Curriculum Guide

JOURNEYS IN FILM™
educating for global understanding

FINALIST
Environmental Film Festival in the Nation's Capital
2021

OFFICIAL SELECTION
Wildlife Conservation Film Festival
2021

AWARD OF EXCELLENCE
Nature Without Borders International Film Festival
2021

OFFICIAL SELECTION
St. Louis International Film Festival
2021

Platinum Remi Award
WorldFest-Houston International Film Festival
2021

HUMANS HAVE TRIGGERED EARTH'S OWN CYCLES OF WARMING—IS IT TOO LATE TO STOP THEM?

CLIMATE EMERGENCY: FEEDBACK LOOPS

MOVING STILL PRODUCTIONS, INC. PRESENTS "CLIMATE EMERGENCY: FEEDBACK LOOPS"

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FEEDBACKLOOPSCLIMATE.COM

Climate Emergency: Feedback Loops

Curriculum Guide

Journeys in Film
www.journeysinfilm.org

Educating for Global Understanding

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About *Journeys in Film*

Journeys in Film is a 501(c)(3) nonprofit organization that amplifies the storytelling power of film to educate the most visually literate generation in history. We believe that teaching with film has the power to help educate our next generation with a richer understanding of the diverse and complex world in which we live.

We transform entertainment media into educational media by designing and publishing cost-free, educational resources for teachers to accompany carefully chosen feature films and documentaries while meeting mandated standards in all core subjects. Selected films are used as springboards for lesson plans in subjects like math, science, language arts, social studies and more. Our resources support various learning styles, promote literacy, transport students around the globe, and foster learning that meets core academic objectives.

In addition to general subject areas, Journeys in Film's programs engage students in meaningful examinations of human rights, poverty and hunger, stereotyping and racism, environmental issues, global health, immigration, and gender roles. Our teaching methods are successful in broadening perspectives, teaching for global competency, encouraging empathy, and building new paradigms for best practices in education. We seek to inspire educators, school administrators, community members and home-schooling parents to use our innovative curriculum to capture the imagination and curiosity of their students.

We also develop discussion guides for films that don't necessarily lend themselves to academic standards but cover topics and themes that are valuable for classroom discussions and in other settings, such as after school clubs, community screenings, and college classes.

Journeys in Film is a 501(c)(3) nonprofit organization.

Why use this program?

In an age when literacy means familiarity with images as much as text and a screen has become a new kind of page, 21st-century students are more connected to media than any previous generation. This offers educators unprecedented opportunities to engage students in learning about a variety of subjects and issues of global significance. Films, television, documentaries, and other media platforms can provide an immediate, immersive window to a better understanding of the world and matters affecting all of us.

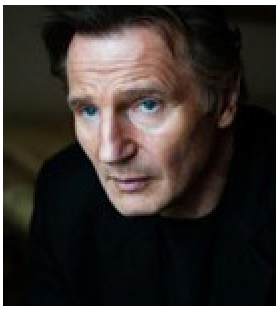
We teach our students literature that originated from all around the world, but we tend to forget that what often spurs the imagination is both visual and auditory. Films evoke emotion and can liven up the classroom, bringing energy to a course. We believe in the power of films to open our minds, inspire us to learn more, provide a bridge to better understanding the major issues of 21st-century concern, and compel us to make a difference.

When properly used, films can be a powerful educational tool in developing critical thinking skills and exposure to different perspectives. Students travel through these characters and their stories: They drink tea with an Iranian family in *Children of Heaven*, play soccer in a Tibetan monastery in *The Cup*, find themselves in the conflict between urban grandson and rural grandmother in South Korea in *The Way Home*, and watch the ways modernity challenges Maori traditions in New Zealand in *Whale Rider.* Journeys in Film brings outstanding and socially relevant documentaries to the classroom that teach about a broad range of social issues in real-life settings, such as famine-stricken and war-torn Somalia, a maximum-security prison in Alabama, and a World War II concentration camp near Prague. They explore complex and important topics like race and gender. Students tour an African school with a Nobel Prize–winning teenager in *He Named Me Malala* and experience the transformative power of music in *The Music of Strangers: Yo-Yo Ma & the Silk Road Ensemble* and *Landfill Harmonic*.

Our hope is that this generation of youth will contribute to the betterment of humankind through kindness and understanding, together with scientific knowledge to help solve some of the world's most pressing issues.

Our goal is to create relevant and engaging curricula and programming around media that encourage cross-cultural understanding, empathy, and knowledge of the people and environments around the world. We aim to prepare today's youth to live and work as globally informed, media- literate, and competent citizens.

A Letter from Liam Neeson



Working in films such as *Michael Collins* and *Schindler's List,* I've seen the power of film not only to entertain, but also to change the way audiences see themselves and the world. When I first met Joanne Ashe, herself the daughter of Holocaust survivors, she explained to me her vision for a new educational program called ***Journeys in Film: Educating for Global Understanding***. I grasped immediately how such a program could transform the use of film in the classroom from a passive viewing activity to an active, integral part of learning.

I have served as the national spokesperson for ***Journeys in Film*** since its inception because I absolutely believe in the effectiveness of film as an educational tool that can teach our young people to value and respect cultural diversity and to see themselves as individuals who can make a difference. ***Journeys in Film*** uses interdisciplinary, standards-aligned lesson plans that can support and enrich classroom programs in English, social studies, math, science, and the arts. Using films as a teaching tool is invaluable, and ***Journeys in Film*** has succeeded in creating outstanding film-based curricula integrated into core academic subjects.

By using carefully selected documentary and international films that depict life in other countries and cultures around the globe, combined with interdisciplinary curricula to transform entertainment media into educational media, we can use the classroom to bring the world to every student. Our film program dispels myths and misconceptions, enabling students to overcome biases; it connects the future leaders of the world with one another. As we provide teachers with lessons aligned to Common Core Standards, we are also laying a foundation for understanding, acceptance, trust, and peace.

Please share my vision of a more harmonious world where cross-cultural understanding and the ability to converse about complex issues are keys to a healthy present and a peaceful future. Whether you are a student, an educator, a filmmaker, or a financial supporter, I encourage you to participate in the ***Journeys in Film*** program.

Please join this vital journey for our kids' future. They are counting on us. ***Journeys in Film*** gets them ready for the world.

Why We Must Act Now

"We're reaching the stage in the heating of the earth when fundamental systems are disrupted: the jet stream, the Gulf Stream, even the way the planet reflects and absorbs sunlight. As these five films will make clear to to all who view them, we are kicking off feedback loops beyond our ability to control—once we've melted the Arctic no one has a plan for refreezing it; the great forest fires pour ever more carbon into an already overloaded atmosphere. We've run out of margin—we must act now to stop the burning of fossil fuel that lies at the bottom of this cascading crisis."

—Bill McKibben, author, environmentalist, and co-founder of anti-carbon campaign group *350.org*

"The global average temperature continues to set new records. Extreme heat waves and intense droughts now affect much of the globe, damaging agriculture and facilitating wildfires. Simultaneously some regions are experiencing extreme storms, precipitation, and flooding. These specific changes were anticipated by some scientists 40 years ago, but the changes were not supposed to happen until 2100 or later. Why now? The direct warming has melted reflective ice and snow and released additional heat trapping gases from permafrost and other lands. These feedbacks have amplified the warming and disrupted the climate decades to a century sooner than anticipated. We can unwind this accelerating downward spiral by rapidly reducing heat trapping gases and by allowing more forests and other natural systems that are already removing 31% of our annual emissions each year to accumulate additional carbon out of the atmosphere. This will eventually slow global warming and diminish the feedbacks, facilitating the return to a more benign climate. The feedback loop videos identify four major feedbacks and clearly demonstrate how they interact to accelerate further warming and increase the resulting climate change consequences."

— William Moomaw, Professor Emeritus, The Fletcher School, Tufts University
Lead author of the Nobel Prize-winning Intergovernmental Panel on Climate Change

Introducing *Climate Emergency: Feedback Loops*

The five short films of *Climate Emergency: Feedback Loops* were released in 2021, a year after one of the hottest years on record. In 2020, the Earth experienced a range of extreme weather that may have finally caught the attention of policy-makers:

- A Siberian heat wave set temperature records in excess of 100 degrees Fahrenheit within the Arctic Circle.
- Wildfires ravaged the western United States and Australia.
- The Atlantic hurricane season, with an extraordinary 30 named storms, caused over $46 billion in damages to property.
- The area of Arctic sea ice was at a record low.
- Super Typhoon Goni hit the Philippines with sustained winds of 195 miles per hour.
- Monsoon flooding in China destroyed or damaged 1.4 million homes and businesses.

Extreme as these events were, scientists are even more worried about the Earth's natural feedback loops that have the potential to create even more disastrous weather events. According to an article in *Scientific American,* "…catastrophic climate change could render a significant portion of the Earth uninhabitable consequent to continued high emissions, self-reinforcing climate feedback loops and looming tipping points."[1]

What is a feedback loop? Feedback loops are a continuous system in which a change in one (or more) parts of the system act to influence the rest of the system, either positively (increasing the effects of the system) or negatively (decreasing the effects of the system). A positive feedback loop is a circular chain of events that can amplify a change within a system. In a negative feedback loop, series of events dampen the change within the system, helping make it more stable.

1 https://www.scientificamerican.com/article/the-climate-emergency-2020-in-review/

The five films of *Climate Emergency: Feedback Loops* use stunning video, interviews with leading climate scientists, and thoughtful narration by Richard Gere to educate the viewer on key feedback loops greatly accelerating climate change. The "Introduction" film drives home the point that human activity is increasing global warming and leading to climate change. It explains the concept of feedback loops and shows briefly how this concept applies to forests, atmosphere, permafrost, and albedo.

"Forests" explains that the world's trees have long served as a "carbon sink," removing carbon dioxide from the air, storing carbon in wood, leaves, branches, and trees' soils, and in turn releasing water vapor and oxygen. The shrinking of forests, due to human activities like logging and clearing areas for agriculture, means that less carbon is captured and global temperatures increase.

In the video "Permafrost," the viewer learns that this area of frozen ground, which covers about a quarter of the Northern Hemisphere, stores massive amounts of carbon underground. As it begins to thaw, microscopic animals are waking and feeding on frozen vegetation and animals and then releasing more gases into the atmosphere, creating additional warming.

"Atmosphere" deals with warming that is altering the Earth's weather pattern and making extreme weather events more common. Even the jet stream is being affected, resulting in warmer weather moving north and stalling for longer periods of time, with consequent changes in rainfall patterns and flooding.

"Albedo" refers to the ability of Arctic ice to reflect the sun's rays and temper their warming effect. However, the volume of ice is decreasing; it has shrunk 75% in the past forty years, and consequently the albedo effect has diminished. The Arctic may soon be ice-free in the summer.

Taken together, these five short films make the case that time is running out to prevent catastrophic climate change, change that could result in the extinction of whole species and drastically affect human societies. Unless we demand and implement dramatic changes, the Earth will reach a "tipping point" from which there is no return.

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To the Teacher

This curriculum guide, like other **Journeys in Film** resources, is based on several fundamental beliefs:

- That a well-made, relevant film is an excellent way to convey information and teach students important critical thinking skills.
- That talented teachers interacting with real students on a daily basis are best positioned to write good lesson plans.

There are five lessons in this guide. Although it is possible to use all of these lessons, most teachers will select just one or two to use with their classes.

Lesson 1 teaches students about anthropogenic climate change (climate change resulting from human activity) and the role that forests play in the Earth's carbon cycle. After an introduction to the concept of feedback loops, students learn about the processes of photosynthesis and transpiration and how a tree is both a source and a sink of CO_2. Students learn about the structure of trees from their leaves to their roots and study samples of different types of wood. The fourth topic is forest dieback as the result of disease, air pollution, insect infestation, and fires, and how this dieback affects the carbon cycle. Finally, students study the three dominant forest types to learn which is most at risk from climate change.

Lesson 2 teaches students about permafrost and how it has been affected by climate change. They become familiar with the basic concepts of global warming, climate change, increased temperature in Arctic regions, increased concentrations of greenhouse gases released into the atmosphere when the permafrost thaws, damage to structures and artifacts, the release of mercury into the environment, and the potential for the release of ancient pathogenic organisms. Hand-on labs simulate microbial growth, decomposition, and gas release in thawing permafrost. A summative assessment focuses on the regional and global effects of greenhouse gas emissions due to microbial decomposition in thawing permafrost.

Lesson 3 addresses the topics of feedback loops, water vapor, the role that clouds play in Earth's climate, and the impact of changes in the jet stream. Students work in groups to research these topics and teach one another about them. Then they move to looking at their own state more closely by studying data from their State Climate Office. They also learn more about young people who are activists fighting against climate change. (Note: If you are planning to teach Lesson 5, you may wish to skip Part 3 of this lesson or combine it with the research activity in Lesson 5.)

Lesson 4 is on albedo and its role in climate change. This lesson also begins with the concept of feedback loops. Then students study the relationship between melting sea ice and climate change and the implications of this relationship for the planet. A lab reinforces the concepts with a collection of substances of different colors and textures designed to represent different types of surfaces on Earth exposed to a light source.

Lesson 5 is a different kind of lesson from the previous ones. During this lesson, students research a group of young climate change activists, learning about their actions and the organizations they belong to. They work to design a project that would help to re-green their own community or region, considering the resources they would need to put their project into action, the permissions they would have to secure, and the ways that they would be able to measure whether their project was successful.

It is vitally important that students not feel discouraged or hopeless as they contemplate the feedback loops that are accelerating climate change. In addition to Lesson 5, you may wish to encourage them to explore Project Drawdown (https://drawdown.org/). "Drawdown" is defined on this website as "the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline." This non-profit organization reviews and evaluates potential climate solutions, advances communication about such solutions, and works with partners to accelerate climate solutions.

For more information about other free Journeys in Film curriculum and discussion guides, please see the Journeys in Film website at www.journeysinfilm.org.

Lesson 1

Forests

Enduring Understandings

- Forests help cool a warming Earth.
- Feedback loops can amplify either the worsening or the improvement of the climate crisis.
- Forests play an important role in the climate crisis.
- Trees have complex structures (leaves, trunks, and roots).
- There are three dominant types of forests on Earth: tropical, boreal, and temperate.

Essential Questions

- What is a feedback loop?
- How can forests be both carbon sources and carbon sinks?
- What is photosynthesis?
- What is transpiration? How does it differ from evaporation?
- What is the structure and function of wood in the carbon cycle?

Notes to the Teacher

This lesson is designed to teach students about anthropogenic climate change (climate change resulting from human activity) and the role that forests play in the Earth's carbon cycle. Topics include photosynthesis, transpiration and how it differs from evaporation, the structure and function of wood in the carbon cycle, carbon sources and sinks, and the three dominant forest types and their respective roles in the carbon cycle.

The lesson is divided into five parts that build on one another. Part 1 introduces the concept of feedback loops. After reading the first two paragraphs of **Handout 1: Feedback Loops**, students will view the video "Forests" and complete most of the handout together as a class. If they have already seen the "Introduction" video at https://feedbackloopsclimate.com/ and are familiar with the concept, you may wish to skip the first step in this part of the lesson.

Part 2 introduces students to the processes of photosynthesis and transpiration and explains a tree's "day job" as a source (of water vapor) and sink (uptake of CO_2) relative to the water and carbon cycles. The goal is learning about the light-dependent and light-independent reactions of photosynthesis to make sure students know when each reactant and product is used in the process. The video on photosynthesis from Paul Anderson's Bozeman Biology site is excellent, especially for high school biology classes. Be sure to view it first (14 minutes long) before showing it to your students.

Part 3 introduces students to the structure of trees, from their leaves and/or needles, to the structure of their wood and bark, and finally to their roots and their interaction with other trees and the soil. If possible, before the lesson, visit a local lumberyard and collect wood samples of both hardwoods (Angiosperms) and softwoods (Gymnosperms). Often there will be discarded pieces of such wood samples available at no cost if you explain the reason why you are collecting them. Cut pieces of each type of wood to expose the end-grain surfaces, allowing you and your students to see growth rings, and with the help of a 10X hand lens, the porosity of the hardwood samples. If available, select red oak (ring porous) and maple (diffuse porous), as well as pine or spruce (non-porous). Collect enough samples of each type of wood for the number of groups you plan to have in your class.

Also collect some twig samples with attached leaves of each of the three types of trees: a softwood (such as pine or spruce), an oak, and a maple. If you do not have these types of trees available, collect at least twigs of a conifer (softwood) and a deciduous (hardwood) tree. Be sure to collect enough twig samples for the number of students in your class. Trim each twig to expose a clean cross section of the end-grain, exhibiting both wood and bark. If possible, select twigs old enough to have produced two or three or more growth rings. You should also locate a dichotomous tree identification key for trees in your area; many are available on a statewide basis. Be sure to familiarize yourself with how to use the key before the class begins.

At the end of the lesson is a set of magnified images of wood sections on **Teacher Resource 1** which you may wish to project for the class to supplement this part of the lesson. You will also find text describing each of the slides.

Part 4 is concerned with the impact of forest dieback, as the result of disease, air pollution, and fires, on the carbon cycle. Students brainstorm the impact of the death of one tree and then read about large-scale forest dieback due to fires and other environmental conditions. They investigate the series of wildfires that occurred in the United States in 2020 and 2021 and research the most recent forest dieback situations. Finally, they discuss the impact of the loss of photosynthesis and transpiration across large areas of land and the feedback loop that occurs as a result.

Part 5 introduces the three dominant forest types and their sensitivity to human pressures, including the climate crisis. According to the “Forests” video, the tropical and boreal forests are the most susceptible to the warming climate. The tropical forest is most at risk and the closest to collapse, due to human destruction (burning to clear land for agriculture, cutting and exporting of valuable tropical hardwoods, etc.). The boreal forest, which holds two-thirds of all forest carbon, is the next most vulnerable, due to thawing of permafrost and wildfires in dead and dying forests. The temperate forest is noted as the least vulnerable, since these forests in the eastern United States are now growing back after the early clearing, and old growth forests in the Northwest continue to store large amounts of carbon. The video points out that green management of these forests is our best hope of the three forest types for maintaining a stable and functional climate system.

This lesson on forests is designed to teach students about the basic inputs and outputs of photosynthesis and transpiration and the role each process plays in the Earth’s climate system. This will help students understand that trees do not convert carbon dioxide into oxygen as many people believe. Instead, the oxygen we breathe comes from the splitting of water molecules; the carbon dioxide is transformed into carbohydrates, such as wood, bark, and energy molecules (sugar and starch) needed for tree growth. In addition, students will learn how wood structure and leaves facilitate water and nutrient transport from soil to leaves, and eventually (in the case of oxygen and water vapor) to the atmosphere. Root function (absorbing water and dissolved soil nutrients) is facilitated by beneficial fungi (mycorrhizae), allowing interactions between trees in a collaborative manner. (Note the Woodwell quote in the video at 0:30–1:13.)

The Earth’s climate has changed throughout history. Just in the last 650,000 years, there have been seven glacial cycles of advance and retreat, with the abrupt end to the most recent ice age about 12,000 years ago, marking the beginning of the modern climate era—and of human civilization. Most of the previous climate changes were attributed to very small variations in Earth's orbit that change the amount of solar energy our planet receives. The current warming is of significance because most of it is extremely likely (greater than 95 percent probability) the result of human activity, primarily the burning of fossil fuels since the mid-20th century. This is proceeding at a rate that is unprecedented in millennia.

This lesson focuses on the significant role that forests must play in acting as an important carbon sink, and the potential of feedback loops in that role, as our planet continues to warm dramatically. Living forests are an example of a negative feedback loop, removing CO_2 from the atmosphere and storing carbon, and thus acting as a carbon sink; dead or dying forests are an example of a positive feedback loop, releasing the stored carbon through wildfires, etc., and thus becoming a carbon source.

Here are some additional helpful resources:

The NASA Global Climate Change website https://climate.nasa.gov/ is suggested to provide a brief introduction and background for the teacher on the facts surrounding climate change.

The Union of Concerned Scientists website https://www.ucsusa.org/climate presents a solid climate-change science source. Other sources listed on that site and in the Additional Resources section of the lesson plan also will be useful for this lesson.

Project Drawdown has several relevant webpages about possible solutions for the temperate forest, the tropical forest, tree intercropping, tree plantations, and more. They are listed at https://drawdown.org/solutions/table-of-solutions.

Laurie David and Heather Reisman's *Imagine It: A Handbook for a Happier Planet* (New York: Rodale Books, 2020) provides suggestions for individuals and families to change their own habits in order to reduce their use of natural resources.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-Literacy.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-Literacy.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

Next Gen Sciece Standards addressed by this lesson

HS-LS1-3 From Molecules to Organisms: Structures and Processes
Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.

HS-LS1-5 From Molecules to Organisms: Structures and Processes
Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.

HS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics
Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-LS2-6 Ecosystems: Interactions, Energy, and Dynamics
Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Duration of Lesson

This lesson could take 2–3 class meetings depending on the level of detail you feel is required for your students. Watch the "Forest" video ahead of time and prepare notes for class discussion. If you use one or more of the optional extended activities provided at the end of this lesson plan, you will need additional time.

Assessments

Brainstorming notes
Handouts and worksheets
Class discussions
Student or group projects and presentations

Materials

Video "Introduction" at https://feedbackloopsclimate.com
Video "Forests" at https://feedbackloopsclimate.com/forests/
Handout 1: Feedback Loops
Handout 2: The Carbon Cycle
Handout 3: Photosynthesis and Transpiration
Handout 4: Tree Structure
Handout 5: Forest Dieback
Handout 6: The Three Types of Forests
Teacher Resource 1: Light Microscope and SEM Images of Wood

Procedure

Part 1: Introduction to feedback loops

1. If time permits and students have not already seen the video "Introduction" at https://feedbackloopsclimate.com, begin the class by showing this video.

2. Explain to students that they are now going to see another short video that will explain more about the impact of climate change on forests and demonstrate how this is part of an important feedback loop. Distribute copies of **Handout 1: Feedback Loops** to students and read through the first two paragraphs together.

3. Ask students if they have heard the term "feedback loops" before. Have them define the term in their own words and give examples of feedback loops they are familiar with. (For example, milking a cow stimulates the production of more milk; a drop in the stock market can lead to a rush to sell which in turn leads to a further drop.)

4. Show the video "Forests" at https://feedbackloopsclimate.com/forests/ and conduct a discussion based on the second question on the handout. Give them a few minutes to answer the question after the discussion.

5. Explain that the class is going to learn much more about forests and the processes described in the video in the next few classes.

6. Have students complete the rest of the handout. For Question 3, suggest that they may want to solicit ideas from their family and friends as well. Answers to Question 4:

> Positive Feedback Loop: Fewer trees, leading to more CO_2, leading to higher temperatures, leading to fewer trees, etc.

Negative Feedback Loop: More trees, leading to less CO_2, leading to lower temperatures, leading to more trees, etc.

7. Distribute copies of **Handout 2: The Carbon Cycle** and have students read it for homework, making notes of any questions they have.

Part 2: Photosynthesis and Transpiration

1. Begin class by asking students, “Where does most of the matter of a tree come from?” Have students brainstorm a list of what makes up the tree (e.g., wood, bark, leaves, flowers, roots, and fruit).

2. Next, brainstorm a list of possibilities of what plants and trees need to grow. Accept all ideas at first and list them on the board. (Students may say light, carbon dioxide, water, oxygen, chlorophyll, chloroplasts, minerals, soil, leaves, etc.)

3. Start a class discussion to see what students know or remember about photosynthesis. Then distribute copies of **Handout 3: Photosynthesis and Transpiration** and have students read about photosynthesis. Hold a discussion to clarify any questions that they have.

4. Show students how to construct the basic photosynthesis chemical formula of inputs and outputs by working together as a group: light + carbon dioxide gas + water yields oxygen gas + glucose (food). This can then lead to writing the formula using the chemical symbols: $6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$.

