carbon emissions on climate change are widespread and well-known—from changing weather patterns to loss of sea ice and accelerated sea level rise—and it's the responsibility of people of all ages to combat it.

It will take a combination of individual actions, along with national and global efforts, to reduce our carbon emissions. While students may not currently be able to contribute to the development or implementation of SAF, it's important for them to learn as much as they can about how the world can combat climate change and how citizens and companies can work toward building a more sustainable future.

How does this connect to careers?

Chemist: Chemists investigate the properties and reactions of matter. Those that focus on sustainable aviation fuels and biofuels study the chemical processes that produce these fuels and analyze compounds to see what yields the best possible fuel.

Microbiologist: Microbiologists study the growth and development of microscopic organisms like bacteria, plant cells, and algae, and they can apply what they learn to develop new ways of producing sources or feedstock for sustainable aviation fuels.

Process Engineer: Process engineers design new industrial processes, asses existing equipment, review current processes, and create plans for improvement. Process engineers who specialize in SAF may determine the best ways to produce sustainable aviation fuel as effectively and cost-efficiently as possible.

How does this connect to our world?

Humans are responsible for almost the entire increase in greenhouse gases that have entered the atmosphere over the last 200 years. In particular, China, the United States, and the countries of the European Union are the world's three largest greenhouse gas emitters.[3]

The largest source of these emissions is the burning of fossil fuels for electricity, heat, and transportation.[4]

Aviation contributes about 2 percent of all human-induced carbon dioxide emissions. It is projected that this number will increase to 3 percent by 2050, making the success and implementation of sustainable aviation fuels even more important.[1]

While exploring environmentally friendly options is crucial for all modes of transportation around the world, incorporating SAF into the commercial aviation industry may be less complex than introducing it to other forms of transportation. This is mainly because A) There are fewer fuel depots for airplanes than there are gas stations for cars and B) While private citizens own their own vehicles, commercial planes are controlled by airlines—making the integration of SAF simpler to manage.[1] Therefore, it may be up to the airline industry and companies like Boeing to lead the way in sustainable fuels so other industries can follow.

Sources

1 "Beginner's Guide to Sustainable Aviation Fuel." Air Transport Action Group. aviationbenefits.org/media/166152/beginners-guide-to-saf_web.pdf.

2 "Global carbon emissions growth slows, but hits record high." Stanford News. news.stanford.edu/2019/12/03/global-carbon-emission-increase/.

3 "Global Emissions." Center for Climate and Energy Solutions. c2es.org/content/international-emissions/.

4 "Sources of Greenhouse Gas Emissions." United States Environmental Protection Industry. epa.gov/ghgemissions/sources-greenhouse-gas-emissions

Blueprint for Discovery

DAY 1

1. Begin class by thanking students for joining Boeing's Sustainability Research team. Explain that Boeing is dedicated to building a more sustainable future. While there are many ways to do this, the research team's first assignment will be to help Boeing decide how to move forward as the company looks to expand its use of sustainable aviation fuels.
2. Take a step back for a moment and ask the class: What does the world use fuel for? Be sure students mention transportation (road, sea, air, and space), home uses such as cooking or heat, and electricity generation.
3. Explain that about 90 percent of the fuel used in these circumstances comes from burning fossil fuels. Oil (petroleum), coal, and natural gas are all fossil fuels. While most airplanes and other spacecraft rely on petroleum for energy, Boeing wants to begin relying more heavily on other options.
4. Distribute one Energy Options handout to each student and tell the class that you are about to play a short video that explains *why* Boeing is looking to explore alternative fuel options. Instruct students to jot notes on their Energy Options chart as they watch. Encourage them to worry less about the similarities between sustainable aviation fuels and petroleum-based fuels and instead focus on notes that describe the differences between them.

   Before you begin the video, quickly mention that it will refer to "biofuels" and not "sustainable fuels." Explain that the aviation industry has shifted from biofuels to using sustainable aviation fuels (SAF) because the term biofuels refers to fuels produced from plant or animal materials whereas sustainable aviation fuel can now be produced from non-biological resources, too.
5. Then play the Biofuels: *Renewable Jet Fuel* video. Pause the video for a few seconds at 0:25, 1:11,1:46, and then again at the end to give students a chance to jot notes.
6. When the video is complete, ask students to explain the largest differences between sustainable aviation fuels and petroleum. Be sure students understand that:
   - Sustainable aviation fuels can be made from many different sources, such as seeds and nuts, algae, microbes, edible plants, and forest wastes.
     - Explain that petroleum is actually made from dead plants, algae, and bacteria—but it was created underground over millions of years as these fossils transformed into a liquid oil after being exposed to heat and pressure. Today, petroleum can only come from this underground source.