5. Show the video from Paul Anderson’s Bozeman Biology site on photosynthesis at https://www.youtube.com/watch?v=g78utcLQrJ4 and assign any relevant reading from your student textbook.

6. Now ask students, “How do water and dissolved soil nutrients move up the trunk of a tree?” Have students brainstorm ideas on how water flows from the soil, up the trunk, and out into the leaves, describing potential mechanisms. Define *transpiration* as the loss of water vapor from leaves out through stomates when they open. Ask: Could this be a part of the mechanism that drives the upward water flow? Then have them read the second part of the handout, on transpiration.

7. Have a discussion on how the process of photosynthesis may be involved in the production of oxygen, which also exits the leaf through open stomates. Water vapor, produced in the process of transpiration, condenses in the atmosphere to become clouds. Explain to students that more atmospheric water vapor is produced from transpiration than is produced from evaporation from the surface of rivers, lakes, and the oceans.

8. For homework, give students copies of **Handout 4: Tree Structure** and ask them to read it carefully to prepare for the next class.

Part 3: The structure of trees

1. Spend some time at the beginning of class reviewing with students what they learned from **Handout 4** and answering any questions they may have.

2. Arrange students into groups and give each group a set of the sample twigs to study.

3. Using a dichotomous identification key for your region, have your students identify each of the three types of twigs provided. Often such keys will be based on leaf characteristics.

4. Have the students use either a magnifying glass or a 10X hand lens to examine each type of twig, looking at the cut end and identifying the bark, the wood, any evidence of growth rings, possibly a central pith, etc. Is the bark layered? If possible, have them identify pores in the hardwood twigs.

5. Once they have identified some of the differences in wood structure of the three types of twigs (porous or non-porous, ring or diffuse porous, etc.), have them look at the wood samples, again with a magnifying glass or 10X hand lens, focusing on the cut end-grain wood structure. Do all of the wood samples exhibit growth rings? Have them consider the width of the growth rings. Are the ring dimensions uniform or are they variable for each type of wood? If you have been unable to procure wood samples, show magnified images of hardwood or softwood using the images on Wood Micro-structure and Identification from **Teacher Resource 1: Light Microscope and SEM Images of Wood**, which can be found at the end of this lesson. At the end of the slide show, you will find text identifying and describing the slides; adapt this material as appropriate for your class.

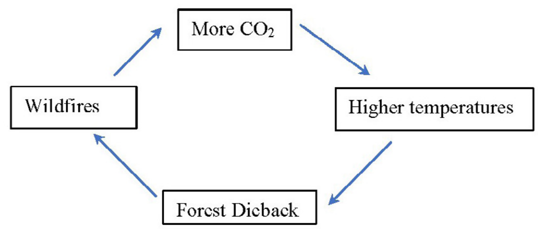
6. Have students hypothesize about what the growth ring dimensions suggest about the climatic conditions in which each species was growing. Can the students identify earlywood (also known as spring wood) and latewood (also known as summer wood) portions of each growth ring?

7. Describe how the water and nutrients move through the wood, traveling either in the pores of the hardwoods, or in the tracheids of the softwood.

Part 4: The impact of forest dieback on the carbon cycle

1. Ask the students to brainstorm about the impact on the carbon cycle when a tree dies, either due to disease, drought, or fire.

2. Copy this diagram onto the board and explain that this illustrates a feedback loop represented by this scenario. Ask: Is this an example of a negative or positive feedback loop? (Positive)



3. Distribute copies of **Handout 5: Forest Dieback** and give students time to read it, underlining words with which they are unfamiliar. Then discuss the content of the reading to answer any questions they might have.

4. Remind students about the long-term drought across the western part of the U.S. and the disastrous forest fire damage of 2020 and 2021. Divide students into groups and give them time to research this topic on the Internet. Assign one of the following websites to each group. Have them prepare a summary of the information that they find; then ask them to check for more recent information as well:

https://www.cnn.com/2021/07/31/weather/us-western-wildfires-saturday/index.html

https://www.nifc.gov/fire-information/nfn

https://www.usatoday.com/story/news/nation/2021/08/02/western-wildfires-progress-poor-air-quality/5453352001/

https://www.npr.org/2021/07/21/1018865569/the-western-wildfires-are-affecting-people-3-000-miles-away https://apnews.com/article/fires-environment-and-nature-california-5129408f55d27e9a3ebb426453014003

https://www.sciencemag.org/news/2020/09/wildfires-continue-western-united-states-biologists-fear-vulnerable-species

https://www.nytimes.com/spotlight/wildfires-west?.?mc=aud_dev&ad-keywords=auddevgate&gclid=CjwKCAjwr56IBhAvEiwA1fuqGrdEcwB-D7IwLE1VAXRq_8ewHuUK_BoMkZEHq-tvQpowk_zhMXqjcABoCIt0QAvD_BwE&gclsrc=aw.ds

5. Ask students to report on the information that they have found. Discuss the impact of the loss of photosynthesis and transpiration across large areas of land (dramatic reduction in CO_2 uptake and water vapor release), making the temperatures higher and the landscape drier. In addition, all the stored carbon in the trees (the carbon sink) becomes a carbon source, the fire releasing CO_2 into the atmosphere, also raising the temperature.

Part 5: The tropical, boreal, and temperate forests as carbon sinks

1. Have the students watch the "Forests" video again, this time with a focus on the relative roles each of these three forest types have in acting as carbon sinks in the Earth's carbon cycle.

2. Ask the students to compare tropical forest carbon sinks (most carbon stored above ground in forest biomass) with boreal forest carbon sinks (much stored underground in the permafrost) and the temperate forest sinks (both above and below ground). Here are some questions to ask to guide discussion:

- Which of these forest types is least susceptible to damage from climate change, and why? (Temperate forests, since early clearing of these forests in the eastern U.S. are now growing back, and old growth forests in the Northwest continue to store large amounts of carbon.)
- Which of these carbon sinks are likely to become carbon sources if the climate crisis continues unabated? (Both tropical and boreal forests.)
- What role does the production of wood pellets play in the temperate forest as part of the forest feedback loop? (This is the major threat to the extensive evergreen forests of the Southeast, since it results in the cutting and removal of these forests, reducing the uptake of CO_2, and burning wood pellets, releasing their stored carbon as CO_2.)
- Is the burning of wood pellets to heat homes in the winter really an environmentally sound idea? Why or why not? (It is not sustainable, even if replanting is involved, because it will take 60–100 years to replace the logged forests. It is not an environmentally sound idea. It may have seemed like a good idea at the time because forests are a source of renewable energy, but young forests store less carbon than older forests.)

3. Conclusion: Give students time to write in their journals or notebooks: What are the three most important things you have learned in this lesson on forest feedback loops? Why are they so important?

Handout 1

Feedback Loops

Feedback loops are part of a closed system (the weather system is an example) in which a change to one or more component parts impacts (changes) the other parts. Feedback loops can be either negative or positive. In a positive feedback loop, an increase in one or more parts amplifies or increases the other parts. In a negative feedback loop, a decrease in one part results in decreases in the others.

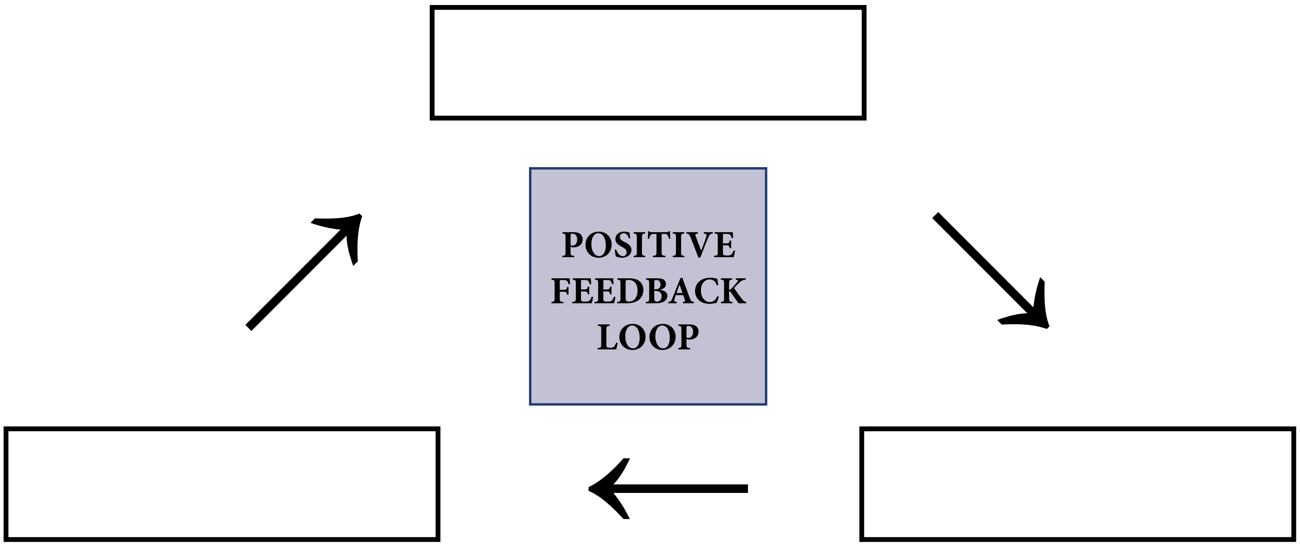
The "Forests" video introduces several examples of both positive and negative feedback loops that are related to changes in forests. We know that forests cool the Earth, and changes in the number and size of forests will affect the climate system. More forests will result in the removal of CO_2 in the atmosphere, as the result of increased photosynthesis, thus cooling the climate (a negative feedback loop). Loss of forests, as the result of logging, disease, forest fires, or overall forest dieback, results in more CO_2 in the atmosphere, warming the planet and amplifying occurrence of disease, forest fires, and forest dieback (a positive feedback loop).

1. Had you ever heard of feedback loops before seeing the video? If so, where?

2. In trying to limit future climate change, why is it important to understand the role that feedback loops play?

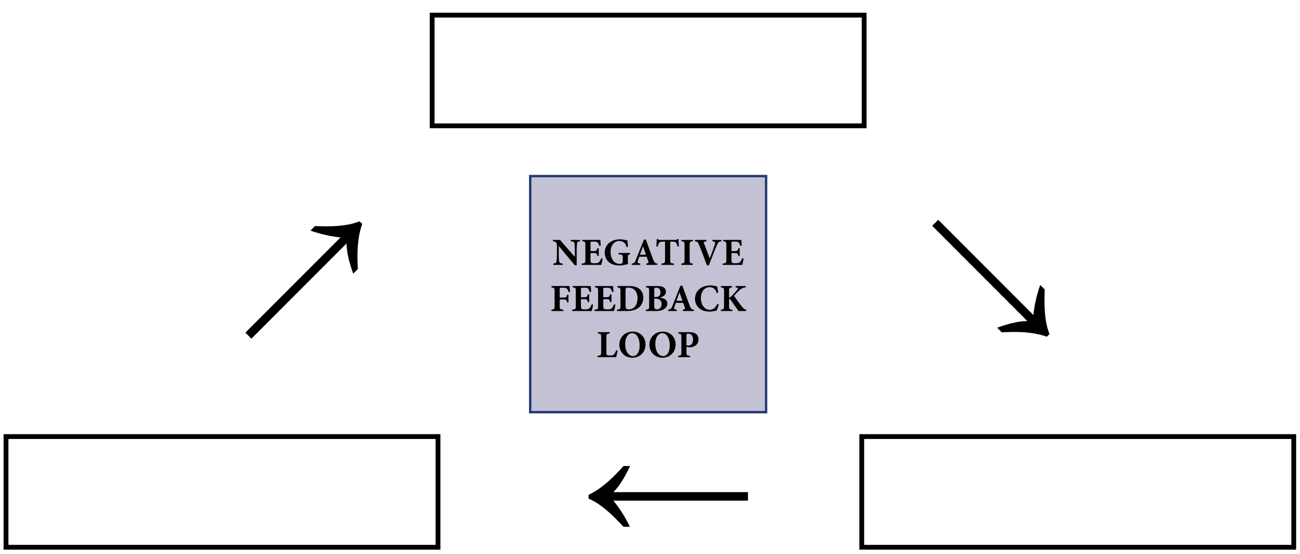
3. What are some steps that you could take in your own home and school to address the current climate crisis?

4. In the diagram below, using words provided in the Word Bank, give an example of a negative feedback loop and a positive feedback loop.



WORD BANK

More CO_2	Higher Temperatures	More trees
Shorter days	Less CO_2	Fewer Trees
Fewer trees	Lower Temperatures	More O_2
More sunlight	Less sunlight	Less O_2
		Longer Days

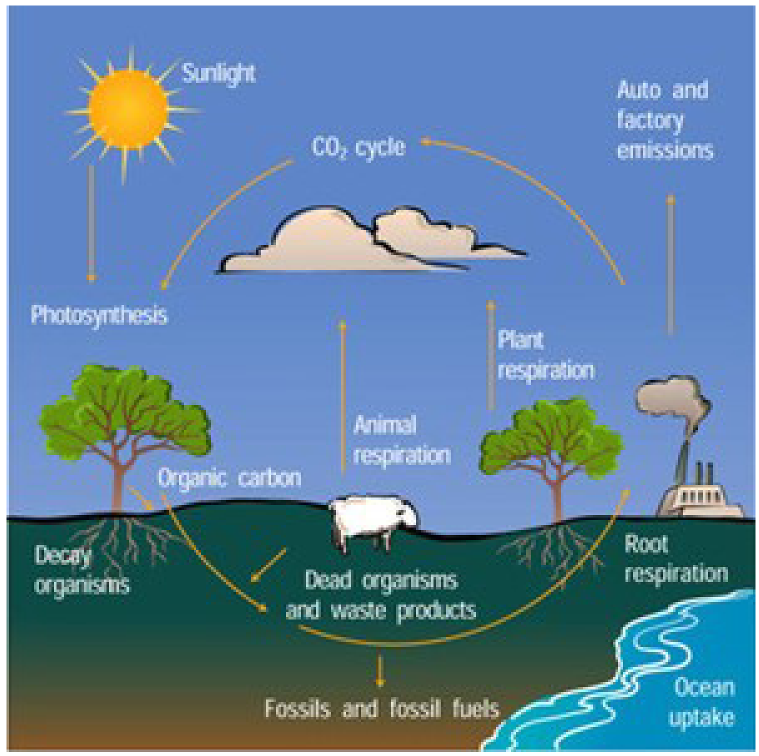


Handout 2

The Carbon Cycle

All life on Earth is carbon-based, and forests play a major role in the cycling of carbon through Earth's systems: the atmosphere, the hydrosphere, the biosphere, and the lithosphere (sometimes called the geosphere). As the result, the carbon cycle is a biogeochemical cycle whereby a wide range of carbon compounds (carbohydrates, hydrocarbons, etc.) are exchanged within the four Earth Systems.

There are four steps to the carbon cycle. First, CO_2 is absorbed by green plants through the process of photosynthesis. As we know, forests store large amounts of carbon as wood. Second, these plants are consumed by animals and the carbon accumulates in their bodies. Third, both the animals and plants eventually die, decay, and release much of that carbon back into the atmosphere. Due to geological processes, some of the carbon is not released back into the atmosphere but is buried and becomes fossil fuels (coal, oil, and natural gas). Lastly, these fossil fuels are used as a source of energy, powering our motor vehicles, heating our homes, and driving our economies, pumping large amounts of CO_2 back into the atmosphere; this warms the atmosphere, creating the current climate emergency.



[Image source: Mrs. McComas, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons]

Look at the simple diagram of the carbon cycle above. In the "Forests" video, the point is made that forests collectively represent a significant carbon sink. A carbon sink refers to a mechanism that removes and stores carbon. In the case of forests, the formation of wood is a major sink, as is stored carbon in forest soils. As we will see, the relative amounts of above-ground and below-ground sinks vary with the type of forest (tropical, temperate and boreal).

Handout 3

Photosynthesis and Transpiration

The process of **photosynthesis** occurs in some microbes (cyanobacteria and bacteria) and in green plants, including all forest trees (both hardwoods and softwoods), as well as palm trees, bamboo, and some tropical ferns. Photosynthesis occurs in cellular organelles called **chloroplasts**. The chemical process of photosynthesis requires three things: a source of visible light (sunlight or artificial light), water (taken in through a tree's root system), and carbon dioxide (CO_2, which enters the leaves through small pores called stomates or stomata). The basic formula for photosynthesis is shown below.

$$CO_2 + H_2O \overset{\text{Light}}{=} C_6H_{12}O_6 + O_2$$

The process of photosynthesis occurs in two steps. The first, called the Light Reaction, results in the splitting of water molecules (H_2O) into hydrogen atoms (H_2) and oxygen atoms (O), as well as chemical energy involving the hydrogen atoms. The second step is called the Calvin cycle, in which CO_2 is combined with other carbon compounds using the chemical energy to produce carbohydrates, such as glucose or fructose. Oxygen, which humans and all other aerobic organisms use for respiration, is produced as a by-product of the light reaction of photosynthesis. Trees use the carbohydrates to make wood, which is composed of cellulose. Thus, wood is stored CO_2.

Transpiration is the process whereby water vapor (water in the form of a gas) passes out of the leaf, through the stomates in the epidermal layers of the leaf, into the atmosphere. The water lost as water vapor is then replaced in the leaf by water in the wood from twigs, pulling more water from the wood of the tree trunk, and in turn, pulling water into the roots from the soil. The process of transpiration in the leaves is the way trees move water and dissolve soil nutrients from the roots into the wood. So wood is not just stored CO_2; it is also the pipeline through which the water needed for photosynthesis moves up the tree to the leaves.

Transpiration is also a way of moving soil water into the atmosphere, where it condenses into water droplets around tiny dust particles (aerosols) to form clouds. Evaporation is another way that water vapor enters the atmosphere. (Trees are cloud generators! In tropical forests, 60% or more of the rain that falls in the tropics has come from the tropical forests themselves!)

Transpiration is much more efficient at adding water vapor to the atmosphere than evaporation alone. That is because evaporation occurs only over open bodies of water (rivers, lakes, oceans, etc.). Transpiration adds more water vapor to the atmosphere because the extensive roots systems of plants, especially of trees, cover a greater area of soil when compared with the same area of open water. Combined, evaporation and transpiration are called **evapotranspiration**.

When forest dieback occurs, as the result of disease, insect damage, fire, etc., the photosynthetic capacity of forests is greatly diminished; the transpiration process is interrupted as well. This results in a warmer climate (less CO_2 being absorbed and stored as carbohydrates, especially wood) and a drier one (less transpiration). It is really important that our actions let trees do their job!

Handout 4

Tree Structure

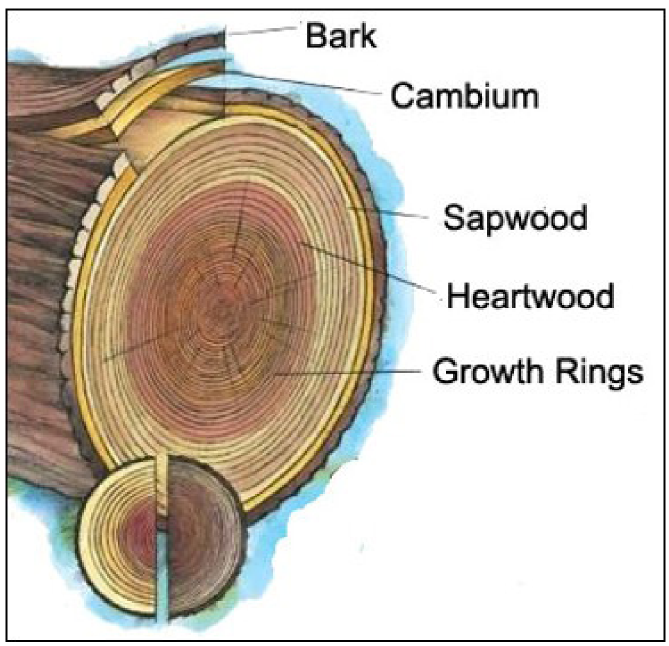
The Wood

The wood in a tree has three functions: first, to conduct water and dissolved soil nutrients upward from the roots to the leaves; second, to support the tree's **canopy** (its twigs and leaves) and raise it to the sunlight where it competes with the canopies of other trees in the forest; and third, to store carbohydrates (sugars converted to starch) produced by photosynthesis in the leaves. The wood cells of trees are 95% dead at functional maturity when they are performing the functions of conducting and supporting. The remaining 5% of the cells of the wood are living and function as starch storage cells. All of these cells—conductive, support, and storage—are produced by the **vascular cambium**, a site of active **mitosis** (cell division) during the spring and early summer months. The cambium is located between the wood and the bark.

The active vascular cambium produces a new growth ring each spring. The most recent growth rings are called **sapwood** and function in conducting the sap (water and nutrients). The older growth rings constitute the **heartwood** of a tree, which functions primarily in support and storage, but not conduction. Each growth ring is composed of thin-walled earlywood cells and thick-walled latewood. The conductive cells of each growth ring are **pores** in hardwoods (angiosperms or deciduous trees) and **tracheids** in softwoods (gymnosperms or evergreen trees). The terms *hardwoods* and *softwoods* are deceptive and do not refer to the hardness of the wood. Some hardwoods (angiosperms) have very soft wood, such as balsawood, and some softwoods (gymnosperms) have very hard wood, such as some species of pine.

The wood of each tree is produced by cell division (mitosis) in the vascular cambium each spring. Each wood cell has cell walls composed mostly of cellulose, a structural carbohydrate made from the sugars (glucose and fructose) produced in photosynthesis. Thus, the cellulose cell walls of wood are an example of stored carbon (a sink) that was produced from atmospheric CO_2 produced in the Calvin cycle of photosynthesis.

The diagram below illustrates the parts of a tree stem. Note the growth rings, the sapwood and heartwood, the cambium (vascular cambium), and the bark to the outside of the cambium. The inner part of the bark, the phloem, conducts photosynthetic products (sugars) down from the leaves to where the cambium can use them to make the cellulose cell walls of the wood, the main carbon sink of the tree.

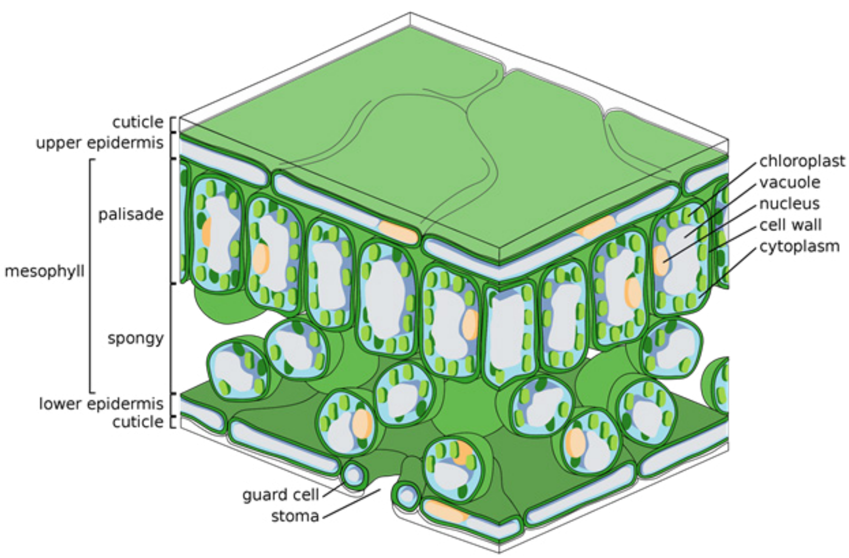


[Source: U.S. Forest Service at https://www.fs.usda.gov/learn/trees/anatomy-of-tree

The Leaves

The leaves of a tree are the site of photosynthesis and the capture of CO_2 from the atmosphere. The CO_2 enters the leaf through **stomates** in the **epidermis** of the leaf. Once inside the leaf, the CO_2 diffuses into the main photosynthetic cells of the **mesophyll**, mostly the palisade cells, and from there, into chloroplasts. In the **chloroplasts**, the light reaction breaks water molecules into hydrogen atoms and oxygen atoms. In the process of splitting the water, chemical energy in the form of ATP is produced. The hydrogen atoms and the ATP will be used in the Calvin cycle to capture CO_2 to make sugars, and the oxygen (a by-product of the light reaction) will diffuse out of the mesophyll through stomates and into the atmosphere.

Photosynthesis produces sugars (glucose and fructose containing the captured atmospheric CO_2) and oxygen. The oxygen enters the atmosphere as a waste product and the sugars are taken out of the leaf in the phloem and carried down to where the vascular cambium converts them into cellulose in the cell walls of the wood cells. Below are diagrams of the leaf structure and the photosynthetic process. If all of this sounds like magic, it is! Just trees doing their job!



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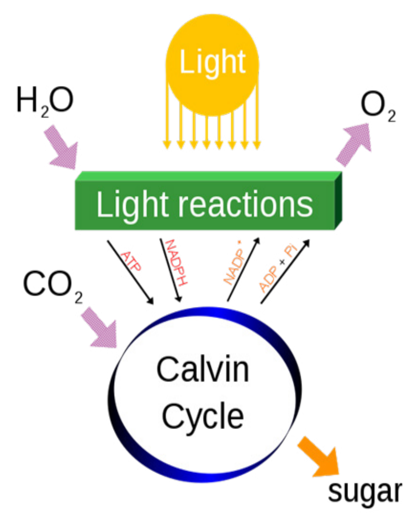


Daniel Mayer (mav) - original imageVector version by Yerpo, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons

The Roots

The roots of a tree are the organs that extend throughout the soil, absorbing soil water and dissolved soil nutrients. The roots also become woody, anchoring the tree in place. Most tree species have beneficial fungi growing on their roots, called **mycorrhizae**, an example of a symbiotic relationship where both the tree and the fungi benefit. The tree benefits from the fungus, which collects water and dissolves nutrients from organic and inorganic material in the soil, while the fungus benefits by receiving sugar from the tree. The term mycorrhiza comes from "myc-" meaning "fungus," and "rhiza" meaning "root." In the soil, the roots and their mycorrhizae come in contact with the roots and mycorrhizae of neighboring trees. This is how trees communicate with one another—through their root/fungus network. This has been called the "Wood Wide Web," a term coined by Dr. Suzanne Simard, a forest ecologist from the University of British Columbia.

The dissolved soil nutrients are used by the tree to make a wide range of organic, carbon-based molecules needed in the tree's metabolism. Some of these nutrients come from inorganic minerals in the soil, while others come from organic debris in the soil, including decaying leaf litter and animal matter. Below is a diagram of a seedling, showing its root system. Once the seedling matures into a tree, it will have a much more extensive root system.

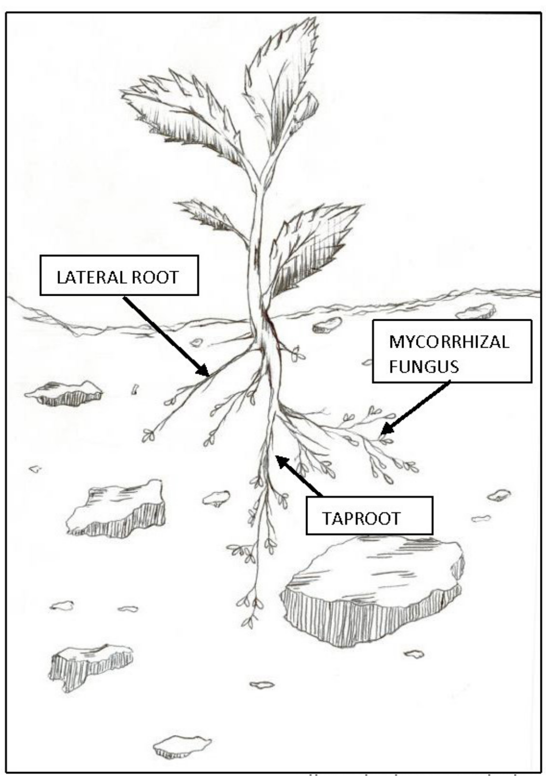


Image by M. Mattingly

Handout 5

Forest Diebacks

Forest dieback or forest decline occurs when large numbers of trees, even an entire forest, suddenly dies, often due to an unknown cause. Typical causes of recent forest diebacks have been prolonged drought, dramatic temperature changes (too cold or too hot), pathogens (insects, such as bark beetles, or fungal pathogens), parasites, and/or pollution, such as ground-level ozone or acid rain. Physical climate change (increased warming due to heat-trapping atmospheric gases) and chemical climate change (air pollution or water pollution) often have a negative impact on forests. Such impacts may affect forest functions such as photosynthesis, nutrient uptake, and normal water transport in wood or bark. Below are two examples of recent forest diebacks or declines.

Acid Rain Damage

When air pollutants, like nitrogen dioxide from automobile exhaust and sulfur dioxide from coal-burning factory smokestacks, combine with cloud moisture, **acid rainfall** of nitric acid or sulfuric acid occurs. Acid rain damage had a significant impact on high-elevation conifer forests in the northeastern United States during the 1970s and 1980s, and a similar type of damage, termed *Waldsterben* (*Wald* is the German word for forest and *Sterben* means death or dying), also occurred on high-elevation conifer forests in Central Europe during the same period. Both were thought to be due to air pollution and acid precipitation impacts on red spruce needles in the United States and Norway spruce needles in Germany, Czechoslovakia (now the Czech Republic and Slovakia), Hungary, and other Eastern European countries.

Recent research has shown that ground level ozone (O_3, also a pollutant) was also involved, entering through the stomates of the needles and weakening the cellular membranes of the mesophyll cells. Acid cloud moisture then had the effect of destroying the chloroplasts in the mesophyll cells, especially of older needles, dramatically reducing their photosynthetic activity. The one-two punch of ground-level ozone followed by exposure to acid cloud chemistry resulted in large-scale dieback of spruce forests across the northeastern United States and Central Europe.

Forest diversity also played a significant role in the impact of acid rain damage in conifer forests. In the United States, red spruce trees were very susceptible to acid rain damage, but balsam fir trees were not. Since the high-elevation conifer forests in the Appalachian Mountains consisted of a mix of the two conifer species plus hardwood species such as birch, the decline of the red spruce was not as obvious because the other types of trees were unaffected. In Central Europe, however, the conifer forests were a monoculture of only Norway spruce, resulting in a total collapse of those forests. Political action in both the U.S. and Europe dramatically reduced the amount of air pollution by the early 1990s, resulting in significant improvements in forest health in the high-elevation conifer forests in the Northern Hemisphere in the 1990s.

Bark Beetle Damage

Bark beetle damage continues to be a significant problem in conifer forests of the western U.S. The beetles bore into the bark of conifer trees in order to lay their eggs in the inner bark (the phloem) and the cambial zone, thus giving their larvae a supply of sugars and other organic compounds for their growth. As the beetles eat these tissues required for tree growth (i.e., to produce new wood), the trees die over a period of a few years. In addition to eating the tender tissues, fungal spores are often introduced by the egg-laying activities and they germinate. This results in filling those tissues and the new growth ring of wood with fungal cells that clog the conductive cells of the wood; this prevents water and nutrients from reaching the canopy.

Healthy conifer trees produce a range of **resins** (a highly viscous substance) and **terpenes** (aromatic compounds) that inhibit insects like bark beetles from boring holes in the bark. These protective chemicals are long chains of carbon atoms with attached hydrogen atoms, a class of compounds called hydrocarbons, resulting from the capture of carbon dioxide from the atmosphere. The process of making these protective **hydrocarbons** requires water, and when a drought occurs, the trees are unable to make the protective chemicals, and thus the trees become susceptible to bark beetle attacks. A prolonged drought, like the recent one in the western United States, has resulted in extensive areas of dead trees unable to protect themselves, killed both by bark beetles and the drought. Lightning strikes, careless campers, or other causes can result in massive and destructive wildfires like the ones that we are now experiencing across the western states.

The 2018 Camp Fire in Paradise, California, destroyed over 11,000 homes, and 85 people lost their lives. In 2021, the Dixie Fire in California has now surpassed 2018's Mendocino Complex Fire (459,123 acres) and 2020's Southern California Lightning Complex Fire (396,624 acres). Climate models indicate that such drought-induced wildfires may become the "new normal" across large areas of the West. In addition to the loss of life and property, consider the loss of photosynthetic CO_2 capturing capacity and transpiration-fed cloud moisture and rainfall patterns, as well as the release of massive amounts of CO_2 into the atmosphere from the burning trees. Such conditions convert trees that had been carbon sinks into carbon sources. Consider the feedback loops, both positive and negative, at play in such forest dieback scenarios.

Handout 6

The Three Types of Forests

As the "Forest" video shows, there are three dominant types of forests on Earth: tropical forests, temperate forests, and boreal forests. Each of these types of forests is a carbon sink while alive, but may become a carbon source once it dies. While living, all forests capture carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis in their leaves (either broad-leaves in deciduous trees, or needles or scales in conifers), converting sunlight into chemical energy and CO_2 into sugars (carbohydrates, chemically $C_6H_{12}O_6$). In the process, oxygen (O_2) is released as a waste product. The sugars produced are converted into cellulose cell walls that make up wood, a stored form of carbon, thus making trees a carbon sink.

One of the important ways of dealing with the climate emergency presented in the "Forests" video is to develop ways of protecting and promoting these carbon sinks. How do these types of forests differ as carbon sinks? As carbon sinks, the three types of forests store carbon differently, some storing more carbon above ground in the tree trunks (tropical and warm temperate forests) and some storing more carbon below ground in the soil (moist, cool temperate, and boreal forests).

A below-ground carbon sink is characterized by lots of organic matter, typically made up of roots, soil organisms, such as earthworms and insects, bacteria, fungal (mycorrhizal) hyphae, decaying wood, and leaf litter, etc. Soil rich in organic matter is often referred to as *topsoil,* while soil poor in organic matter is mostly mineral matter and is called *subsoil*. Go to the U.S. Forest Service web page at https://www.fs.usda.gov/ccrc/topics/global-carbon to see a graph of the biomass (i.e., stored carbon) of the different types of forests and the differences in the amounts of topsoil and subsoil that characterize the three forest types. Also note that cool moist temperate soils and boreal moist soils exhibit the most organic matter and thus represent the greatest soil carbon sinks.

Tropical Forests

It is apparent from the graph that tropical forests (both wet and moist) store much of their carbon above ground. Due to the rapid turnover rate, little leaf litter develops in tropical forests. A wet tropical forest is a tropical rainforest growing mostly in equatorial regions of the Earth. These wet tropical forests have no dry season, while moist tropical forests have a limited dry season. They too are equatorial in their distribution, and both wet and moist tropical forests are characterized by very high species diversity. They are dominated by a large number of deciduous broadleaf species.

Their continually warm, wet climate makes them more productive than any other terrestrial environment on Earth. Due to extensive deforestation over the past 40–50 years, there is approximately 30% less carbon being stored here in tropical forest than in the 1990s. In fact, due to human pressure from logging and ranching, tropical forests ecosystems are on the verge of going from carbon sinks to carbon sources, converting their stored carbon back into CO_2.

Temperate Forests

Temperate forests are found in the temperate regions of the Earth (eastern and northwestern North America, Central Europe and northeast Asia). Temperate forests occur between 25 degrees and 50 degrees of both north and south latitudes; they are mild-climate forests. Warm temperate forests store about equal amounts of carbon above and below ground. (Warm moist temperate forests may also be called sub-tropical forests.) The cool temperate moist and cool temperate dry forests store more carbon below ground. Temperate forests are composed mostly of deciduous tree species, spending about half of the time in a dormant leafless condition.

Boreal Forests

Boreal forests are characterized by the fact that they store most of their carbon below ground and are often associated with permafrost. The term *boreal* means "north," and most of the boreal forest trees are conifers (evergreen) species. Most boreal forest soils represent the largest carbon sinks, with many boreal soils also characterized by permafrost. The ice of permafrost soils locks in the gases released by the decay process, CO_2 and methane (CH_4), not allowing them to enter the atmosphere to cause increased warming. As the northern latitudes warm more rapidly than the rest of the planet, the thawing of permafrost soils beneath boreal forests presents a dangerous feedback loop in which stored carbon can decay, releasing CO_2 and CH_4, a greenhouse gas 30 times more powerful at trapping heat than CO_2. The large-scale thawing of permafrost has been labeled as a potential "carbon bomb" in the climate crisis.

Teacher Resource 1

Light Microscope and SEM Images of Wood

On the following pages you will find magnified images of wood to share with your students. The images are as follows:

Slide 1. A comparison of scanning electron microscope (SEM) images of a softwood (a red pine) and a hardwood (white oak), illustrating the differences between the two major types of wood, as seen in cross section (XS), radial section (RS), and tangential section (TS). Note the 3-D nature of the cells. Remind the students that the cell walls of all cells shown in both wood types are made up of cellulose (i.e. stored carbon dioxide). It took 6 CO_2 molecules to make each carbohydrate molecule ($C_6H_{12}O_6$), and there are hundreds of millions of cellulose molecules in each cell wall!

Slide 2. This is a light microscope 35X image of a cross section of a six-year-old white pine twig with the wood stained red and the bark stained blue. The red wood cells (vascular tracheids) are dead and the blue (parenchyma) cells are living. Note the blue vascular ray cells radiating out through the wood cells from the central pith. Also note the blue resin ducts in the growth rings of the wood. The purpose of the resin canals or ducts is to produce resin that protects the tree from insects such as bark beetles.

Slide 3. This is light microscope 100X image of a cross section of the wood of white pine, showing one complete growth ring with one resin duct. The radial files of small, more or less circular cells are the dead vascular tracheids that conduct water and nutrients from the soil up to the leaves (needles) in the tree's canopy. The tracheids also function as support cells, in addition to conduction. The very narrow files of cells are the living vascular rays, which store starch and conduct water and nutrients laterally to older growth rings. The next slide is a longitudinal section of white pine wood.

Slide 4. This is a light microscope 100X image of a longitudinal (radial) section of the wood of white pine, showing one complete growth ring. Note the vertical orientation of the vascular tracheids that appeared to be circular in cross section in the previous slide. Remind the students that these dead vascular tracheids conduct water and nutrients from the soil up to the leaves (needles). Running horizontally across the image is a vascular ray. Compare slides 3 and 4 with the SEM image of red pine seen in Slide 1.

Slide 5. This is a scanning electron microscope (SEM) 200X image of a radial section (RS) of white pine wood, showing the vertically-oriented vascular tracheid cells and the horizontally-oriented vascular ray cells. Note that the tracheids have circular openings (pits) in their cell walls that allow water and nutrients to pass from one tracheid to the next, while the ray cells have larger, window-like pits that allow water and nutrients to pass from tracheids to ray cells. All of the cell walls seen here are made of cellulose molecules (stored CO_2).

Slide 6. This is a scanning electron microscope (SEM) 200X image of a cross section (XS) of red oak wood showing ring porosity, a much more complicated cellular structure. In hardwood trees, the function of conduction and support of the wood is done by two separate cell types: vessel elements conduct and fibers support. The large pores or vessel elements seen here are part of the earlywood of a growth ring, and the smaller pores or vessel elements are part of the latewood of the previous growth ring. Most of the smaller cells surrounding the vessel elements (pores) are the fibers that support the tree as it grows into the forest canopy. Vascular rays are also seen in this image. All of the cell walls in the wood of most hardwoods are much thicker, and thus harder, than the thin cell walls of tracheids in softwoods.

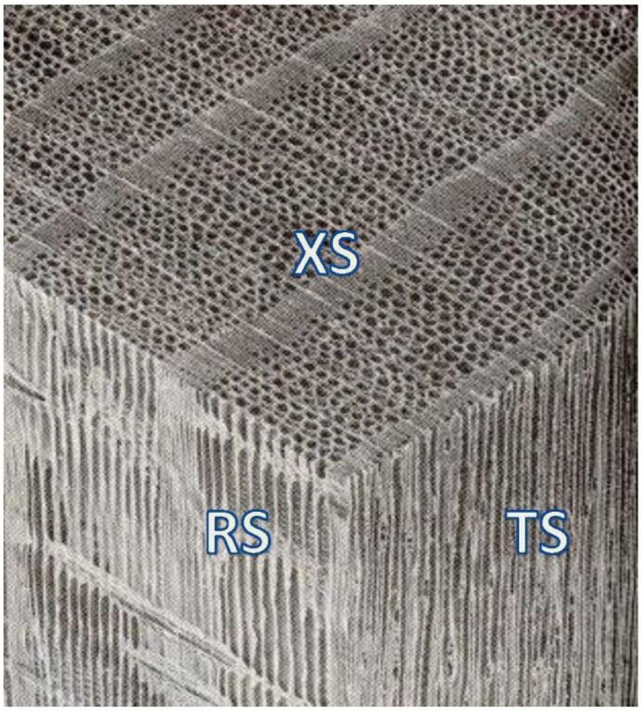
Slide 7. This is a scanning electron microscope (SEM) 500X image of a cross section (XS) of a diffuse porous hardwood. The large circular cells, all about the same size, are the vessel elements or pores, that conduct water and nutrients from the soil to the leaves of the tree's canopy. Most of the smaller cells surrounding the vessel elements (pores) are the fibers that support the tree as it grows into the forest canopy. Vascular rays are also seen in this image.

Slide 8. This is a scanning electron microscope (SEM) 500X image of a tangential section (TS) of a diffuse porous hardwood. Note that the vessel element cells are linked vertically in a continuous chain of cells that stretch all the way from the roots to the leaves, an amazingly functional design for conducting water and nutrients from the soil to the leaves.

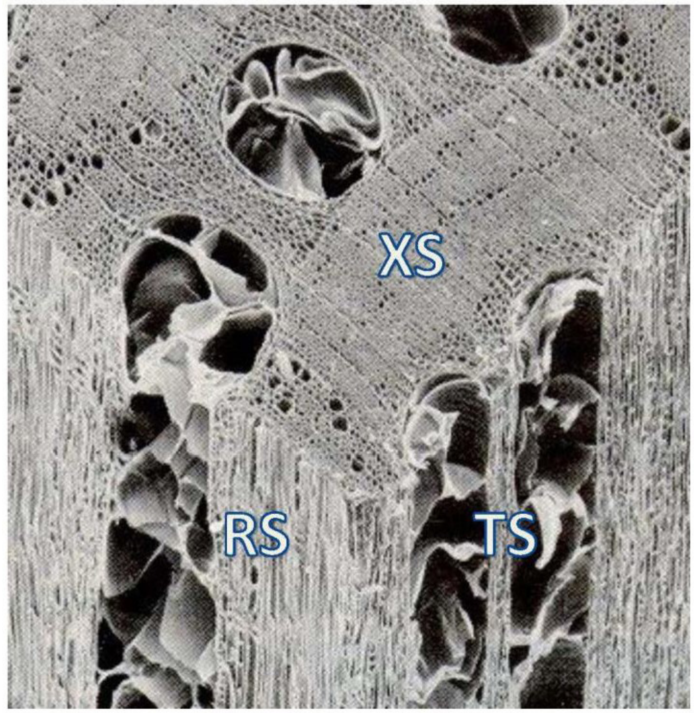
Slide 1

Scanning Electron Microscope (SEM) Images of Wood

Softwood (Red Pine)

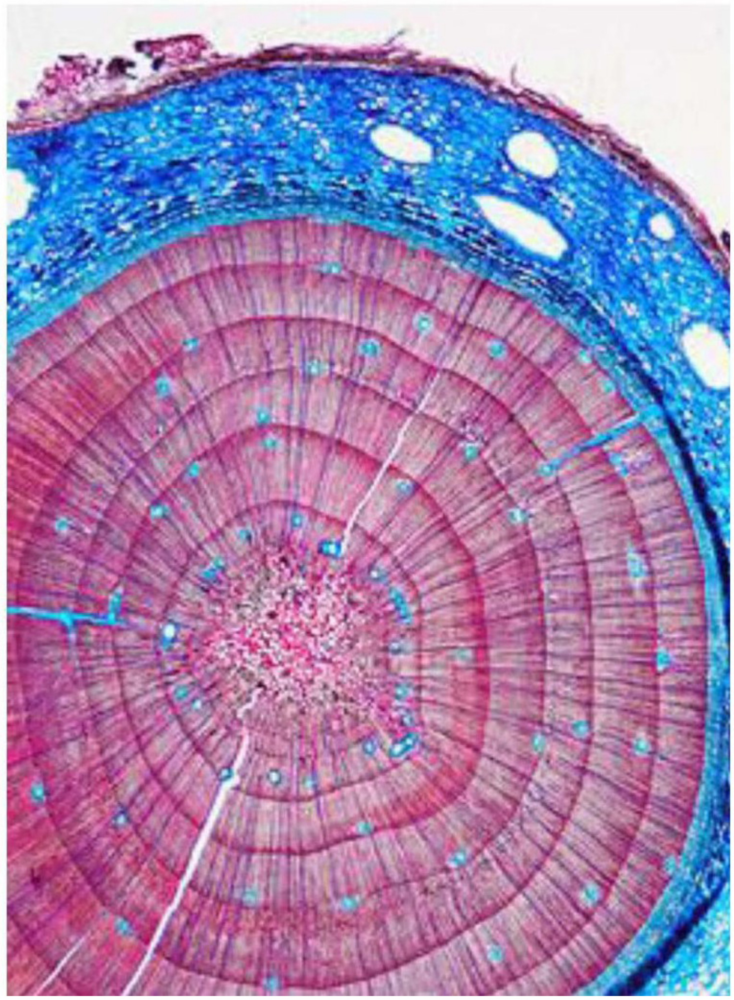


Hardwood (White Oak)



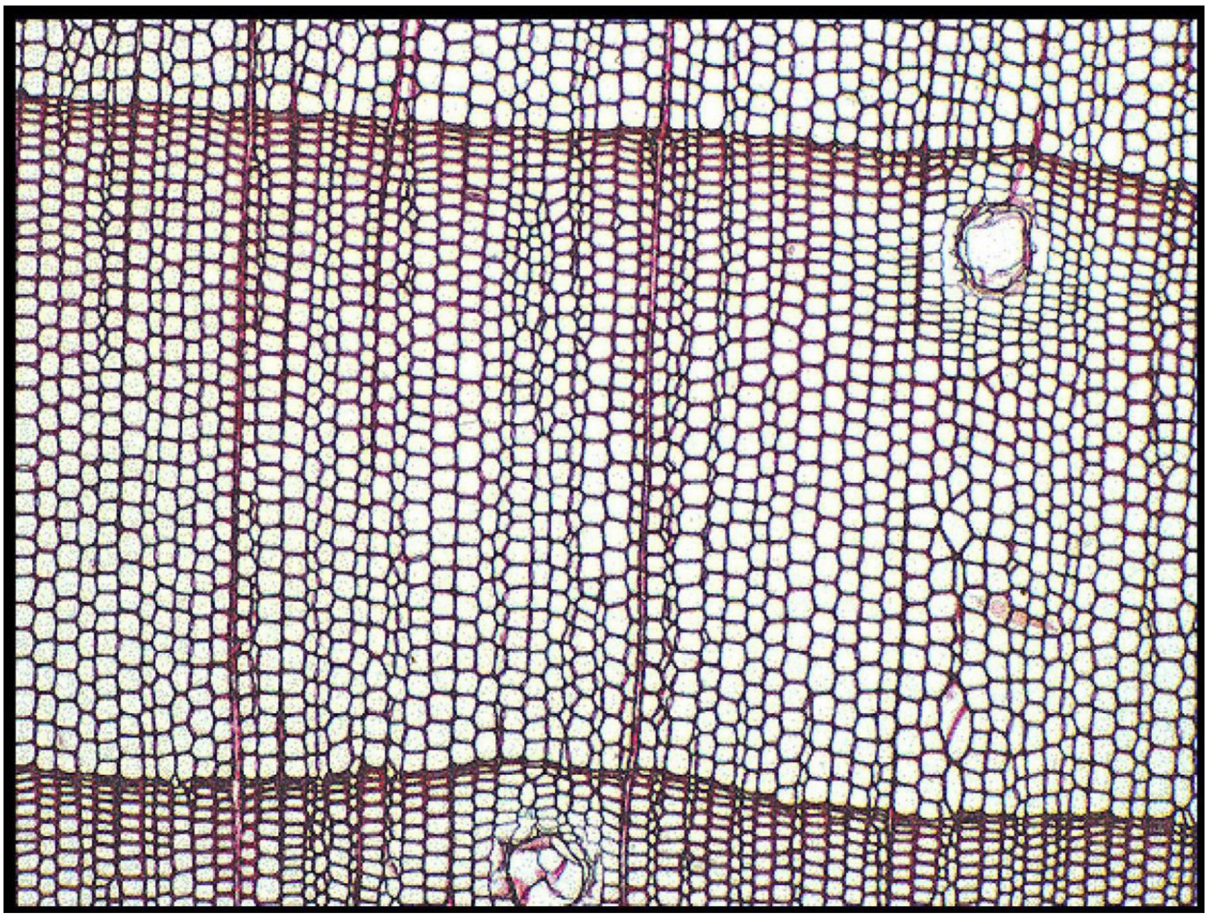
Slide 2

A cross section of a six-year-old white pine twig with the wood stained red and the bark stained blue. The red cells are dead and the blue cells are living. Note the blue vascular rays radiating out through the wood cells from the central pith. Also note the blue resin ducts in the wood.