- Sustainable aviation fuels are renewable while petroleum fuel is not.
    - Explain that fuels made from living plants can be replenished whereas fossil fuels cannot be replaced fast enough to meet our needs.
- Sustainable aviation fuels emit less carbon dioxide.
    - Explain that the oil we extract from the ground must go through a process called "refinement" to be turned into petroleum. Refining petroleum creates air pollution, and burning gasoline produces carbon dioxide. The sustainable feedstock in SAF does not go through this process. Furthermore, the CO_2 consumed by plants when biological SAF sources are grown can actually offset the CO_2 produced when the fuel is used.

7. Then ask students to think-pair-share* similarities between the two fuel types.

***In a think-pair-share, students think about the question independently, discuss their answers with a partner, and then share their thoughts with the larger class.**

- Ensure students understand that both types of fuels can be used to safely power airplanes without making any changes to the airplanes.
- Also be sure students understand that SAF must currently be mixed with petroleum jet fuel before it can be used. But, hopefully, this won't always be the case!

8. Once students have completed their Venn diagrams, ask them to summarize *why* they think Boeing wants to expand its use of SAF.

9. Then explain that while there are many possibilities being explored for SAF, there are seven SAF sources or feedstock that Boeing would like to investigate before deciding which one to focus on moving forward.

Divide the class into seven groups and explain that each research team will focus on a different SAF source: municipal solid waste, used cooking oil, lumber and logging waste, the Salicornia plant, sugarcane, algae, and tobacco plants.

10. Distribute one Sustainable Aviation Fuel Research Notes handout to each student. Explain:

- Questions 1–4 on this handout will help students better understand their SAF and consider its pros and cons. Students should work individually or in pairs to research these questions.
- Groups will then reconvene to share what they have learned and prepare an answer for the final question (5). It is this answer that the groups will present to their peers.
- At the end of these presentations, Boeing's Sustainability Research team will take a vote and decide how Boeing should move forward to expand its use of sustainable aviation fuels.

11. Then distribute the applicable strip from the Research Suggestions handout to each student. Tell the class that these are their research starting points. They should access the websites in the order they are listed as they begin to research their SAF. If students would like to perform additional Internet research after they have read these sources, they may.

Tell students that there is more information available about some SAF sources than others. It's OK for groups to *infer* (or make an educated guess based on their research) some of their answers as long as they can explain their reasoning.

12. Finally, tell the students that they will have the rest of this class session and about half of the following session to complete their research and answer questions 1–4. They will reconvene with their

groups and answer question 5 during the second part of the following class period. Then instruct them to begin their research!

13. As students complete their research, move around the classroom, answering questions as needed. Provide a 5-minute warning when class is almost complete and collect the students' notes and research slips at the end of the class period for safekeeping.

DAY 2

1. Begin by welcoming Boeing's Sustainability Research team back to their second day.
2. Remind the class that groups will spend the first portion of the session finishing their research. When there are 20–25 minutes left in class, students will regroup, work on question 5, and develop their presentations.
3. Redistribute the research notes and suggested website slips to the students and instruct them to continue their work.

   Tip: If it seems like students still have a lot of research to complete, encourage groups to split up the research questions for the time remaining. They can then share what they have learned with each other during the second half of class.
4. Keep an eye on the close, watching for the period's halfway point. Provide a 10-minute warning and a 5-minute warning. Then ask each group to reconvene when the period is half over.
5. Distribute lined paper to each group and instruct students to share what they have learned with one another. They should then collaborate and develop an answer to question 5 on the paper you have provided. Explain that they will present this answer to the rest of the Sustainability Research team, so it should clearly explain their SAF fuel, its main benefits, and any considerations that should be kept in mind. The entire research team will then decide which option Boeing should focus on moving forward.
6. Again provide students with a 10-minute warning and a 5-minute warning for the end of the class period.
7. When the session is complete, collect the class's work. Explain that after quickly reconvening at the beginning of the next session, the groups will present their findings.

DAY 3

1. Begin class by instructing students to find their research groups. Explain that each group will have five minutes to fine-tune its answer to question 5 and decide who will share the response with the class. Encourage students to split up the presentation so many, if not all, group members have a chance to speak.
2. Then bring the class back together and distribute one Sustainable Aviation Fuels: Presentation Notes handout to each student.

   Review the graphic organizer's headers and explain that as each group presents its SAF, the listeners should use this organizer to take notes.

   Tell the class that when all of the presentations are complete, each student will submit a written decision that explains which SAF he or she believes Boeing should focus on. This decision must include supporting evidence from the presentations!
3. Then encourage groups to present one at a time. Ask students to keep their presentations to no more than two or three minutes. You may also allow an additional minute for questions at the end of each presentation. Remind students, as needed, to take notes during each one.

4. Once the presentations are complete, thank the research teams for their thorough investigations. Then distribute one Looking Forward handout to each student. Explain that for the rest of the period students will use their research notes to independently identify the one SAF source they believe will be best for Boeing to focus on moving forward.

   Review the handout's directions together. Then deduct five minutes from the end of the class session and tell the class they will have this much time to write their claim.