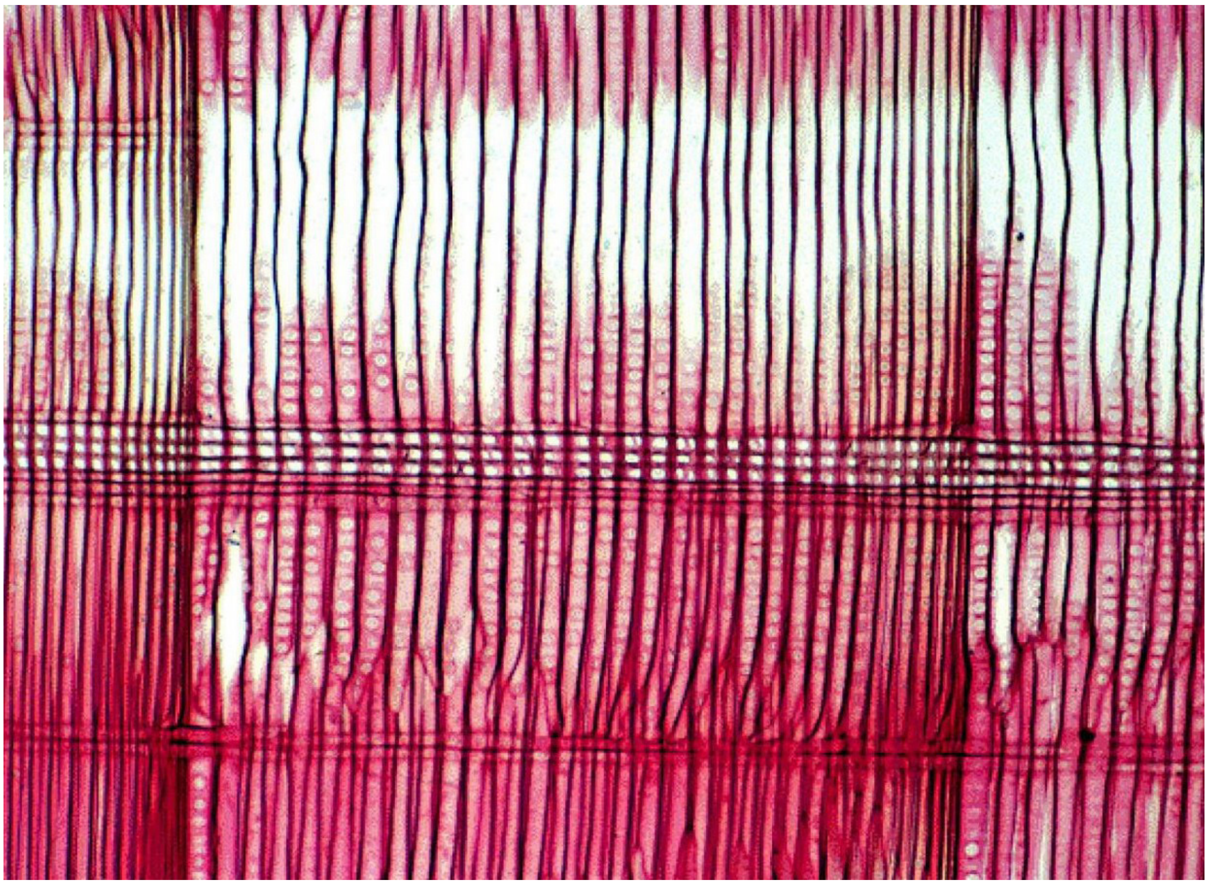
Slide 3

White Pine wood XS showing two resin ducts



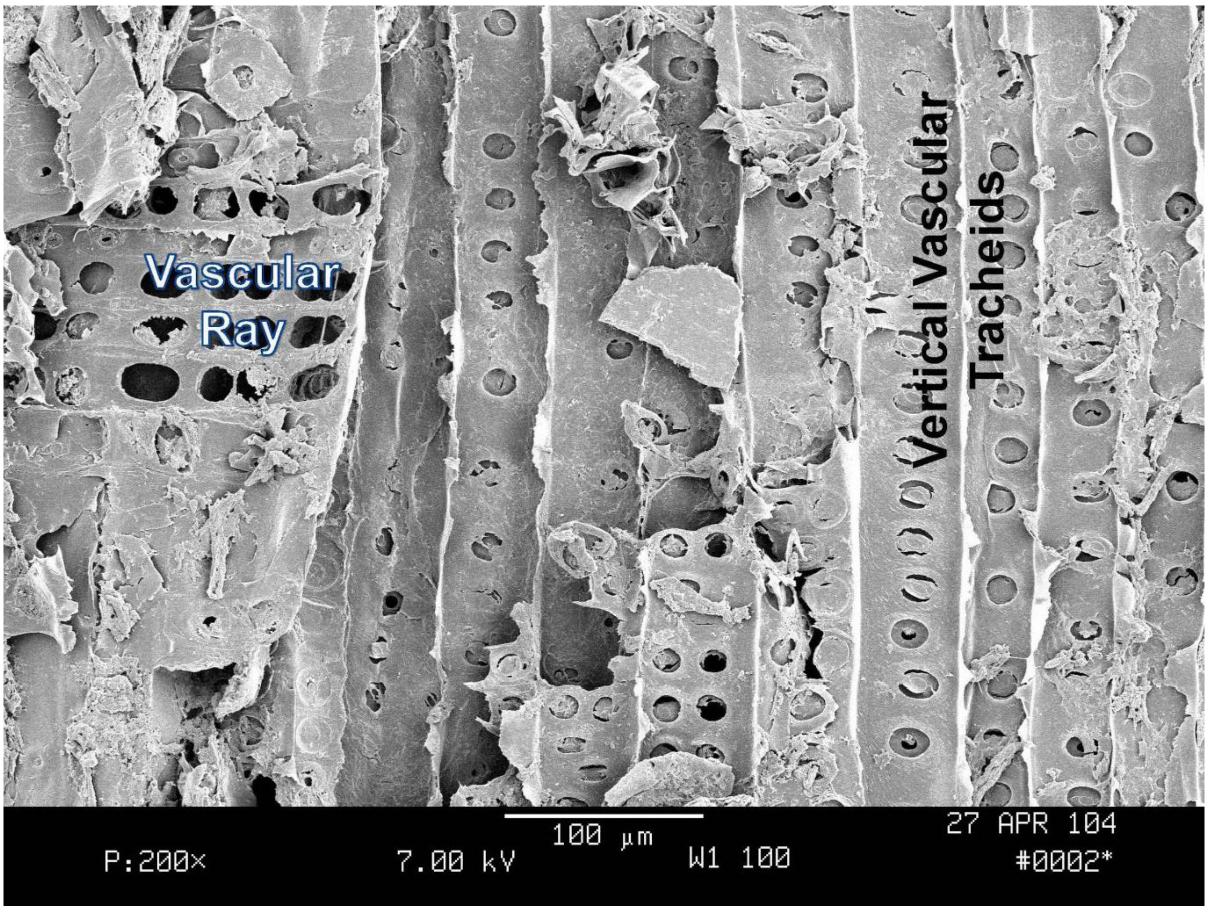
Slide 4

White Pine RS, showing longitudinal tracheids



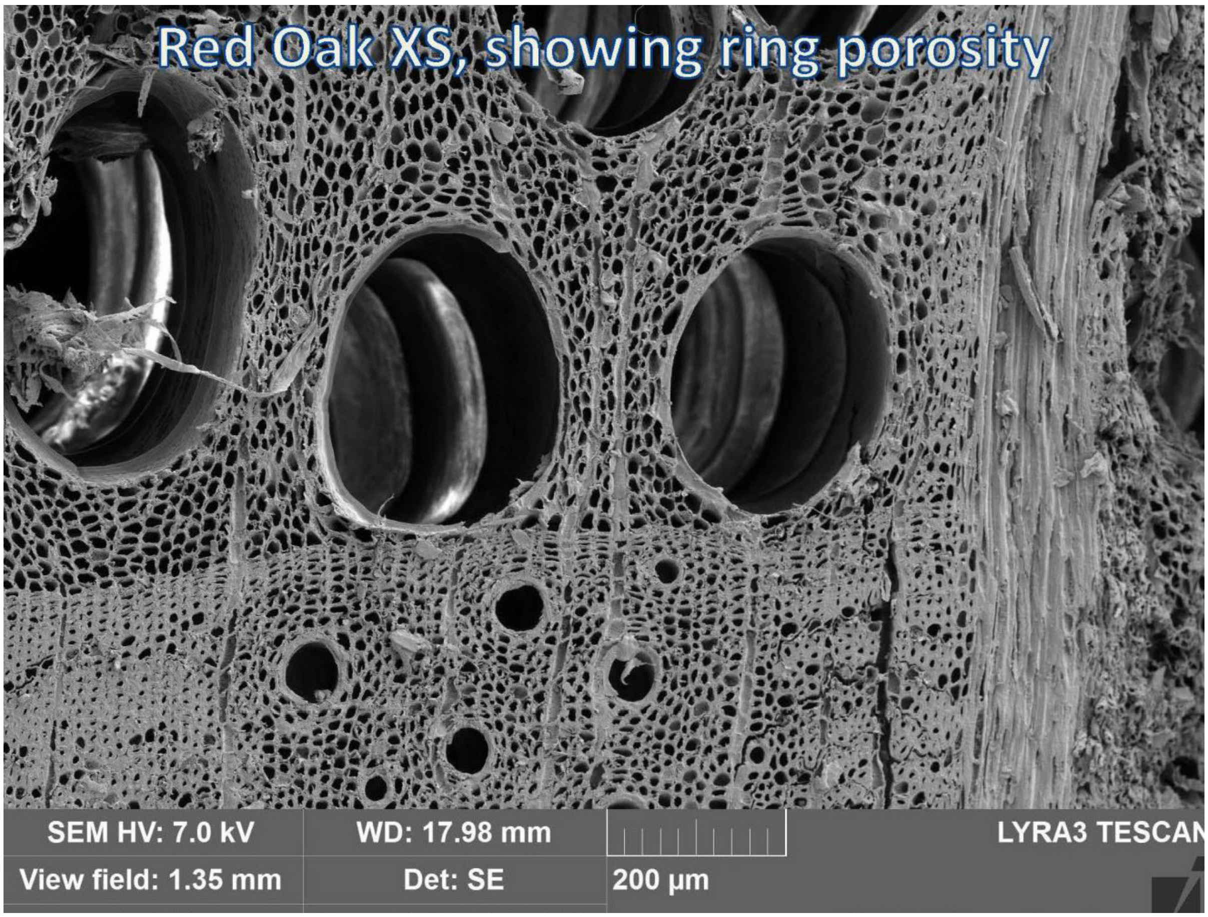
Slide 5

Vascular Cells



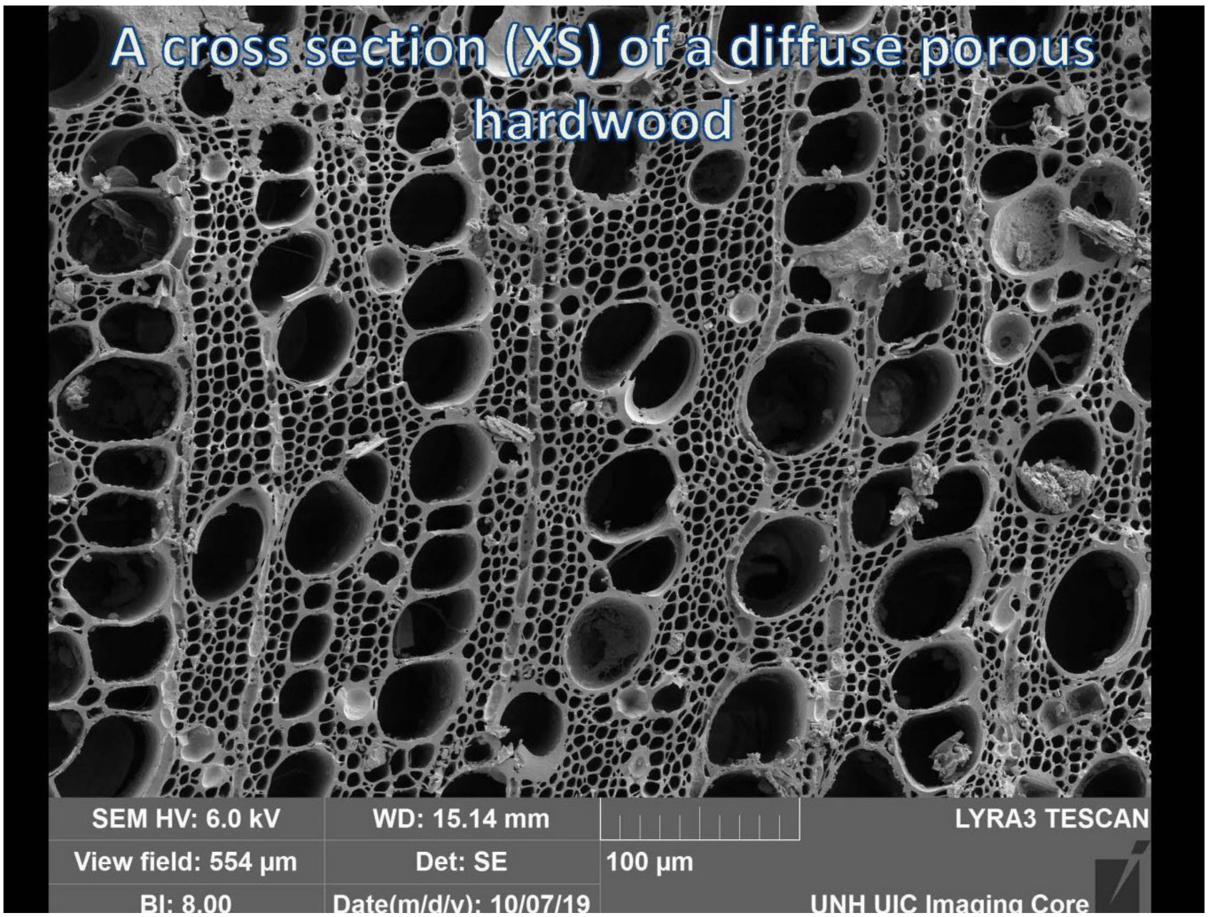
Slide 6

Red Oak XS, showing ring porosity



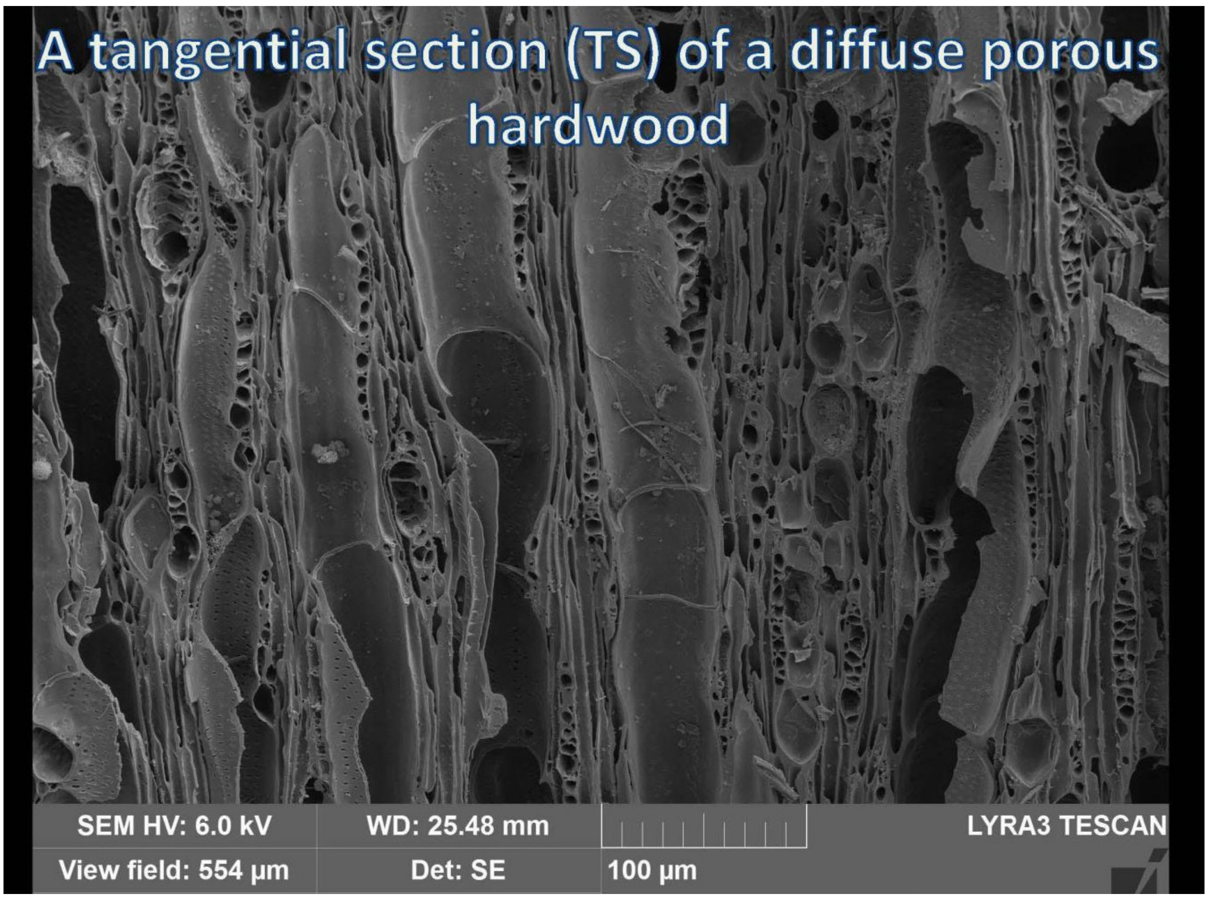
Slide 7

A cross section (XS) of a diffuse porous hardwood



Slide 8

A tangential section (TS) of a diffuse porous hardwood



Lesson 2

Permafrost

Enduring Understandings

- Almost one quarter of the Northern Hemisphere is covered in permafrost, mostly in Earth's higher latitudes, near the North and South Poles, and in regions with higher mountains.
- Thawing permafrost in high latitude regions is now a carbon source contributing to, rather than slowing, climate change.
- When permafrost thaws, organic material, such as plant matter, is decomposed by microbes; this process eventually releases carbon dioxide, methane, and nitrous oxide into the atmosphere. Carbon dioxide and methane contribute to carbon loading in the atmosphere.
- Mercury is released when organic matter in permafrost thaws and microbial decomposition releases the mercury previously locked in the frozen matter.
- As permafrost thaws, ancient microbes locked in the permafrost thaw and are released into the environment, potentially causing illness in humans and other organisms.

Essential Questions

- What is the difference between global warming and climate change?
- What is the difference between a carbon dioxide sink and a carbon source?
- What is permafrost and where is the greatest amount of permafrost found?
- Where is most of the organic matter found in permafrost?
- What happens to the frozen organic matter and to the environment when permafrost thaws?
- How do the greenhouse gases released by microbes in thawed permafrost affect global warming and climate change? How might they affect human health?

Notes to the Teacher

Global warming and **climate change** are related but not identical concepts. Global warming refers to the rise in global temperatures that is mainly due to increasing concentrations of greenhouse gases in the atmosphere. Climate change refers to the increasing changes in the measures of climate over a long period; these include rising temperatures, increased storm intensity and frequency, a decrease in sea ice, rising sea levels, an increase in permafrost thawing, changing drought and fire risk, crop failures, ground collapse, and shifting threats to human health and disease patterns. Climate change feedback is important in understanding global warming. Feedback loops in climate change speed up or slow down a warming trend. A positive feedback accelerates a temperature rise, and a negative feedback slows it down.

It is important to stress at the beginning of this lesson that there must be a balance between the worldwide need for resources and efforts to decrease the amount of greenhouse gases affecting the temperature of the Earth. The complex relationship between human activity and global warming/climate change is constantly evolving, and scientific research can be interpreted in various ways.

Permafrost is any ground that remains 0°C or colder for two straight years or more; it contains a mixture of soil, rocks, and sand, held together by ice. The upper layer of permafrost contains a large amount of organic matter that does not decompose due to the cold temperatures; the lower layer of permafrost contains a large amount of minerals. Above the permafrost is an active layer of soil that thaws during the warmer months and then refreezes; it ranges from a few centimeters to many meters deep depending upon the region. Historically, the Arctic regions, the regions around the North Pole, accumulated carbon in soils and vegetation and acted as a net sink of atmospheric carbon dioxide (CO_2).

There are four parts to the entire lesson on permafrost. The introductory section of the lesson introduces the scientific terminology for discussing permafrost, while two subsequent labs are designed to help students deepen their understanding of these concepts. Each part takes a minimum of two class periods of 45 minutes to one hour. Each takes a hands-on approach to learning, followed by group analysis and class discussion of key concepts. Finally, there is a summative assessment. The suggested order of this introductory lesson and the related labs on permafrost can be altered depending upon each teacher's approach to this unit and the time needed to perform the activities.

The introductory section on terminology focuses on introducing the effect of microbes found in thawing permafrost. Before the first class session, make a copy of **Handout 1: Introduction to the Effect of Permafrost Thawing on Microbial Action** for each student. Each pair of students needs to have access to the Internet. During the first part of the lesson, students review the suggested Internet references, research terms, and place the terms in the appropriate boxes in the table; they may need to complete this for homework. During the second part of the lesson, they discuss and answer the questions provided on the handout. During the third part of the lesson, the class will review the terms and diagram and then discuss the basic concepts of global warming, climate change, increased temperature in Arctic regions, increased concentration of greenhouse gases released into the atmosphere when the permafrost thaws, damage to structures and artifacts, the release of mercury into the environment, and the potential for the release of ancient pathogenic organisms.

Part 2 of the lesson simulates microbial growth and gas release in thawing permafrost. Before beginning this lab, make a copy of **Handout 2: Simulating Microbial Growth, Decomposition, and Gas Release in Thawing Permafrost** for each student. During the first session, students swab a mixture of yeast, sugar, and water onto a nutrient agar or Sabouraud agar plate that they place in a 30^{o}C incubator or on a side counter at room temperature. During the second session, after the preparation of another yeast, sugar, and water mixture, students perform tests on gas production by yeast at 4^{o}C, 32^{o}C, and 100^{o}C. They draw and record observations and discuss the results in class. An answer sheet with photographs of the various stages of the lab is available on **Teacher Resource 2** at the end of the student handout.

Part 3 of the lesson simulates the effect that microbial decomposition and gas release have on the thawing permafrost landscape. Before the first class session, make a copy of **Handout 3: Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost** for each student. Decide if you want to do the lab yourself as a classroom demonstration or if you will have student groups do it. An answer sheet with photographs of the various stages of the lab is available on **Teacher Resource 3** at the end of the student handout.

[Note: The amount of materials needed for Parts 2 and 3 of the lesson will depend upon whether the activity will be done as a class demonstration or by groups of six students. If the activity is to be done by groups of students, nitrile gloves, aprons, and goggles must be worn. If materials are limited, the activity can be completed using common household items.]

Part 4 is the **summative assessment** and focuses on the regional and global effect of greenhouse gas emissions due to microbial decomposition in thawing permafrost. Before the first class session, make a copy of **Handout 4: Summative Assessment: The Global Effect of Greenhouse Gas Emission Due to Microbial Decomposition in Thawed Permafrost** for each student. Each pair of students needs to have access to the Internet and a color printer. Additionally, each pair of students will need poster board, markers, colored pencils, pencils, Sharpies, a glue stick, scissors, and a ruler.

The summative assessment will take four class sessions of 45 minutes to one hour. During the first two class sessions, have each group research and collect information. Then allow two class sessions for groups to create their scientific posters. Finally, have each group present their poster. At the end of the handout is a rubric for students to evaluate their own work and for your to use in grading the poster and presentation.

Common Core Standards addressed by this lesson

CCSS.ELA-LITERACY.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-LITERACY.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.11-12.2
Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

CCSS.ELA-LITERACY.RST.11-12.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

CCSS.ELA-LITERACY.RST.9-10.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-LITERACY.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

CCSS.ELA-LITERACY.RST.11-12.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

CCSS.ELA-LITERACY.RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

CCSS.ELA-LITERACY.RST.11-12.8
Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

CCSS.ELA-LITERACY.RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

Next Gen Sciece Standards addressed by this lesson

HS-PS1-5 Matter and its Interactions
Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

HS-ESS2-2 Earth's Systems
Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

HS-ESS2-4 Earth's Systems and Weather and Climate
Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS-ESS3-5 Weather and Climate and Earth and Human Activity
Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.

HS-LS2-3 Ecosystems: Interactions, Energy, and Dynamics
Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

HS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics
Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

HS-LS4-5 Natural Selection and Evolution and Biological Evolution: Unity and Diversity
Evaluate the evidence supporting claims that changes in environmental conditions may result in (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Duration of Lesson

Fourteen 45-minute to one-hour sessions

Part 1: 3 class sessions
Part 2: 3 class sessions
Part 3: 4 class sessions
Part 4: 4 class sessions

Assessments

Completion of handouts
Group discussions
Poster presentation (summative assessment)

Materials

For Part 1:

Handout 1: Introduction to the Effect of Permafrost Thawing on Microbial Action
Computer, tablet, or phone with Internet access
Projector or smart board

For Part 2:

Handout 2: Simulating Microbial Growth, Decomposition, and Gas Release in Thawing Permafrost
3 250-ml Erlenmeyer flasks (or plastic soda bottles) of equal size
100-ml graduated cylinder
3 large beakers or bowls (to set flasks into)
3 latex balloons of equal size
1 hot plate
3 thermometers (Celsius)
Metric ruler
Quick or rapid rising yeast (Saccharomyces cerevisi ae) —room temperature, frozen, and boiled samples
Table sugar
Water
Ice
3 cotton swabs
3 nutrient or Sabouraud agar petri dishes
Metric scale (or measuring teaspoon)
Sharpie
Nitrile gloves
Goggles
Aprons

For Part 3:

Handout 3: Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost
250-ml beaker (or large cup)
100-ml graduated cylinder
Thermometer (optional)
Hot Plate (optional)
Quick or rapid rising yeast (Saccharomyces cerevisiae) — room temperature, frozen, and boiled samples
Table sugar
Water
Flour
Bowl
Rolling pin
Tinfoil or wax paper
Metric scale or measuring teaspoon
Nitrile gloves
Goggles
Aprons

For Part 4:

Handout 4: Summative Assessment—The Global Effect of Greenhouse Gas Emission Due to Microbial Decomposition in Thawed Permafrost
Computer, tablet, or phone with Internet access
Color printer access
Poster board
Markers, colored pencils, pencils, Sharpies
Glue stick
Scissors

Procedure

Part 1: Introduction to the effect of permafrost thawing on microbial action

1. Begin the class by showing this video clip from the National Science Foundation on thawing permafrost: "Changing Planet—Thawing Permafrost" at https://www.youtube.com/watch?v=yN4OdKPy9rM. Ask students to write briefly about their initial reactions to the film and then give them a chance to share what they have written. Then point out that the video was released in 2011. Ask students what they think has happened to the permafrost since that time.

2. Then show the film "Permafrost" from *Climate Emergency: Feedback Loops* at https://feedbackloopsclimate.com/permafrost/. Point out that this film was completed in 2021 and ask students to summarize what has happened in permafrost regions in the last ten years.

3. Distribute copies of **Handout 1: Introduction to the Effect of Permafrost Thawing on Microbial Action**. Read the background information and have students scan the table for the information they will need. Make sure to clarify any student questions.

4. Arrange students into pairs and provide Internet access, either in the library or on their own devices. Allow students sufficient time to complete their research and fill in the terminology table while you circulate to supervise and answer any additional questions. You may wish to assign some of this research for homework, giving student partners time at the beginning of the next class session to check their answers with each other.

5. After the terminology tables are complete, have each pair of students discuss the questions at the end of the handout and fill in their answers to the questions; this may extend into the next class session. If desired, have the students discuss as a whole class their group answers to the questions. (See **Teacher Resource 1: Answer Sheet for Handout 1** for suggested answers to the questions.)

6. Conclude by projecting the diagram at https://www.flickr.com/photos/gridarendal/47957343471 and ask students to identify and explain the processes that they see. Be sure to cover basic concepts of global warming, climate change, temperature increase in Arctic regions, the increased concentration of greenhouse gases released into the atmosphere when the permafrost thaws, damage to structures and artifacts, the release of mercury into the environment, and the potential for the release of ancient pathogenic organisms.

Part 2: Simulating Microbial Growth, Decomposition, and Gas Release in Thawing Permafrost

1. Decide whether the simulation will be done as a class demonstration or by individual groups.

2. Prior to the experiment, prepare room temperature yeast, frozen yeast, and boiled yeast.

3. Distribute copies of **Handout 2: Simulating Microbial Growth, Decomposition, and Gas Release in Thawing Permafrost.**

4. Read the background information with the class and review the directions on the handout. Make sure to clarify any student questions. Additionally, make sure to stress safety precautions if completing the activity in individual groups.

5. Arrange students into groups with the prescribed materials necessary. Suggest that they check the list of materials on the handout to be sure that the lab set-up is complete and that they are familiar with all the materials.

6. Allow students sufficient time to set up Part A of the experiment while you circulate to supervise and answer any additional questions.

7. After 24–48 hours, have students observe the amount of yeast growth and complete Table 1.

8. On day 2, have students set up Part B of the experiment and observe activity in the 4ºC, 32ºC, and 100ºC flasks containing the yeast, sugar, and water mixture. Have students complete Table 2.

9. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers to the questions.

10. In conclusion, have the students discuss as a whole class their group answers to the questions. See **Answer Sheet for Handout 2** for suggested answers to the questions.

Part 3: Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost

Note: If materials are limited, the activity can be completed using common household items and cold, warm, and hot water from the faucet. Additionally, there is an optional extension that can be used for more advanced students to design an additional experiment to simulate the effects of gas emission on the permafrost landscape at various temperatures.

1. Distribute copies of **Handout 3: Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost**.

2. Read the background information and review the directions on the handout. Make sure to clarify any student questions. Additionally, make sure to stress safety precautions.

3. Arrange students into groups with each group given the prescribed materials necessary. Suggest that they check to see that the lab set-up is complete and that they are familiar with all the materials.

4. Allow students sufficient time to set up Part 1 of the experiment while you circulate to supervise and answer any additional questions.

5. Have each student group record observations in Table 1.

6. On day 2, have students set up Part 2 of the experiment and observe any changes in the shape of the dough. Have students complete Table 2.

7. On day 3, have each student group record any changes in the shape of the dough that occurred after several hours or overnight.

8. After the activity is completed, have students discuss the questions at the end of the handout and fill in their answers to the questions.

9. Lastly, have the students discuss as a whole class their group answers to the questions. See **Answer Sheet for Handout 3** for suggested answers to the questions.

Part 4: The Global Effect of Greenhouse Gas Emission Due to Microbial Decomposition in Thawed Permafrost (Summative assessment)

1. Distribute copies of **Handout 4 Summative Assessment: The Global Effect of Greenhouse Gas Emission Due to Microbial Decomposition in Thawed Permafrost.** Provide students with a rubric for the summative assessment. (A sample poster rubric is provided below.)

2. Read the background information and review the directions on the handout. Make sure to clarify any student questions.

3. Arrange students into pairs. Allow students sufficient time to research and to prepare the poster while you circulate to supervise and answer any additional questions.

4. After the students have completed their posters, have them present their posters to the class.

5. After all posters have been presented, have students discuss as a whole class the information presented. See **Guidance for Handout 4: Summative Assessment.**

Reference Material

https://www.nature.com/articles/d41586-021-00659-y

https://www.nature.com/articles/ismej2011163

https://agsci.source.colostate.edu/bacteria-release-cli-
mate-damaging-carbon-from-thawing-permafrost/

https://news.osu.edu/getting-to-know-the-microbes-that-
drive-climate-change/

https://news.arizona.edu/story/discovery-of-microbe-hid-
ing-in-permafrost-raises-concerns-about-future

https://e360.yale.edu/features/how-melting-permafrost-is-be-
ginning-to-transform-the-arctic

https://www.energy.gov/science/ber/articles/uncovering-mi-
crobial-food-web-thawing-permafrost

https://gml.noaa.gov/education/info_activities/pdfs/TBI_ni-
trogen_cycle.pdf

https://www.nature.com/articles/s41396-018-0176-z

https://climatekids.nasa.gov/permafrost/

https://www.epa.gov/climate-indicators/greenhouse-gases

https://www.fema.gov/pdf/about/programs/oppa/climate_
change_paper.pdf

https://polarjournal.ch/en/2020/09/21/thawing-perma-
frost-soils-release-mercury/

https://nca2014.globalchange.gov/highlights/overview/cli-
mate-trends

https://www.thesciencedictionary.com/

https://climate.nasa.gov/resources/global-warming-vs-cli-
mate-change/

https://climatekids.nasa.gov/greenhouse-cards/

https://climatekids.nasa.gov/permafrost/

https://pubs.er.usgs.gov/publication/70204709

https://ecoss.nau.edu/wp-content/uploads/2019/08/Turetsky-
et-al.-2019_Nature_Comment.pdf

https://arctic.noaa.gov/Report-Card/Report-Card-2019/Art-
MID/7916/ArticleID/844/Permafrost-and-the-Global-Car-
bon-Cycle

https://www.wired.com/story/abrupt-permafrost-thaw/

https://gml.noaa.gov/education/info_activities/pdfs/TBI_
earth_spheres.pdf

https://gml.noaa.gov/education/info_activities/pdfs/TBI_ni-
trogen_cycle.pdf

https://gml.noaa.gov/education/info_activities/pdfs/PSA_an-
alyzing_a_feedback_mechanism.pdf

https://www.fws.gov/refuge/arctic/activel.html

https://gml.noaa.gov/outreach/info_activities/pdfs/TBI_
trace_gases_and_climate_change.pdf

http://www.ces.fau.edu/nasa/module-4/causes/carbon_story.
php

http://www.ces.fau.edu/nasa/module-4/causes/sinks-car-
bon-dioxide.php

http://www.ces.fau.edu/nasa/module-4/causes/sources-car-
bon-dioxide.php

http://www.ces.fau.edu/nasa/module-4/causes/methane-car-
bon-dioxide.php

http://www.ces.fau.edu/nasa/module-4/causes/other-green-
house-gases.php

https://www.osti.gov/servlets/purl/1508979

http://globecarboncycle.unh.edu/CarbonCycleBackground.
pdf

https://serc.carleton.edu/eslabs/carbon/5b.html

https://www.youtube.com/watch?v=7DGE2uMrhag

https://www.youtube.com/watch?v=yN4OdKPy9rM

https://www.youtube.com/watch?v=Q39M-CkbBTY

https://www.nps.gov/articles/denali-permafrost-carbon.htm

https://www.nationalgeographic.com/science/article/colossal-
crater-found-Siberia-what-made-it

https://www.nature.com/articles/nature.2014.15649

https://www.nature.com/articles/ismej200858

https://www.exploratorium.edu/cooking/bread/yeast_temp.
html

https://nsidc.org/cryosphere/frozenground/methane.html

https://nsidc.org/cryosphere/frozenground/climate.html

Handout 1

Introduction to the Effect of Permafrost Thawing on Microbial Action

It is estimated that approximately 24% of the land in the Northern Hemisphere has permafrost under its surface. When permafrost remains frozen, carbon found in organic matter remains trapped and there is a net sink of atmospheric carbon dioxide. However, organic matter in thawed permafrost becomes a carbon source as carbon dioxide and methane, byproducts of microbial decomposition, are released into the atmosphere.

Additionally, activating microbes in thawing permafrost can lead to:

- an increase in microbial production of nitrous oxide, another greenhouse gas.
- the release of highly toxic amounts of mercury that were previously bound to undecomposed organic matter.
- the alteration of the landscape due to microbial gas production in thawing permafrost.
- the potential for ancient microbes found in thawed permafrost to cause illness in humans and other organisms.

In this activity, you have several objectives:

- To research terminology related to microbial action in thawing permafrost and climate change feedback loops.
- To understand the difference between a source of carbon and the net sink of atmospheric carbon dioxide.
- To understand how decomposition in thawing permafrost releases greenhouse gases, minerals, and mercury.
- To understand how decomposition of organic matter can lead to the alteration of permafrost landscapes.
- To understand how potentially pathogenic ancient microbes may be released by thawing permafrost.

Procedure

1. Read the following resource pages and watch any video clips found on the resource pages. As you work, continue to fill in the table.

Climate Science Investigations: Causes of Climate Change
The Carbon Dioxide Story
http://www.ces.fau.edu/nasa/module-4/causes/carbon_story.php

Sinks of Carbon Dioxide
http://www.ces.fau.edu/nasa/module-4/causes/sinks-carbon-dioxide.php

Sources of Carbon Dioxide
http://www.ces.fau.edu/nasa/module-4/causes/sources-carbon-dioxide.php

Methane and the Carbon Cycle
http://www.ces.fau.edu/nasa/module-4/causes/methane-carbon-dioxide.php

Other Greenhouse Gases
http://www.ces.fau.edu/nasa/module-4/causes/other-greenhouse-gases.php

2. Watch the following video clips and complete the terminology table.

A massive, 164-feet deep crater suddenly opened up on Siberia's Arctic
https://www.youtube.com/watch?v=7D-GE2uMrhag

BBC Earth Lab
What Diseases Frozen in Ice could be Hidden in our Glaciers? | Earth Lab
https://www.youtube.com/watch?v=Q39M-CkbBTY

3. Answer the questions at the end of the table as completely as possible with your partner.

Permafrost/Climate Change Terminology

Term	Definition / Explanation
Global warming	
Climate change	
Greenhouse gases	
Climate change trends	
Climate change feedback loops	
Carbon flux	
Permafrost	
Active layer	

Soil organic matter (SOM)	
Soil decomposition	
• **Carbon dioxide**	
• **Methane**	
• **Nitrous oxide**	
• **Mineralization**	
• **Mercury**	
Net sink of carbon	
Carbon source	

Cryovolcanism	
Cryopegs	
Infrastructure	
Artifacts	
Pathogenic microbe	

Conclusion

Discuss the following questions with your group members and record your answers in the spaces provided.

1. What is the role of permafrost as a net sink of carbon? Using some of the terms you previously defined, explain your answer.

2. What causes permafrost to become a source of carbon dioxide and other greenhouse gases? Explain your answer.

3. How can microbial decomposition cause an increase in the release of highly toxic mercury? Explain your answer.

4. How can microbial decomposition lead to the alteration of frozen landscapes and possible damage or destruction of infrastructure? Explain your answer.

5. How can permafrost thawing potentially release pathogenic microbes? Explain your answer.

Teacher Resource 1

Answer Sheet for Handout 1: Introduction to the Effect of Permafrost Thawing on Microbial Action

Note: Students have varying levels of understanding; answers should be discussed and clarified by the teacher.

Global warming	The rise in global temperatures mainly caused by increasing concentrations of greenhouse gases in the atmosphere.
Climate change	A long-term change in the average weather patterns that have come to define Earth's local, regional, and global climates.
Greenhouse gases	Gases that allow sunlight to pass through the atmosphere but prevent the sun's heat from leaving the atmosphere. The main greenhouse gases are: • Water vapor • Carbon dioxide • Methane • Ozone • Nitrous oxide • Chlorofluorocarbons
Climate change trends	The apparent change in global climate across a wide range of observations primarily due to the amount of heat-trapping gases emitted globally and how sensitive the Earth's climate is to those emissions.
Climate change feedback loops	In climate change, a feedback loop is something that speeds up or slows down a warming trend. A positive feedback loop accelerates rising temperatures, and a negative feedback loop slows rising temperatures.
Carbon flux	Carbon pools (also called stocks or reservoirs) are present in the Earth's atmosphere, soils, oceans, and crust. When viewing the Earth as a system, carbon pools store large amounts of carbon. Any movement of carbon between carbon pools is called a carbon flux. Carbon fluxes connect carbon pools together to create cycles and feedback loops.
Permafrost	Any ground that remains completely frozen—0°C or colder—for at least two continuous years. Permanently frozen grounds are most common in regions with high mountains and in Earth's higher latitudes—near the North and South Poles. Permafrost contains a mixture of soil, rocks, and sand, held together by ice.
Active layer	The top layer of soil above permafrost that thaws during the warm summer months and freezes again in the fall. In colder regions, the ground rarely thaws, and the active layer is very thin, typically 10 to 15 centimeters. In warmer regions, the active layer can be several meters thick.

Soil organic matter (SOM)	SOM is an important component of the global carbon cycle. SOM contains more carbon than plant biomass and atmospheric carbon combined. SOM contributes to a carbon flux to and from the atmosphere.
Soil decomposition	The recycling of nutrients that have been used by an organism to build its body. The process in which organic matter is degraded and converted into simpler organic forms. Greenhouse gases, minerals, and mercury are released during soil decomposition processes.
• **Carbon dioxide**	Decomposers break down dead material from plants and other organisms and release carbon dioxide into the atmosphere, where it can become available for photosynthesis.
• **Methane**	Emitted during the decomposition of organic wastes. Methane enters the atmosphere and eventually combines with oxygen (oxidizes) to form more CO_2. Methane converts to CO_2 by a simple chemical reaction.
• **Nitrous oxide**	Produced by microbes that break down nitrogen in soil.
• **Mineralization**	The conversion of organic compounds into inorganic compounds during the process of decomposition.
• **Mercury**	Released from organic matter during the process of decomposition. Highly toxic.
Net sink of carbon	Anything that absorbs more carbon dioxide from the atmosphere than it releases.
Carbon source	Anything, natural or artificial, that produces carbon and/or any chemical compounds composed of carbon, such as carbon dioxide and methane.
Cryovolcanism	Cryovolcanism is a volcanic phenomenon that occurs in environments with extremely low temperatures. Cryovolcanoes erupt liquid water, methane, ammonia, or sulfur dioxide onto the icy surface of a planet or satellite.
Cryopegs	A body of unfrozen ground that is perennially cryotic (less than 0°C) and entirely surrounded by perennially frozen ground.
Infrastructure	The basic systems and services, such as transportation and power supplies, that a country or organization uses to work effectively.
Artifacts	Any object made by human beings.
Pathogenic microbe	Microbes containing certain abilities to cause infections or diseases within a host organism.

1. What is the role of permafrost as a net sink of carbon? Using some of the terms defined, explain your answer.

- Permafrost acts as a net sink of carbon when more carbon is stored in the frozen soil than emitted into the atmosphere as carbon dioxide and methane.
- Because permafrost is frozen, large amounts of carbon captured from the atmosphere and from soil organic matter (SOM) remain stored.
- It is estimated that soil organic matter (SOM) in permafrost stores more than 50% of global terrestrial carbon.
- Carbon enters terrestrial ecosystems during photosynthesis in which plants use carbon dioxide to produce organic molecules. Because the active layer remains frozen for part of the year, decomposition of plants and other organic matter slows, and carbon remains stored in permafrost.

2. What causes permafrost to become a source of carbon dioxide and other greenhouse gases? Explain your answer.

- An ecosystem is a carbon source when there is less carbon uptake and more carbon is emitted into the atmosphere. When permafrost thaws, microbial decomposition of soil organic matter (SOM) increases the release of the greenhouse gases, carbon dioxide, methane, and nitrous oxide.
- During aerobic microbial respiration, carbon dioxide is released as a waste product and is emitted into the atmosphere. Permafrost thaw increases the metabolic rate of aerobic microbes, thereby increasing the output of carbon dioxide into the atmosphere.
- During several anaerobic microbial metabolic processes, methane, carbon dioxide, and nitrous oxide are emitted as waste products. Permafrost thaw increases the metabolic rate of anaerobic microbes, thereby increasing the output of methane, carbon dioxide, and nitrous oxide into the atmosphere.
- Permafrost thaw can cause cracks and sink holes to occur, which can then lead to the release of greenhouse gases previously locked in permafrost regions.

3. How can microbial decomposition cause an increase in the release of highly toxic mercury? Explain your answer.

- Mercury in soil comes mainly from atmospheric deposition and becomes bound to soil organic matter (SOM). Microbial decomposition releases mercury from the organic matter.
- Decomposition in permafrost does not occur, and mercury remains bound to SOM. However, when permafrost thaws, decomposition causes mercury to be released into the soil and atmosphere.
- As temperatures increase and permafrost thaws, decomposition increases, which causes high levels of mercury to be released in the environment.
- Increased atmospheric mercury release due to microbial decomposition in permafrost can lead to wide global distribution of mercury in the upper atmosphere. Upper atmospheric mercury can travel to the lower atmosphere and potentially to the Earth's surface during rainstorms.

4. How can microbial decomposition lead to the alteration of frozen landscapes and possible damage or destruction of infrastructure? Explain your answer.

- Methane is released by some anaerobic microbes as a product of anaerobic respiration and can be stored in subsurface reservoirs found in permafrost.

- Methane remains stable and frozen in permafrost. As permafrost warms, and its internal strength decreases, it may be less able to withstand the build-up of subsurface gases. The increase in subsurface gases such as methane can cause an explosion in the permafrost, leading to the formation of craters.
- Increased gas pressure of trapped methane and other gases in thawing permafrost can push away the upper layers of permafrost and form a crater.
- Craters and cracks in permafrost regions could become more common due to global warming. Buildings, homes, and other structures built on permafrost could potentially become damaged or destroyed as the frozen landscape becomes altered.

5. How can permafrost thawing potentially release pathogenic microbes? Explain your answer.

- Thawing permafrost has the potential to expose the remains of various organisms, including humans. Ancient pathogenic microbes that thaw and are released into the environment may have the ability to cause disease in organisms.
- Humans and other organisms may not have the ability to produce an immune response to ancient microbes that have not been present in the environment for millennia.