5. After you give students a 5-minute warning, collect their work when no time remains. As you do, look at the SAF selection that each student circled and sort the responses. Once all work has been sorted, count the "ballots" and share the SAF source that the Sustainability Research team has selected as Boeing's new focus area.

6. Finally, conclude by thanking students for their hard work, research, and analysis. Remind students of the importance of collaborating to build a sustainable future and explain that many STEM careers work together to support SAF, including microbiologists, chemists, chemical engineers, operations engineers, aircraft fuelers, aircraft mechanics, and construction workers. Encourage students to explore careers in sustainability and the environment as they begin to consider their own futures and the future of our planet.

Extend

Students can consider other potential uses for biofuels in their everyday life. After selecting a category (such as transportation, heating, or cooking), students can research the current state of biofuel in this area and develop a short-term or long-term plan for incorporating biofuel into this aspect of their lives and/or their community.

National Standards

Next Generation Science Standards

Earth and Human Activity:

- MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.
- MS-ESS3-5: Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.
- Disciplinary Core Idea ESS3.D: Global Climate Change: Human activities, such as the release of greenhouse gases from burning fossil fuels, are major factors in the current rise in Earth's mean surface temperature (global warming). Reducing the level of climate change and reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding of human behavior and on applying that knowledge wisely in decisions and activities. (MS-ESS3-5)

C3 Framework for Social Studies State Standards

- D2.Geo.4.6-8: Explain how cultural patterns and economic decisions influence environments and the daily lives of people in both nearby and distant places.
- D4.1.6-8: Construct arguments using claims and evidence from multiple sources, while acknowledging the strengths and limitations of the arguments.

Common Core English Language Arts Standards

Reading:

- CCRA.R.1: Read closely to determine what the text says explicitly and to make logical inferences from it; cite specific textual evidence when writing or speaking to support conclusions drawn from the text.

Writing:

- CCRA.W.1: Write arguments to support claims in an analysis of substantive topics or texts using valid reasoning and relevant and sufficient evidence.

Speaking and Listening:

- CCRA.SL.4: Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose, and audience.

Energy Options

Sustainable aviation fuels and biofuels	Both	Petroleum

Sustainable aviation fuels and biofuels	Both	Petroleum

Research Suggestions

Municipal Solid Waste

- tinyurl.com/y34dejv5
- tinyurl.com/sbdbhvf (page 6)
- tinyurl.com/scuqh94

Used Cooking Oil

- tinyurl.com/ya7wxeoa
- tinyurl.com/w5dhxm5

Lumber and Logging Waste

- tinyurl.com/uurmq8f
- tinyurl.com/uxpkt7f

Salicornia Plant

- tinyurl.com/rjyjym5
- tinyurl.com/y54g292b
- tinyurl.com/suhaqwf

Algae

- tinyurl.com/sbdbhvf (p 7)
- tinyurl.com/w7btzbz
- tinyurl.com/spc4xl4

Sugarcane

- tinyurl.com/qkfzzuv
- tinyurl.com/y973kuq8

Nicotine-Free Tobacco Plants

- tinyurl.com/zegm99r
- tinyurl.com/wuybtxn

Sustainable Aviation Fuel Research Notes

Directions: As you research your sustainable aviation fuel (SAF), answer the questions below.

1. Briefly describe this type of sustainable aviation fuel (SAF). What is it and how does it work?

2. Why is this SAF better for the environment than regular jet fuel? Are there any considerations (or negative effects) to keep in mind?

3. How could this SAF affect communities in positive and/or negative ways?

4. Think about how developing this fuel could affect people's everyday lives, local jobs and economies, living conditions, etc.

5. Does it seem like this type of SAF is sustainable? In other words: Is it possible to develop and use this fuel in large quantities and continue to use it at this pace? Why or why not? Be sure to consider whether the source of this fuel is renewable (or can be easily replenished).

6. Share your findings with your group. Then work together to summarizewhat you learned as you prepare to share your SAF with the rest of your peers. Be sure to include: A) What is this SAF? B) What are the biggest benefits of this SAF? C) What important considerations should be kept in mind?

Sustainable Aviation Fuels: Presentation Notes

SAF Type	What is it?	Benefits or Positive Characteristics	Considerations or Negative Characteristics
Municipal Solid Waste			
Used Cooking Oil			
Lumber and Logging Waste			
Sugarcane			
Salicornia plant			
Algae			
Nicotine-free tobacco plants			

Looking Forward

As a member of Boeing's Sustainability Research team, decide:
Which sustainable aviation fuel do you believe Boeing should focus on moving forward?

Circle one:

municipal solid waste	used cooking oil
lumber and logging waste	Salicornia plant
sugarcane	algae
tobacco plants	

Use evidence from the research presentations to explain:

- At least two positive reasons that support why this SAF is the best option.
- At least two reasons why this SAF is the best option.