Handout 2

Simulating Microbial Growth, Decomposition, and Gas Release in Thawing Permafrost

Background Information

Permafrost acts as a carbon sink and stores carbon for an indefinite period. Soil organic matter (SOM) contains carbon and is a component of permafrost. When permafrost remains frozen, organic matter cannot be decomposed, and carbon remains locked in the soil. However, when permafrost thaws, previously frozen microbes become metabolically active and decompose organic matter. During the process of degrading organic matter, microbes release carbon dioxide, methane, and nitrous oxide into the environment. Carbon dioxide and methane, two greenhouse gases, are sources of atmospheric carbon.

Objective

To compare microbial growth and the amount of gas that is released during microbial metabolism at various temperatures.

Materials

Per group of six or for class demonstration:

- 3 250-ml Erlenmeyer flasks (or plastic soda bottles) of equal size
- 100-ml graduated cylinder
- 3 large beakers or bowls (to set flasks into)
- 3 latex balloons of equal size
- 1 hot plate
- 3 thermometers (Celsius)
- Metric ruler
- Quick or rapid rising yeast (Saccharomyces cerevisiae)—room temperature, frozen, and boiled samples
- Table sugar
- Water
- Ice
- 3 cotton swabs
- 3 nutrient or Sabouraud agar petri dishes
- Metric scale (or measuring teaspoon)
- Sharpie
- Nitrile gloves
- Goggles
- Aprons

Methods

Part A:

1. Obtain three petri dishes.
2. Label the bottom of each dish with the initials of the group members.
3. Label one dish *frozen yeast*, one dish *room temperature yeast*, and one dish *boiled yeast*.
4. Obtain the frozen yeast culture from the teacher and swab the sample on the frozen yeast agar plate.
5. Repeat step 4 using the room temperature yeast culture and then the boiled yeast culture.
6. Incubate the agar plates for 24–48 hours at 30°C or at room temperature.
7. Draw and record observations on the three plates in Table 1. Record the type of agar used, the number of hours incubated, and the incubation temperature.

Part B:

1. Obtain three 250-ml Erlenmeyer flasks (or plastic soda bottles) of equal size.
2. Label each flask with the initials of the group members.
3. Label one flask *4°C* one flask *32°C*, and one flask *100°C*.
4. Place 4 grams (approximately 1 level teaspoon) of yeast and 4 grams of sugar into each flask.
5. Set each flask into a larger beaker (or bowl).
6. Set a thermometer into each of the three larger beakers surrounding the Erlenmeyer flask.
7. Obtain three balloons of equal size.
8. Measure the width of one of the balloons. In **Table 2**, record the measurement as the initial width of the balloon.

Decomposition and Gas Release at 4°C

1. Place 125 ml of cold water into the 4°C flask
2. Place 200 ml of cold water into the beaker surrounding the 4°C flask.
3. Immediately place a latex balloon over the top of the flask. Record the initial temperature of the water and experimental start time in **Table 2**.
4. Continue to add ice to the water in the beaker surrounding the flask to maintain the water temperature.
5. After 30 minutes, measure the balloon at its widest point while it is still attached to the flask. Record the final temperature of the water, experiment end time, and diameter of the balloon in **Table 2**. Additionally, draw and record observations in **Table 2.**

Decomposition and Gas Release at 32°C

1. Heat water in a 500-ml beaker on a hot plate. Maintain the temperature at 32°C.
2. Place 125 ml of the warm water into the flask.
3. Place 200 ml of the warm water into the beaker surrounding the 32°C flask.
4. Immediately place a latex balloon over the top of the flask. Record the initial temperature of the water and experimental start time in **Table 2.**
5. Continue to add warm water to the beaker surrounding the flask to maintain the water temperature.
6. After 30 minutes, measure the balloon at its widest point while it is still attached to the flask. Record the final temperature of the water, experiment end time, and diameter of the balloon in **Table 2.** Additionally, draw and record observations in **Table 2.**

Decomposition and Gas Release at 100°C

1. Boil water in a 500-ml beaker on a hot plate. Maintain the temperature at 100°C.
2. Place 125 ml of boiling water into the flask.
3. Place 200 ml of boiling water into the beaker surrounding the 100°C flask.
4. Immediately place a latex balloon over the top of the flask. Record the initial temperature of the water and experimental start time in **Table 2.**
5. Continue to add warm water to the beaker surrounding the flask to maintain the water temperature.
6. After 30 minutes, measure the balloon at its widest point while it is still attached to the flask. Record the final temperature of the water, experiment end time, and diameter of the balloon in **Table 2**. Additionally, draw and record observations in **Table 2**.

Observations

Table 1

Frozen Yeast Culture
Sketch and Observations:

____________ Agar
____________ Hours
____________ °C

Room Temperature Yeast Culture
Sketch and Observations:

____________ Agar
____________ Hours
____________ °C

Boiled Yeast Culture
Sketch and Observations:

____________ Agar
____________ Hours
____________ °C

Table 2

Initial width of the balloon: ________________ cm

Decomposition and Gas Release at 4°C
Initial temperature of water: ________________ °C Final temperature of water: ________________ °C Width of inflated balloon after 30 minutes: ________________ cm Change in the width of the balloon after 30 minutes: ________________ cm
Drawing and Observations:

Decomposition and Gas Release at 32°C

Initial temperature of water: ________________ °C

Final temperature of water: ________________ °C

Width of inflated balloon after 30 minutes: ________________ cm

Change in the width of the balloon after 30 minutes: ________________ cm

Drawing and Observations:

Decomposition and Gas Release at 100°C

Initial temperature of water: ________________ °C

Final temperature of water: ________________ °C

Width of inflated balloon after 30 minutes: ________________ cm

Change in the width of the balloon after 30 minutes: ________________ cm

Drawing and Observations:

Conclusion

Discuss the following questions with your group members and record your answers in the spaces provided.

1. What did the yeast and sugar represent in this experiment?

2. What happened to the balloons at 4°C, 32°C, and 100°C? Explain your answer.

3. How do the results of Part A of the experiment relate to Part B of the experiment? Explain your answer.

4. Compare the experimental results with that of microbes found in permafrost under various temperature conditions. Be specific.

5. Using the information gathered in this experiment, explain how microbial decomposition in thawing permafrost may cause Arctic regions to become a carbon source rather than a carbon sink. Explain your answer.

Teacher Resource 2

Answer Sheet for Handout 2: Simulating Microbial Growth, Decomposition, and Gas Release in Thawing Permafrost

Part A Sample Image:

Yeast growth on agar plate at 32°C using room temperature yeast. The amount of growth on the frozen yeast plate should be low. There should be no growth on the plate with the boiled yeast.
https://commons.wikimedia.org/wiki/File:Yeast_agar_plate-01.jpg

Part B Sample Images:

Note: These images show the experiment using common household materials. The experiment is designed to be performed in a more complex manner if materials listed in the activity are available to students.

Household materials that can be used for a simplified version of **Part B**.

Yeast mixture at 4°C. There should be no yeast activity and no expansion of the balloon. However, if the yeast mixture warms, there may be a small amount of gas produced by the yeast. This may be noticed by students when the balloon is removed after 30 minutes.

Yeast mixture at 32°C. The yeast are metabolically active and releasing gas as a byproduct of respiration. There should be visible expansion of the balloon after 30 minutes.

Yeast mixture at 100°C. The yeast were killed by the high temperature and there should be no expansion of the balloon after 30 minutes.

Note: Students have varying levels of understanding; answers should be discussed and clarified by the teacher.

1. What did the yeast and sugar represent in this experiment?

- The yeast represented the microbes, decomposers found in permafrost.
- The sugar represented the soil organic matter found in permafrost.

2. What happened to the balloons at 4°C, 32°C, and 100°C? Explain your answer.

- The optimum temperature range for metabolic activity in yeast is 32–34°C. Therefore, at 32°C, the greatest amount of carbon dioxide from yeast respiration was released, causing the balloon to expand. At 4°C, molecules move very slowly, and therefore the respiration rate of the yeast was slow. Due to the slow rate of respiration at 4°C, little carbon dioxide was released by the yeast, causing no notable expansion of the balloon. At 100°C, molecules moved fast and caused proteins in the yeast to denature, which led to the death of the yeast. Because no respiration occurred at 100°C, no carbon dioxide was released into the balloon.
- At 32°C, the yeast were active, and therefore more carbon dioxide was released as a waste product of respiration. At 4°C and 100°C, there was little to no gas released by the yeast because the temperature was below and above the optimum temperature range for yeast activity.

3. How do the results of Part A of the experiment relate to Part B of the experiment? Explain your answer.

- Because the optimum temperature range for yeast activity is 32–34°C, the greatest amount of yeast growth was seen on the 32°C agar plate. At 4°C, yeast activity slows or stops altogether, and therefore there was little or no growth on the 4°C agar plate. Yeast are killed at 100°C, and therefore there was no growth on the 100°C plate. The thermal death point of yeast is 60°C; however, yeast will begin to die at 50°C. When there is an increase in reproduction, there is an increase in carbon dioxide released during cellular respiration. Therefore, the flask set at 32°C had more yeast that released enough carbon dioxide to inflate the balloon.

4. Compare the experimental results with that of microbes found in permafrost under various temperature conditions. Be specific.

- Many microbes are metabolically inactive in permafrost and remain in a dormant state. While in a dormant state, the microbes do not release carbon dioxide, methane, and nitrous oxide, greenhouse gases, into the atmosphere. However, as permafrost thaws, microbes actively decompose organic matter in the soil and release greenhouse gases into the atmosphere.
- Yeast activity, including reproduction, slowed or stopped at 4°C. Therefore, little to no decomposition of the sugar (an organic substance) by the yeast occurred, and little to no gas was released into the balloon. Because microbes in permafrost are dormant, organic matter in the permafrost is not decomposed, and carbon dioxide, methane, and nitrous oxide are not released into the atmosphere. Permafrost is considered a carbon sink because decomposition does not occur and carbon-containing greenhouse gases are not released into the atmosphere.
- Yeast activity, including reproduction, increases at 32°C. Therefore, decomposition of the sugar (an organic substance) by the yeast occurred and gas was released into the balloon. Because microbes in thawed permafrost are metabolically active, organic matter in the permafrost is decomposed, and carbon dioxide, methane, and nitrous oxide are released into the atmosphere. Thawed permafrost is considered a carbon source when decomposition occurs and carbon-containing greenhouse gases are released into the atmosphere.

5. Using the information gathered in this experiment, explain how microbial decomposition in thawing permafrost may cause Arctic regions to become a carbon source rather than a carbon sink. Explain your answer.

- As permafrost thaws, dormant microbes become active and decompose soil organic matter to perform cellular activities, including reproduction. The warmer the thawing permafrost becomes, the greater the number of microbes, the greater the amount of metabolic activity, and the greater the amount of carbon dioxide and methane released. The carbon-containing greenhouse gases produced by microbes in thawing permafrost are released into the atmosphere. Because the amount of carbon stored becomes less in thawing permafrost, it is now considered a carbon source as more carbon dioxide and methane are released. Additionally, over time, methane in the atmosphere is converted into carbon dioxide by a simple chemical reaction.

Handout 3

Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost

Background Information

Carbon dioxide and methane are two greenhouse gases released during decomposition. There is much less methane in the atmosphere than carbon dioxide. However, methane traps approximately thirty times more heat than carbon dioxide. Scientists are concerned that permafrost thawing will dramatically increase methane and carbon dioxide in the atmosphere.

Methane naturally exists in permafrost. Methane can exist in permafrost as methyl hydrate (methyl clathrate), molecules of methane frozen into ice crystals. Methyl hydrate forms under high pressure and low temperature. If temperature or pressure changes occur in the Arctic, ice will break apart, releasing methane into the atmosphere.

Organic matter in permafrost is made of dead plants and animals that have been frozen for thousands of years. When permafrost thaws, the organic matter is decomposed, releasing carbon dioxide and methane into the atmosphere.

As permafrost thaws, it collapses, releasing gases that form cracks in the landscape. Additionally, it is theorized that large pockets of gas trapped in permafrost form large craters in a process called cryovolcanism. As permafrost thaws, gas pressure increases, pushing away the overlaying layers, which collapses the permafrost and forms a crater.

Objective

To understand how permafrost thawing can cause alterations in the landscape as the gas previously locked in the permafrost is released into the atmosphere.

Materials

Per group of three:
250-ml beaker (or large cup)
100-ml graduated cylinder
Thermometer (optional)
Hot plate (optional)
Quick or rapid rising yeast (Saccharomyces cerevisiae)—room temperature, frozen, and boiled samples
Table sugar
Water
Flour
Bowl
Rolling pin
Tinfoil or wax paper
Metric scale or measuring teaspoon
Nitrile gloves
Goggles
Aprons

Methods

Part 1:

1. Add 12 grams of yeast and 4 grams of sugar into a 250-ml beaker or large cup
2. Add 100 ml of water to the 250-ml beaker.
3. Stir the mixture of yeast, sugar, and water in the beaker.
4. Let the beaker sit for 30 minutes. In **Table 1**, draw and record observations at 15-minute intervals.
5. Continue to let the beaker sit for several hours or overnight. In **Table 2,** draw and record observations after several hours.

Part 2:

1. Place 2 cups of flour in a bowl. Slowly mix in water to make a dough that is soft and pliable.
2. Make a fresh mixture of 12 grams of yeast and 4 grams of sugar into a 250-ml beaker (or large cup)
3. Add 100 ml of water to the 250-ml beaker.
4. Stir the mixture of yeast, sugar, and water in the beaker and let it sit for 5 minutes.
5. Separate the dough into two pieces, one large piece and one small piece. Place the dough on separate sheets of tinfoil or wax paper.
6. Shape the larger dough piece into a mound and use a thumb to make a large depression in the middle of the mound. With wet fingers, smooth the mound of dough, including along the edges of the depression.
7. Use a rolling pin to flatten the small piece of dough. Make sure the rolled dough is very thin.
8. Fill the depression in the larger piece of dough with the yeast, sugar, and water mixture.
9. Cover the larger mound with the smaller, flattened sheet of dough and smooth again with wet fingers.
10. Let the dough sit for 45 minutes. In Table 2, draw and record observations at 15-minute intervals for 45 minutes.
11. Continue to let the dough sit overnight. In Table 2, draw and record observations after the 24-hour period.

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Drawings and Observations

Table 1

Drawing and observations at 0 minutes
Drawing and observations after 15 minutes
Drawing and observations after 30 minutes
Drawing and observations after ___________ hours

Table 2

Drawing and observations at 0 minutes
Drawing and observations after 15 minutes
Drawing and observations after 30 minutes
Drawing and observations after 45 minutes
Drawing and observations after 24 hours

Conclusion

Discuss the following questions with your group members and record your answers in the spaces provided.

1. What happened to the gas emission of the yeast in ***Part 1*** and ***Part 2*** over 30–45 minutes? Explain.

2. What happened to the gas emission of the yeast in ***Part 1*** and ***Part 2*** after several hours? Explain.

3. How does this experiment simulate a change in the Arctic landscape due to the emission of gas produced by microbes during permafrost thawing? Explain.

Part 3 (Optional Extension):

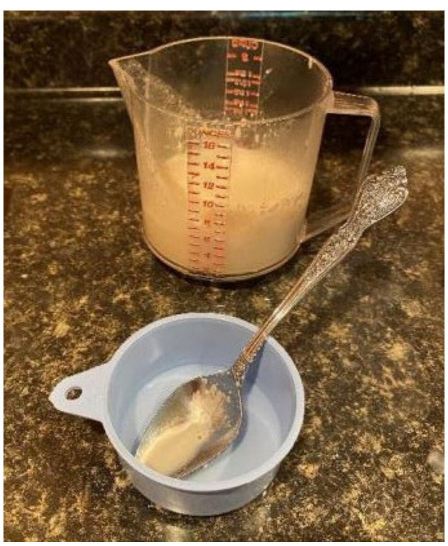
Use the materials provided to design an experiment to simulate the effects of gas emission on the permafrost landscape at various temperatures.

Teacher Resource 3

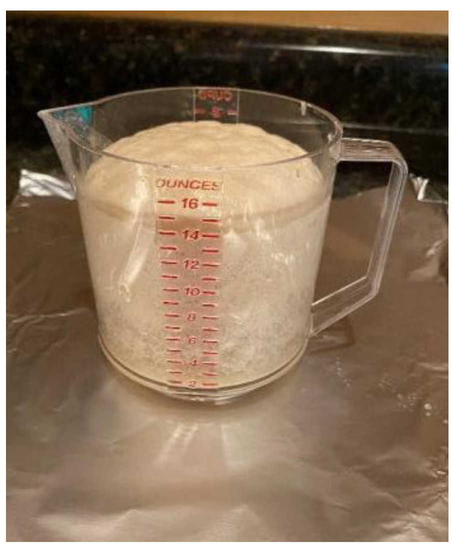
Answer Sheet for Handout 3: Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost

Part 1 Sample Images:

Household materials that can be used for a simplified version of ***Part 1*** and ***Part 2*** of the experiment.



Note: These images show the experiment using common household materials. The experiment is designed to be performed in a more complex manner if materials listed in the activity are available to students.



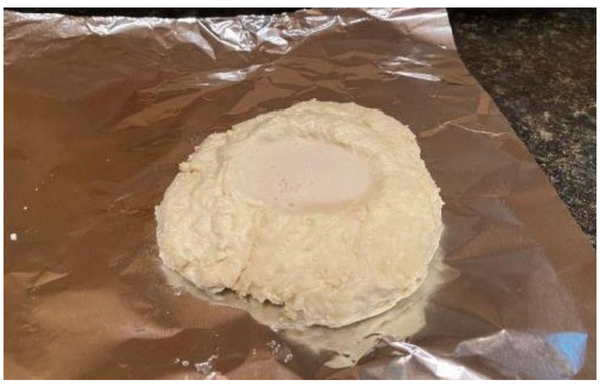
The mixture will expand as more gases are released over a short period of time.

After a period of time, the pressure exerted by the gases in the mixture causes the surface of the mixture to crack and collapse, releasing gases into the environment.

Part 2 Sample Images:

Flour is mixed with water until it is soft and pliable and then separated into two parts, one large and one small. The smaller piece is flattened with a rolling pin. The larger piece of dough is shaped into a mound.

A depression is made in the center of the dough mound.



The depression in the dough mound is filled with the yeast, sugar and water mixture.

The top of the large dough mound is covered with the small, flat piece of dough and allowed to sit. After time, the dough over the yeast mixture expands due to the production of gas by yeast in the depression.

After a period of hours, the pressure of the gases from yeast activity within the dough causes areas of the dough surface to collapse, forming cracks and craters. The gases are then released into the environment.

Conclusion

Note: Students have varying levels of understanding; answers should be discussed and clarified by the teacher.

1. What happened to the gas emission of the yeast in ***Part 1*** and ***Part 2*** over 30–45 minutes? Explain.

- The yeast used the sugar as a source of energy and the rate of respiration increased, which increased the amount of gas production during the 30–45-minute period.
- The number of yeast and the rate of metabolic activity increased over the 30–45-minute period, causing an increase in the production of carbon dioxide.
- As the yeast produced more gas during the 30–45-minute interval, pressure increased, causing the mixture in the beaker to expand and the dough over the yeast mixture to expand.

2. What happened to the gas emission of the yeast in ***Part 1*** and ***Part 2*** after several hours? Explain.

- As the yeast produced more gas, the pressure increased, eventually causing cracks that allowed the gas to escape into the atmosphere.
- As the pressure of the gas emitted by the yeast increased, cracks formed in the yeast mixture and gas was released into the atmosphere. After a longer period of time, the top of the yeast mixture collapsed, and a deep depression was observed.
- As the pressure of the gas increased in the dough, the dough expanded. Over time, cracks were observed in the dough and gas was released into the atmosphere. Eventually, a depression formed in the area where the yeast mixture was concentrated, and several small craters were observed in other areas of the dough.

3. How does this experiment simulate a change in the Arctic landscape due to the emission of gas produced by microbes during permafrost thawing? Explain.

- As the temperature of permafrost increases, the active layer becomes deeper and previously dormant microbes become active and decompose organic matter.
- As the rate of decomposition increases, more gases are released. Eventually the pressure of the gases forms cracks, and possibly craters, releasing large amounts of previously trapped gases into the atmosphere.
- Increased gas emission due to permafrost thawing can lead to weakened ground, cracks, depressions, landslides, and other changes in the permafrost landscape. These changes in the permafrost landscape can lead to effects such as damage or destruction of structures built on permafrost and the disruption of human and animal migration patterns.

Part 3 (Optional Extension):

This extension is for more advanced students who may want to test different environmental conditions that simulate landscape changes in permafrost due to the production of gases during microbial decomposition. Some students may decide to design an experiment with a frozen yeast mixture placed into the dough depression and observe what happens over time. Other students may decide to design an experiment with various temperatures of the yeast mixture placed into different mounds of dough. However, the students should set all parameters of the experiment with no input from the teacher.

Handout 4

Summative Assessment: The Global Effect of Greenhouse Gas Emission Due to Microbial Decomposition in Thawed Permafrost

Background Information

There has been a great amount of attention focused on the effects of melting ice in Arctic regions. However, little attention has been dedicated to the effects caused by the emission of greenhouse gases released into the atmosphere during microbial decomposition in thawed permafrost. Frozen Arctic regions lock large amounts of carbon-containing organic matter in the soil. When the frozen soil thaws, microbes that were dormant become active and decompose the organic matter. The organic matter available causes an increase in the metabolic activity of the microbes. Additionally, microbial reproduction increases due to the increased nutrients available provided by the thawed organic matter. Besides an increase in nitrous oxide, two other greenhouse gases, carbon dioxide and methane, are released during the decomposition process. It is estimated that more than 50% of all terrestrial carbon on Earth is stored in permafrost soil organic matter. An ecosystem in which more carbon is stored than emitted is known as a carbon sink. However, when permafrost thaws, the amount of carbon released into the atmosphere is greater and it becomes a source of carbon. When the uptake of carbon by an ecosystem is less than the amount of carbon emitted, the increase in carbon containing greenhouse gases leads to global warming and climate change.

Objective

To present a poster portraying the regional and global effect of greenhouse gas emissions due to microbial decomposition in thawing permafrost.

Materials

Computer, tablet, or phone with Internet access
Color printer access
Poster board
Markers, colored pencils, pencils, Sharpies
Glue stick
Scissors
Ruler

Methods

Using the information learned in this unit on permafrost, construct a poster showing feedback loops that occur when man-made greenhouse gas emissions lead to thawing permafrost, increased microbial activity, and the release of more greenhouse gases into the atmosphere.

Be creative and use your own sketches or pictures and directional arrows to show interactions that occur in the feedback loop. Pictures can also be obtained using Google Images, then Tools, Usage Rights, Creative Common Licenses (Be sure to check the Creative Common Licenses.) Provide descriptive labels next to each sketch or picture in the poster.

Practice your presentation before you present your poster to the class, and be prepared to answer questions and engage in discussion about it.

Teacher Resource 4

Guidance for Handout 4: The Global Effect of Greenhouse Gas Emission Due to Microbial Decomposition in Thawed Permafrost

Student poster presentations will vary but should show relationships between human activities, global warming, climate change, microbial decomposition in thawing permafrost, and the emission of greenhouse gases.

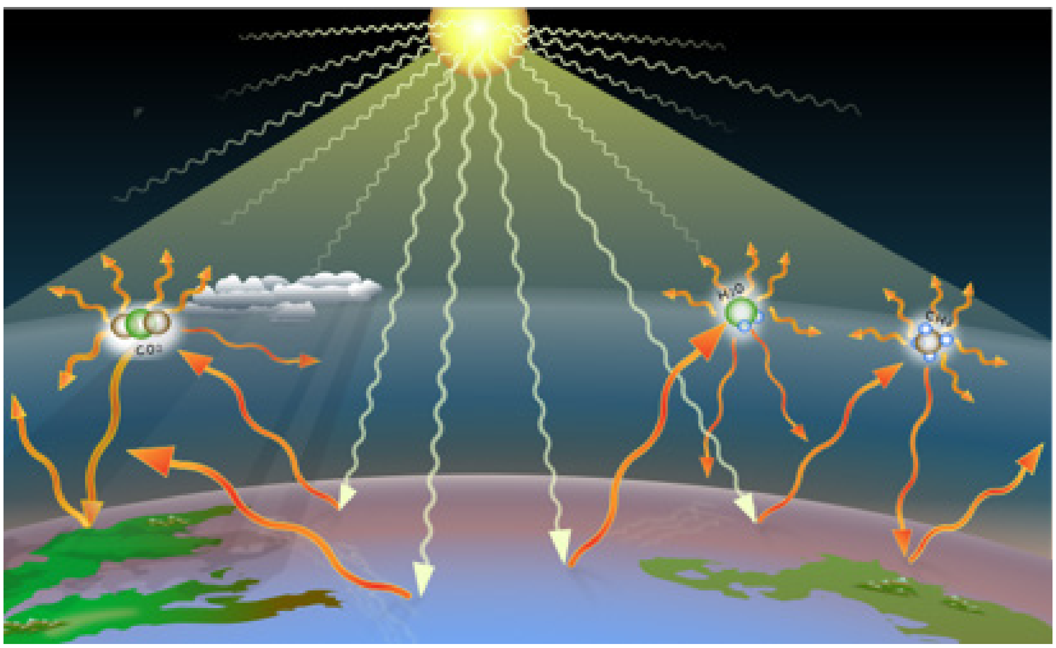
Additionally, the poster should have arrows showing relationships (feedback loops) between the various sketches or pictures presented on the poster.

The images below are samples of the kind of images students might collect; sample commentary is included as well. Images should be placed on a poster in a pattern that shows the links between greenhouse gas production, thawing permafrost, microbial decomposition in permafrost, and the output of more greenhouse gases that lead to global warming and climate change in Arctic regions.

https://commons.wikimedia.org/wiki/File:Smoke_stack-s1a35073v.jpg

NASA Goddard Space Flight Center from Greenbelt, MD, USA. Public domain, via Wikimedia Commons at https://commons.wikimedia.org/wiki/File:Where_is_the_Carbon_Going%3F_(14413362184).jpg

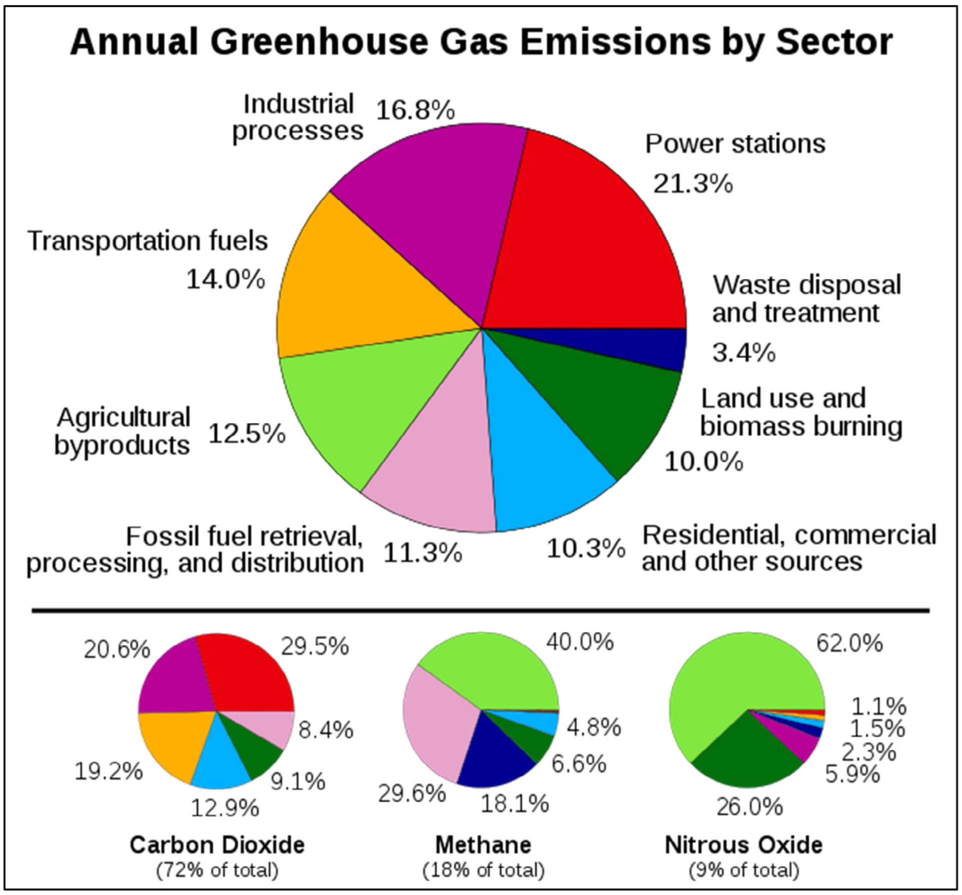
Greenhouse gases trap heat in the atmosphere, which leads to changing climate patterns on Earth. The burning of fossil fuels releases greenhouse gases into the atmosphere. The greatest percentage of greenhouse gas emission from fossil fuel burning is carbon dioxide. However, the greenhouse gases methane and nitrous oxide are also released into the atmosphere.



https://commons.wikimedia.org/wiki/File:Greenhouse-effect-t2.svg

It is estimated that over 90 percent of all greenhouse emissions comes from the burning of fossil fuels by cars, trucks, ships, and trains.

These graphs indicate the approximate percentage of man-made greenhouse gases coming from eight categories, as estimated by the Emission Database for Global Atmospheric Research version 3.2, fast track 2000 project. The top graph shows the sum of all man-made greenhouse gases, weighted by their global warming potential over the next 100 years (72% carbon dioxide, 18% methane, 8% nitrous oxide and 1% other gases). The lower graphs show the comparable information for each of three primary greenhouse gases. (The same coloring of sectors is used in all graphs.)



https://commons.wikimedia.org/wiki/File:Greenhouse_gas_by_sector_2000.svg

Approximately 70 percent of solar energy that passes through the Earth's atmosphere to the Earth's surface is absorbed by land, water, and the atmosphere to heat the planet. Heat, in the form of invisible infrared light, is then radiated from the Earth's surface back up into the atmosphere and space. About 90 percent of the infrared light is absorbed by greenhouse gases and redirected, causing further warming.

This diagram of the fast carbon cycle shows the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatons of carbon per year. White numbers indicate stored carbon. As seen in the diagram, a large amount of carbon is stored in rocks and sediment.

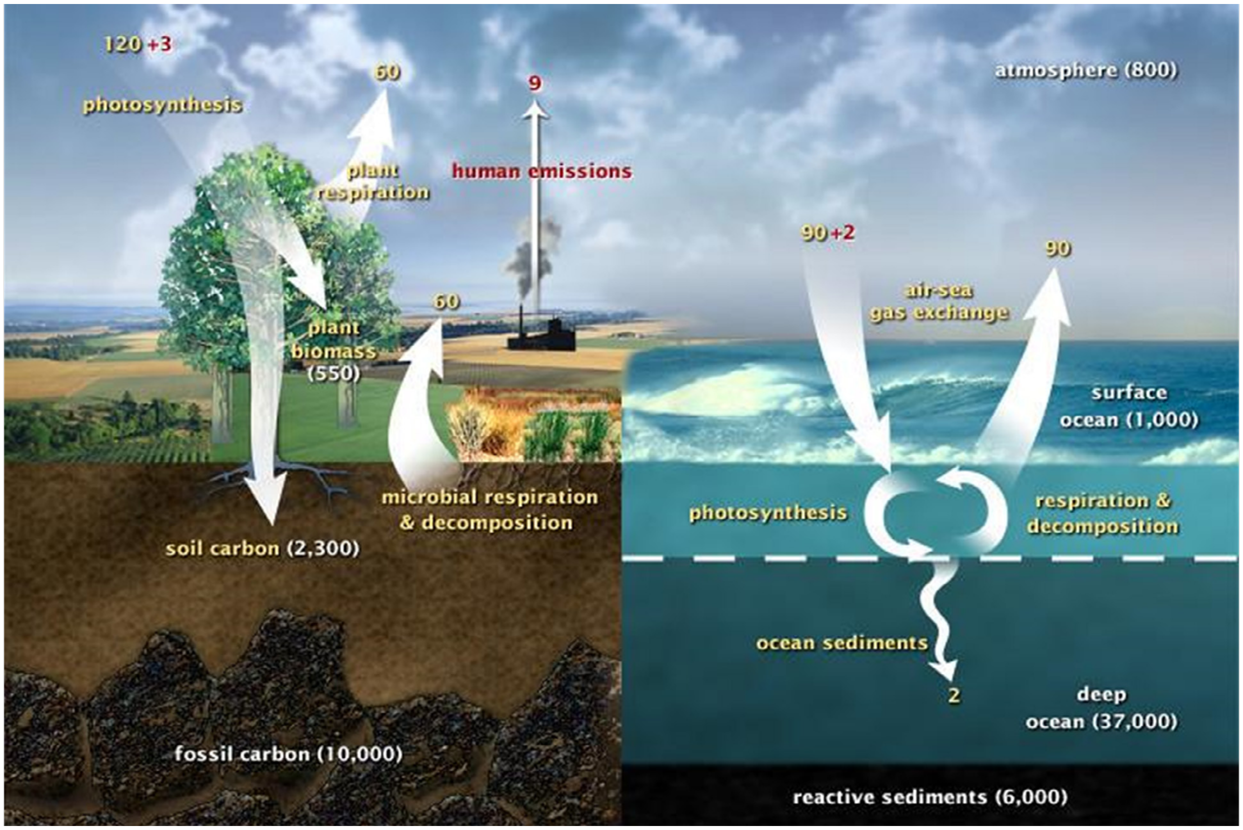
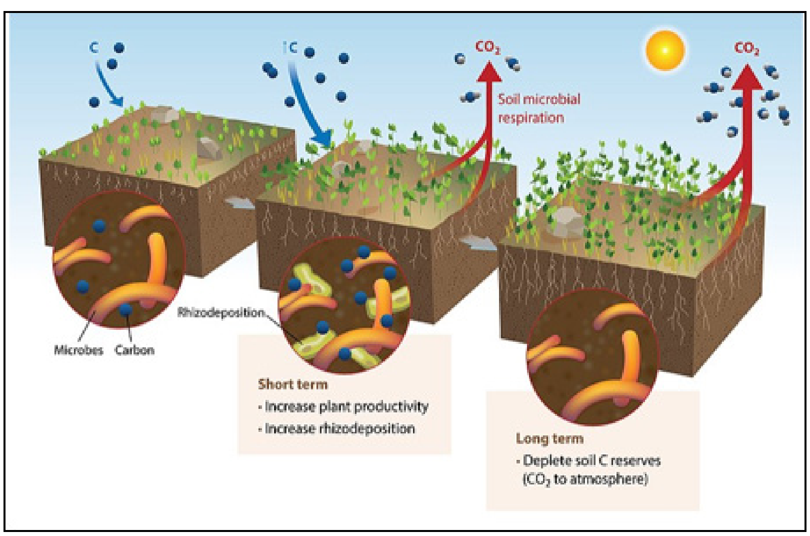


Diagram adapted from U.S. DOE, Biological and Environmental Research Information System.
https://www.flickr.com/photos/atmospheric-infrared-sounder/8263944907



https://commons.wikimedia.org/wiki/File:Predicted_effects_of_elevated_carbon_dioxide_on_soil_carbon_reserves.jpg

As global warming occurs, climate changes are observed. One of the climate change trends is the thawing of permafrost. As the permafrost thaws, the active layer becomes deeper. Previously frozen soil organic matter (SOM) and microbes thaw. The microbes decompose the organic matter and release greenhouse gases into the atmosphere.

https://www.flickr.com/photos/140969380@N07/29968660735

Additionally, as the soil organic matter in Arctic regions is decomposed, the surface of the land becomes unstable, causing cracks, landslides, and other geological events to occur that change the landscape. Some scientists even theorize that craters form when large amounts of gases cause an increase in pressure, resulting in the collapse of the once stable permafrost surface. As the landscape in Arctic areas changes and gases are no longer trapped below the surface, more greenhouse gases are released into the atmosphere, causing more heat to be trapped, which further increases global warming and climate change.

Sample Rubric for Summative Assessment
Poster Presentation Rubric

Student Name ______________________ **Class Period** ______________________

CATEGORY	4	3	2	1
Required Elements	The poster contains all required elements plus additional information.	All required elements are included in the poster.	The poster is missing one required element.	The poster is missing several required elements.
Labels	All important items on the poster are clearly labeled and legible from a few feet away.	Almost all important items on the poster are clearly labeled and legible from a few feet away.	Some items on the poster are clearly labeled and legible from a few feet away.	No important items on the poster were labeled clearly, or the labels were too small to read from a few feet away.
Images	All images are relevant, contribute to the viewer's understanding, and have some citations.	All images are relevant and contribute to the viewer's understanding. Some, but not all, graphics have source citations.	All images are relevant. A few images have a source citation.	Images are not relevant to the topic. Few or no images have a source citation.
Appearance	The poster is very attractively designed. Execution of the poster is neatly done.	The poster is attractively designed and neatly executed.	The poster is attractively designed but not neatly executed.	The poster is not appealing because it is poorly designed or messy.
Text	There are no mistakes in grammar, syntax, or mechanics on the poster.	There are 1 or 2 mistakes in grammar, syntax, or mechanics on the poster.	There are 3 or 4 mistakes in grammar, syntax, or mechanics on the poster.	There are 5 or more mistakes in grammar, syntax, or mechanics on the poster.

Lesson 3

Atmosphere

Enduring Understandings

- Global warming is altering Earth's weather patterns dramatically. A warmer atmosphere absorbs more water vapor, which in turn traps more heat and warms the planet further in an amplifying feedback loop.
- Climate change is disrupting the jet stream, triggering a feedback loop that brings warm air northward and cold air southward, further warming the Arctic and causing weather patterns to stall in place for longer.
- The atmosphere is complex, and scientists continue to work to understand how fossil fuel emissions are altering the chemistry and general dynamics of the atmosphere and therefore contributing to climate change.
- Clouds play a critical role in trapping heat, as well as reflecting energy away from Earth.
- Since the problem has been human driven, so is the solution. A social change is required to help bring the Earth back into its natural cyclical pattern.

Essential Questions

- What are feedback loops and how do they impact climate?
- What role do clouds play in Earth's climate?
- How does water vapor affect temperature?
- How does the jet stream influence climate, and how has it changed over time?
- How do we reduce carbon emissions?
- How can we spread awareness and reduce our carbon footprint?

Notes to the Teacher

This lesson is designed to teach students about climate locally, regionally, and globally, while providing opportunities to practice scientific literacy and presentation skills, learn about educational and career pathways in climate science, and explore possible solutions to the climate change problem.

The lesson is divided into four parts. Part 1 of this lesson is designed to address the first four essential questions listed at left. Students will work in groups of four to discuss, research, and teach one another about each essential question. (Groups can be determined by the teacher prior to class.) Each student will be responsible for preparing a presentation to demonstrate understanding of one essential question.

The second part introduces students to the possible changes to the climate in their state or region. It teaches students how to locate and explore the climate archives that each land-grant university maintains. (A land-grant university is an institution of higher learning designated under the Morrill Acts of 1862 and 1890. In response to the Industrial Revolution, states were given federal lands to sell to raise money for colleges that would teach practical skills like agriculture, science, engineering, and even military science. These generally became large state public universities.)

Students will act like scientists by asking a question that they want to explore, conducting the necessary research, preparing their findings using tables and graphs, incorporating one thing they learned from the atmosphere chapter, and then presenting their findings to the class. There is also an extension activity if students are interested in exploring other climate-change-related stories anywhere in the world.

Before teaching Part 2, search the Internet for the state climate office for your state. Each state's climatology data are kept by the State Climatologist; their offices are located on each state's land-grant campus (for example, at the University of New Hampshire, the University of Vermont, University of Massachusetts Amherst, etc.) Locate the archived climate history for your state and become familiar with its organization and data so that you can assist your students in their research.

Part 3 gives students an opportunity to listen to young people who are activists fighting against climate change. After considering the example of Malala Yousafzai, who started a global movement to protect girls' right to an education, students listen to speeches by an array of climate activists, including the well-known Greta Thunberg. Then they consider ways they can make their own voices heard on this subject.

To follow up with this lesson, consider moving on to Lesson 5, "Re-Greening the Earth," which helps students research particular steps that could be taken.

Common Core Standards addressed by this lesson

CCSS.ELA-Literacy.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.RH.11-12.7
Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, as well as in words) in order to address a question or solve a problem.

CCSS.MATH.CONTENT.HSF.IF.B.6
Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.

Next Gen Science Standards addressed by this lesson

HS.Interdependent Relationships in Ecosystems
Students who demonstrate understanding can:

HS-LS2-6.
Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and extreme changes, such as volcanic eruption or sea level rise.]

HS-LS2-7.
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity. [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

HS-LS4-6.
Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity. [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

The performance expectations to the left were developed using the following elements from the NRC document A Framework for K-12 Science Education:

Science and Engineering Practices
Constructing Explanations and Designing Solutions
Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations. (HS-LS2-7)

Disciplinary Core Ideas
LS2.C: Ecosystem Dynamics, Functioning, and Resilience

- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. (HS-LS2-2),(HS-LS2-6)
- Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7)

LS4.D: Biodiversity and Humans

- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). (secondary to HS-LS2-7)
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (secondary to HS-LS2-7), (HS-LS4-6)

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (secondary to HS-LS2-7),(secondary to HS-LS4-6)
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (secondary to HS-LS4-6)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8),(HS-LS4-6)

Scale, Proportion, and Quantity

- The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (HS-LS2-1)
- Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. (HS-LS2-2)

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-LS2-6),(HS-LS2-7)

Duration of Lesson

Part 1: 3 class periods—Atmosphere and Climate Change
Part 2: 2–3 class periods—Climate Patterns in Your State
Part 3: 1–2 class periods—Meet the Scientists
Part 4: 4–5 class periods—Student Activism Project and Presentations

Assessments

Brainstorming notes
Handouts, webquest, and worksheets
Class discussions
Student or group projects and presentations

Materials

Handout 1: Essential Questions Worksheet
Handout 2: Student Feedback Form
Handout 3: Climate Patterns in Your State
Basic art supplies for making posters
Whiteboard or overhead to record and display class ideas and questions
Computers with Internet access
Climate Emergency: Feedback Loops documentary "Atmosphere" at https://feedbackloopsclimate.com/atmosphere/

Procedure

Part 1: Atmosphere and Climate Change

1. Explain to students that a well-designed lesson has at least one important question for students to investigate; then tell them that this lesson has four questions they will be studying. Pass out copies of **Handout 1: Essential Questions Worksheet** and read through the four Essential Questions. Tell students they will be working in small groups and will be responsible for researching and teaching their group members about one of the four questions.

2. Watch the *Climate Emergency: Feedback Loops* documentary "Atmosphere" with the entire class.

3. Divide the class into groups of four and have the groups spread out around the room. If you have an odd number of students, here are some options:

a. More than one student in the group could create presentations on the same essential question.
b. Students from the same group could work together on a single presentation of an essential question.
c. The group could work together to create presentations for questions not selected by individuals.

4. Give time for group members to determine which question each student will select for this activity. They should circle their chosen question in the space provided on **Handout 1**. Allow students time to work together to brainstorm what each remembers from the video about any of the four essential questions to help each other get started. Students should write down these ideas in the space provided on the handout. If desired, have students begin their research for homework.

5. Begin the next class by letting students know they will have most of the class period to research and create a plan for a presentation poster. As they work, circulate around the room to check in with students and help as needed.

6. About 15 minutes before the end of the period, have students sketch and share with you a draft of a poster on their essential question that they will be using for the small group presentation.

7. For homework, have students complete the poster and prepare talking points for a two- to three-minute presentation for the next class period.

8. At the beginning of the next class, distribute a copy of **Handout 2: Student Feedback Form** to each student. Then have students return to their initial groups.

9. Explain to students that now each student in the group will take a turn to present a poster and talking points that answer the essential question to group members. During the presentation, group members need to take notes on the information learned from the poster and presenter. After each presentation, they should record comments and questions for the presenter in the space provided on **Handout 2**. When they have finished, they should provide feedback to the presenter in the form of comments and questions. Group members can also offer specific compliments and constructive criticism for the presenter. The presenter should write notes about the feedback from group members in the space provided on the Student Feedback Form.

10. Have students begin their small group presentations; they should be happening simultaneously in the classroom. Rotate among groups to observe, listen, and guide discussion as necessary.

11. Wrap up the class period by having students share take-aways from the process. Possible questions include:

- What was most interesting to you?
- What did you learn?
- What did your classmates do well?
- What can we all work on to improve?

Finally, summarize the session to help students connect the four essential questions by asking: How does Earth's atmosphere affect global climate? Give students an opportunity to complete **Handout 2** to summarize the answer to this question.

Important points for students to cover on the poster and in discussion:

<u>What are feedback loops and how do they impact climate</u>?

- Feedback loops are a continuous system in which a change in one (or more) parts of the system act to influence the rest of the system, either positively (increasing the effects of the system) or negatively (decreasing the effects of the system). [See below for examples of how changing factors (clouds and water vapor) may impact the climate system.]

<u>What role do clouds play in Earth's climate?</u>

- Clouds can affect Earth's climate in two major ways.
    - Clouds reflect sunlight back into space, reducing the warming effect that sunlight has on the Earth's surface (exposed rocks and soil, water, urban areas, etc.) This effect results in reduced warming of the Earth's atmosphere.
    - Clouds can also act as a blanket, preventing the natural cooling that occurs overnight if the skies are clear.
- If increased evaporation (including transpiration) occurs due to warming, increased cloudiness may have the effect of slowing the warming of the atmosphere.
- If, on the other hand, increased evaporation/transpiration results in increased levels of water vapor (see below) instead of clouds, the rate of atmospheric warming will increase.

How does water vapor affect temperature?

- Water vapor is a powerful greenhouse gas, more powerful than CO_2 or CH_4 (methane), and will increase atmospheric enhanced greenhouse warming.
- Several major climate models differ in their projections of future warming, based on their assumptions regarding more clouds (reduced rate of warming) or increased water vapor (increased rate of warming) in the atmosphere. At this point, it is not clear which of these results may happen.

How does the jet stream influence climate and how has it changed over time?

- The jet stream is a pattern of high-altitude winds moving from west to east around the Earth.
- There are several jet streams, both north and south of the equator. The north polar jet stream has a strong impact on weather patterns in the northern hemisphere by moving high pressure (clear and sunny) and low pressure (cloudy and rainy) systems around the planet.
- Weather is what happens day-to-day or week-to-week, while climate is more long-term (changes over years, decades, or longer).
- The warming of the Arctic has changed jet stream patterns in the northern hemisphere over the past 40–50 years (beginning in the 1970s). Over that period of time, the north polar jet stream has become more erratic, resulting in dramatic changes in our weather, such as frequent fluctuations in hot and cold weather patterns.

Part 2: Climate Patterns in Your State

1. Begin the class by brainstorming questions students would like to answer about climate in their state or region. (10 minutes) Examples could be:
  a. Is my state in a drought?
  b. Is my town experiencing a drought?
  c. Is my state experiencing higher than normal temperatures?
  d. Has there been a change in snowfall or rainfall patterns in the last year, decade, or century?

2. Give each student a copy of **Handout 3: Climate Patterns in Your State**. Tell them to begin by writing down one of the questions they generated during the brainstorming session. Show students how to access their state's climate office and how to filter the necessary data. Then allow students to conduct their own research while you circulate to assist them.

3. Provide time in class for students to locate the appropriate data to answer their question. They should sketch drafts of how to present the data in tables and graphs. (You can decide if you would like students to complete the tables and graphs by hand or using digital tools.)

4. Ask students to include in their report one thing they learned from the "Atmosphere" video to demonstrate their understanding of the material. (They could draw a feedback loop, explain the changes to the jet stream, discuss the frequency and intensity of hurricane activity, or explain the role of water vapor and clouds in the climate system.)

5. Conduct a whole-class discussion of what students have learned about the climate in their state. What are the implications for the future, based on what they learned in the film "Atmosphere"?

6. If desired, assign the extension activity at the end of **Handout 3** to have students analyze the causes and effects of certain recent extreme weather events.

Part 3: Meet Some Student Activists

1. Ask students if it is really possible for a teenager to bring about any movement to stop climate change. Discuss briefly.

2. Ask students if they have ever heard of a young woman named Malala Yousafzai. If they do not recognize the name, explain that she was a teenager in Pakistan when she was almost assassinated because she was advocating for the right of girls to attend school. After she recovered, she became an international leader in the fight for girls' education. She was even invited to address the United Nations and she won a Nobel Peace Prize at age 17. There is a documentary about her called *He Named Me Malala.*

3. Explain to students that there is another global campaign started by a teenager, one that tries to influence governments to adopt policies to stop climate change. Its leader is Greta Thunberg, a Swedish activist born in 2003. She is known all over the world for her actions and speeches to raise awareness of the problems that are inevitable with continued global warming.

4. Go to the Fridays for Future website at [https://fridaysfor-future.org/what-we-do/activist-speeches//](https://fridaysforfuture.org/what-we-do/activist-speeches//) Show the videos of Greta Thunberg's COP 24 speech and the one titled "Our House Is on Fire." Discuss these speeches with students using the following questions as starters:

a. What are the most important points that she raises in these speeches?
b. Are you convinced by her? Do you think adults will listen to her?
c. What kinds of concrete actions could be taken to meet her demands?

5. If possible, show several more speeches from this website.

6. Ask students how they think they could make their own voices heard. Encourage them to think about writing a letter to the editor for their local paper, planning a presentation to the school community, networking with local conservation organizations, etc.

7. For an extension activity, if there is sufficient student enthusiasm, consider using Lesson 5 from this guide, which helps students research and plan one step that could be taken to "regreen the Earth."

Extension Activities

These additional activities will show students the many career opportunities in science and help them understand how to pursue possible interests in climate science.

1. Arrange for students to interview a scientist who is working in the area of climate change. You can locate one through your local university, the climate office for your state, or an environmental agency. The interview can be either in person or on Zoom. Some possible questions students might ask are:

a. What did the scientist want to be as a young person?
b. Were there any surprising changes in the scientist's path?
c. Where did the scientist go to school?
d. When did the scientist know climate science was the right fit?
e. What schools have programs for this kind of work? Are there internships in this field or Extended Learning Opportunities (ELOs) that would provide some experience?

2. Spend a day in the library exploring educational and career pathways.

Additional Resources

IPCC [Intergovernmental Panel on Climate Change] Climate Change 2014 Synthesis Report Summary for Policymakers
http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Howard Hughes Medical Institute (HHMI)—Paleoclimate: A History of Change
http://media.hhmi.org/biointeractive/click/paleoclimate/

NASA—Global Climate Change: Vital Signs of the Planet
https://climate.nasa.gov/

HHMI—Geologic Carbon Cycle
http://www.hhmi.org/biointeractive/geologic-carbon-cycle

Global Footprint Network—Ecological Footprint Calculator
https://www.footprintnetwork.org/our-work/ecological-footprint/

Carbon Brief—Mapped: How Climate Change Affects Extreme Weather Around the World
https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world

Bozeman Biology
http://www.bozemanscience.com/biology-main-page/

USGS—Climate and Land Use Change
https://www.usgs.gov/science/science-explorer/Climate+and+Land+Use+Change

New York Times—"Climate Change Is Complex. We've Got Answers to Your Questions."
https://www.nytimes.com/interactive/2017/climate/what-is-climate-change.html?rref=collection%2Fbyline%2Fjustin-gillis&action=click&contentCollection=undefined&region=stream&module=stream_unit&version=latest&contentPlacement=3&pgtype=collection

Scientific American—10 Solutions for Climate Change
https://www.scientificamerican.com/article/10-solutions-for-climate-change/

Solutions for climate change from Project Draw-down
https://drawdown.org/solutions

Laurie David and Heather Reisman's *Imagine It: A Handbook for a Happier Planet* (New York: Rodale Books, 2020) provides suggestions for individuals and families to change their own habits in order to reduce their use of natural resources.

Handout 1

Essential Questions Worksheet

Name ______________________________ **Date** ______________________

Directions: Your task is to prepare a brief presentation answering one of the four essential questions from the *Climate Emergency: Feedback Loops* documentary "Atmosphere." Please use this worksheet to explore and learn about the question you choose.

Step 1: Select a Question

Spend some time in your small group to determine which question each student would like to take for this activity. Circle your choice below.

Essential Questions

- What are feedback loops and how do they impact climate?
- What role do clouds play in Earth's climate?
- How does water vapor affect temperature?
- How does the jet stream influence climate and how has it changed over time?

Step 2: Brainstorm as a Group

Work with your group members to brainstorm ideas of what was learned from the video about each essential question. In the space below, write notes from the group discussion that pertain to your question.

Step 3: Individual Research

Find information about the answer to your essential question. Record what you learn in a science journal or notebook.

Step 4: Poster Plan

Sketch a rough draft of the poster you will be using in your presentation. Be sure your poster answers your essential question completely. It should be visually appealing with a balance of images, diagrams, and text.

Step 5: Check-In

Share your draft with your teacher and group members for feedback.

Step 6: Project Completion
Create a final draft of your poster and write notecards with talking points for a two- to three-minute presentation.

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educating for global understanding

Handout 2

Student Feedback Form

Name ______________________________ **Date** ______________________________

Directions: Use this sheet to take notes during each group member's presentation. At the end of each presentation, provide feedback to the presenter in the form of comments and questions. Group members can also offer specific compliments and constructive criticism for the presenter. Write notes about the feedback given to you in the space under your question. Then use the information you learn to answer the big question: How does Earth's atmosphere affect global climate?

Essential Questions

- What are feedback loops and how do they impact climate?

- What role do clouds play in Earth's climate?

- How does water vapor affect temperature?

How does the jet stream influence climate and how has it changed over time?

- How does Earth's atmosphere affect global climate?

Handout 3

Climate Patterns in Your State

This is your chance to learn about the climate in your state or region. Each state has a university land-grant school where the climate data for that state are archived. For example, the University of New Hampshire houses the New Hampshire State Climate Office, which can be found here: https://mypages.unh.edu/nhsco/home. Your task is to generate a state- or regional-climate question to research and report out to the class. You may want to know if your state is experiencing a drought or excessive rainfall over the past year or decade.

Step 1: What question would you like to learn more about in your state or region?

Step 2: Locate your state climate office and explore the resources available to answer your question. Write down your notes and findings below:

Step 3: Construct tables and graphs to communicate your findings to the class. Sketch below your rough draft ideas to share with your teacher.

Step 4: Apply one thing you learned in the "Atmosphere" video to help your audience understand the possible changes in climate. Consider feedback loops, impact of water vapor, cloud cover, or changes to the jet stream, for example.

Step 5: Present your results to the class. Be sure to include the following:

a. Question
b. Tables and graphs
c. Summary of findings
d. Knowledge from video to support your presentation
e. Optional: other images to support your findings

Extension Activity: Research a climate change issue that has been in the news recently. You could explore the drought in New England, the heat wave in the Northwest, water shortages in the West, or the Australian wildfires. This website has archived many of the climate-related events around the world to help you generate ideas:

> Carbon Brief—Mapped: How Climate Change Affects Extreme Weather Around the World
> https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world

Lesson 4

Climate Emergency: The Albedo Effect

Enduring Understandings

- Natural systems are interdependent.
- All life on Earth depends on and affects the climate.
- The sun is the primary source of energy for climate systems on Earth.
- The climate of Earth is regulated by complex interactions between systems.
- The climate of Earth is shaped by natural and human-made processes.
- Climate change impacts all human communities.
- The actions of human communities impact the climate of Earth.
- Climate change will have consequences for all Earth systems.

Essential Questions

- What are feedback loops?
- How do positive and negative feedback loops differ?
- What role do feedback loops play in the environment?
- How do feedback loops relate to the climate of Earth?
- Is the climate of Earth changing?
- What evidence do we have that the climate of Earth is changing?
- What contributes to climate change?
- What is the albedo effect?
- How does the albedo effect relate to climate feedback systems on Earth?
- How does the reflectivity of different surfaces affect the amount of energy they absorb?
- How does the melting of Arctic ice affect albedo?
- How does the melting of Arctic ice impact the climate of Earth?

Notes to the Teacher

In this lesson, students learn about the albedo effect and the decreasing ability of the Arctic region to act as a mirror reflecting the sun's rays. They also study how global warming causes the melting of sea ice and land ice at the poles, making the sea level rise and threatening millions of people along global coastlines. The activities in this lesson have been designed for use as individual modules or tiered instruction with each new lesson component building upon the last. A review of the activities prior to delivery is highly suggested to best determine the class time needed for each one and appropriately plan for materials acquisition. While the suggested lesson duration is between three and six one-hour periods, the activities can easily be modified based on time available or the point in the course curriculum where the lesson can best be integrated.

This lesson assumes students have some background on the fundamentals of climate change, the concept of a carbon footprint, and the role of greenhouse gases in climate change. The following resources may be helpful in the event review material is necessary:

- Climate Change: https://youtu.be/dcBXmj1nMTQ
- Climate Change Quiz: https://climate.nasa.gov/quizzes/global-temp-quiz/
- Greenhouse Gases: https://youtu.be/lrst59O9Q1Q

Please note that all suggested video links in this lesson can be displayed on a projector or shared with students for use on individual devices, depending on the classroom technology available.

Part l of this lesson investigates the concept of feedback loops while exploring the unique types and elements of these regulatory cycles which permit Earth's systems to adjust in response to changing conditions. A full set of copies of **Handout 1: Thinking About Systems** is recommended for each class; blank paper and colored pencils/markers may also be necessary. A computer with Internet access and a projector will be useful in showing the TED-Ed video about feedback loops in Step 4, the link for which can be found at https://youtu.be/inVZoI1AkC8.

Handout 1: Thinking About Systems can be completed as an in-class activity or assigned as homework if time is limited. It is also important to note that some or all of this part of the lesson can be assigned prior to Parts 2 and 3, depending on the knowledge level of the class and time available. In the event the concept of environmental feedback loops has already been covered in the course curriculum, feel free to skip ahead to Part 2 of the lesson.

In Part 2 of this lesson, students learn about the albedo effect and the impact of a shifting albedo in response to a changing climate. They will study the relationship between melting sea ice and climate change, thinking critically about the consequences of a lower albedo relative to the future of our planet. A full set of copies of **Handout 2: How Does the Albedo Effect Work**? is recommended for each class; index cards and colored pencils/markers may also be necessary. A computer with Internet access and a projector will be useful in showing the *Climate Emergency: Feedback Loops* film Albedo in Step 5, the link for which can be found at https://feedbackloopsclimate.com/albedo/. **Handout 2: How Does the Albedo Effect Work?** can also be completed as a homework assignment depending on the time available.

In Part 3 of this lesson, students will explore the science behind the albedo effect. They will develop and test hypotheses about the relationship between the albedo and temperature of a system, designing experimental models which reflect how changes in surface reflectivity can impact Earth's climate trends. A full set of copies of **Handout 3: Turn Up the Heat—Investigating the Albedo Effect** is needed for each class, as are the items on the laboratory supply list detailed in the **Materials** section below. It is important to note that each group will need 2 clear containers, such as plastic to-go cartons, plastic cups, jars, or beakers. While standard, non-mercury thermometers are recommended for this activity, wearable/adhesive thermometers or digital temperature sensors would also work. While a number of things can be used as the light source, please note that the distance between the dual container setups and light source should be the same for all groups. (30–40 cm is recommended).

The assorted materials the teacher will need to provide for the investigation in Part 3 should be a collection of substances of different colors and textures designed to represent different types of surfaces on Earth. Examples could include salt/sugar/cotton (snow), soil/gravel (land), ice (sea ice), different foliage types (vegetation), or water (water bodies). The idea here is for groups to have choice surrounding the design of their container setups. This part of the lesson also assumes that students are familiar with experimental design basics and hypothesis testing. Prior experience with plotting data on an X-Y coordinate graph will also be helpful.

Common Core Standards addressed by this lesson

History/Social Studies

CCSS.ELA-LITERACY.RH.9-10.7
Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

CCSS.ELA-LITERACY.RH.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claims.

Science and Technical Subjects

CCSS.ELA-LITERACY.RST.9-10.1
Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

CCSS.ELA-LITERACY.RST.9-10.2
Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

CCSS.ELA-LITERACY.RST.9-10.3
Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

CCSS.ELA-LITERACY.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

CCSS.ELA-LITERACY.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.RST.9-10.8
Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

CCSS.ELA-LITERACY.RST.9-10.9
Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Writing

CCSS.ELA-LITERACY.WHST.9-10.1.A
Introduce precise claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that establishes clear relationships among the claim(s), counter-claims, reasons, and evidence.

CCSS.ELA-LITERACY.WHST.9-10.1.C
Use words, phrases, and clauses to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence, and between claim(s) and counterclaims.

CCSS.ELA-LITERACY.WHST.9-10.1.D
Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

CCSS.ELA-LITERACY.WHST.9-10.1.E
Provide a concluding statement or section that follows from or supports the argument presented.

CCSS.ELA-LITERACY.WHST.9-10.2.A
Introduce a topic and organize ideas, concepts, and information to make important connections and distinctions; include formatting (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension.

CCSS.ELA-LITERACY.WHST.9-10.2.D
Use precise language and domain-specific vocabulary to manage the complexity of the topic and convey a style appropriate to the discipline and context as well as to the expertise of likely readers.

CCSS.ELA-LITERACY.WHST.9-10.2.E
Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

CCSS.ELA-LITERACY.WHST.9-10.7
Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

CCSS.ELA-LITERACY.WHST.9-10.9
Draw evidence from informational texts to support analysis, reflection, and research.

Duration of Lesson

Three to six one-hour periods

Assessments

Completion of the **Thinking About Systems** analysis activity and index card illustrations
Completion of the **How Does the Albedo Effect Work?** group discussion
Completion of the **Turn Up the Heat—Investigating the Albedo Effect** laboratory investigation and reflection questions
Group discussion
Student presentations

Materials

Writing utensils
Blank 8 ½” x 11” paper
Whiteboard
Whiteboard markers
Computer with Internet access
Projector
Large index cards
Colored pencils or markers
Classroom set of materials for the laboratory investigation in Part 3:

- 2 clear containers per group
- 2 thermometers per group
- cardboard
- scissors
- tape
- markers
- 1 light source with incandescent or heat bulb per group
- timer
- assortment of materials to represent Earth’s surfaces (See instructions in Notes to the Teacher above.)

Full class copies of:

Handout 1: Thinking About Systems
Handout 2: How Does the Albedo Effect Work?
Handout 3: Turn Up the Heat—Investigating the Albedo Effect
Teacher Resource 1: Thinking About Systems (Suggested Answers)
Teacher Resource 2: How Does the Albedo Effect Work?

Procedure

Part 1: Feedback Loops 101 (1–2 one-hour periods)

1. Begin by dividing the class into groups of two or three. Ask students to discuss the concept of "cause and effect." Invite each group to think of three examples of cause and effect from their own lives, allowing several minutes for students to share.

2. Invite students to then share examples of cause and effect which are unique to the environment, allowing time for sharing and a short discussion.

3. Explain to students they will have the opportunity to consider some of the advanced cause-and-effect relationships in the environment by exploring the concept of feedback loops. If time permits, invite students with prior knowledge of feedback loops to share what they know.

4. Play the TED-Ed video about feedback loops at https://youtu.be/inVZoI1AkC8. At the end of the video, host a discussion using the following questions and suggested answers as a framework for the conversation. If feedback loops are a new concept for the students, illustrate the examples of positive and negative feedback loops in Questions C and D below as cycles on the board as they are shared. Another suggestion would be for students to do the same.

a. What is a feedback loop? (A response from the environment that relates to the output.)

b. How would you explain the difference between positive and negative feedback loops? (A positive feedback loop is a circular chain of events that can amplify a change within a system. In a negative feedback loop, series of events dampen the change within the system, helping make it more stable.)

c. What is one example of a negative feedback loop from the video? (Predator/prey relationships: Predators eat prey which, in turn, causes a drop in the predator population due to decrease in food access. As the predator population size decreases, the prey population size increases. As the prey population size increases, a greater number are consumed by the predators. In turn, the prey population drops again as the predator population increases.)

d. What is one example of positive feedback loop from the video? (Contribution of organic material to the soil from decomposing plants which, in turn, aids the growth of new plants. Another example would be removing a forest, which makes the land vulnerable to erosion.)

e. Why are positive feedback loops called "positive"? (Because the feedback loop amplifies a particular effect or change from previous conditions.)

f. Can you think of other examples of feedback loops you may have heard about? (While answers here may vary, common responses may also include air conditioning systems, metabolic pathways in the body, the human sweat response, and the human shiver response.)

5. Ask students to work in their same groups to practice their knowledge of feedback loops. Distribute copies of **Handout 1: Thinking About Systems** and blank paper to each student. Review the instructions for the activity and give the groups time to work independently on the prompts. For each environmental system prompt, the students should illustrate the feedback loop as a cycle on the paper provided. They can each work on a complete set or divide the illustrations between members of the group.

6. When groups have finished, invite students to share their responses for each scenario and showcase their illustrations in the form of a class discussion. If time is limited, students can also finish the handout and illustrations as a homework assignment to be discussed as an introduction to Part 2 of the lesson in the next class.

Part 2: The Albedo Effect (1–2 one-hour periods)

1. Begin by asking students to imagine themselves in the middle of the Sahara Desert on the hottest day of the year (potentially 135+°F). Ask them which combination of garments from the options below would keep them most cool.

- Dark clothing or light clothing?
- Short sleeves or long sleeves?
- Shorts or long pants?

Take a class poll and invite several students to share their thinking.

2. Explain that the more brightly colored clothing with the greatest coverage would do the best job of reflecting the sun's energy away from the body, allowing the body to absorb less heat and therefore cool it more effectively. In this case, the combination of lightly colored long sleeves and long pants would be best.

3. Explain that this concept of surface reflectivity is known as the *albedo effect,* adding that any small change to the color or surface area of systems can impact the amount of totally energy reflected. Explain that, in the case above, the lightly colored, longer clothing would have a *high* albedo. Alternatively, the darker, shorter clothing would have a *low* albedo.

4. Explain to the students that the film they are going to watch explains the concept of albedo through the lens of our planet's climate. Distribute a copy of **Handout 2: How Does the Albedo Effect Work?** to each student and explain they will have time after the film to answer the questions provided. If time permits, ask the students to quietly read through the questions and highlight important words and/or phrases that will help guide their attention as they watch.

5. Play the *Climate Emergency: Feedback Loops* film "Albedo" at https://feedbackloopsclimate.com/albedo/. At the end of the film, ask students the following questions and invite several to share their thoughts.

- Why do you think this film was produced? (Answers here may vary.)
- What is the critical environmental theme of this film? (Shifting albedo due to climate change.)

6. Use the questions on **Handout 2: How Does the Albedo Effect Work?** to guide a class discussion; suggested answers to the questions can be found on **Teacher Resource 2**. For Question 3, invite students to illustrate the feedback loop they detailed as part of their response on a blank sheet of paper. (Note: If time is limited, the entire handout can be assigned as homework for the next class.)

7. Ask the students to consider the following question, inviting several to share their thoughts.

- Do you think a shifting albedo at the hands of a changing climate is a problem for our planet? Why? (Answers here may vary.)

8. Explain that this film is part of an initiative called "Climate Emergency," indicating a dire situation for the health of our planet. Distribute one index card to each student and write the following statement on the board:

> **"The models predict that if we continue the path we're on, that the Arctic will experience very dramatic changes, and those changes will reverberate throughout the system—the human system, the biological system, and the socioeconomic system."**

9. Explain that this is one of the last lines of the film they just watched. Ask the students to think about how this statement makes them feel. Ask them to write several sentences which capture their thoughts on the index card. (Note: Students should not put their names on the index cards.)

10. Collect the index cards. Mix them up and read several aloud to the class, one at a time. Invite students to raise their hands if they agree with the sentiment on each card. Read as many as time permits.

Part 3: Modeling the Albedo Effect (1–2 one-hour periods)

1. To check for understanding of the concept of albedo, ask students to answer the following questions by holding up one or two fingers to signify their response. Invite questions or discussion where needed. (Answers are in bold text.)

a. Which has a higher albedo: **(1) a snow-covered meadow** or (2) an asphalt parking lot?
b. Which has a lower albedo: **(1) a forest** or (2) an exposed rock outcropping?
c. Which location has a higher albedo: **(1) Alaska** or (2) Europe?
d. Which body of water has a lower albedo: (1) a shallow pond or **(2) a deep ocean**?
e. Which has a higher albedo: **(1) a vegetable garden** or (2) a rainforest?
f. Which has a higher albedo: **(1) a snow-covered field** or (2) a deep, frozen lake?

2. Explain to students they will have the opportunity to explore the concept of the albedo effect by designing their own laboratory investigation. Divide the class into groups of two or three. Distribute a copy of **Handout 3: Turn Up the Heat—Investigating the Albedo Effect** to each student, and allow groups several minutes to read the "Objective" and "Background" sections.

3. Review the lab instructions with the class. Explain that groups will design two different setups to explore the albedo effect, measuring the change in albedo as a function of temperature within the contained systems they create over time. Remind them that their first setup, Setup 1, should reflect a high albedo system and demonstrate the least amount of temperature change as possible during the 20-minute period. Setup 2, conversely, should reflect a low albedo system and demonstrate the greatest amount of temperature change as possible during the 20-minute period. Explain that the materials students choose for their container designs should relate to different surfaces on Earth. For example, students may decide to use salt to represent a snow-covered surface. Water, alternatively, could represent waterbodies such as rivers, lakes, or oceans. The depth of the water is yet another example of a variable to consider. Remind them to think about the relationship of color and texture to the albedo in choosing the materials for their respective setups.

4. Give groups time to review the Procedure, collect their materials, and begin to design their container setups. Remind students they need approval from you for their proposed experimental setups (see Step 5) before proceeding. Remind students to record their data for each setup in the tables provided and to pay close attention to the instructions in Step 10 regarding the construction of their final graphs.

5. When groups have finished their 20-minute period of data collection, they should begin cleaning up and work on their final graphs.

6. Depending on time available, the Reflection Questions on the last page of **Handout 3** can be completed in class or as a homework assignment. Either way, a class discussion using the questions as a framework will be an important part of the reflection for this investigation.

Extension Activities

Extension Activity 1: Student Voice

Students could write to members of Congress to advocate for climate-positive legislation. This digital tool featuring from the Citizen's Climate Lobby may be helpful: https://community.citizensclimate.org/tools/write-congress-about-the-energy-innovation-and-carbon-dividend-act#/74/.

Extension Activity 2: Game Design

Students could develop board games or activities which demonstrate their understanding of feedback loops and the albedo effect as they relate to the climate of Earth.

Extension Activity 3: Climate Change Impacts

Students could conduct further research on one of the impacts of climate change referenced in the answer to Question 7 of **Handout 2: Exploring the Albedo Effect**. As part of their research, they could detail real-world examples of the impact and design their own awareness campaigns to inspire change within their respective communities. The topics in question are:

- crop reduction
- global increases in food pricing
- erratic weather/increased precipitation
- excessive drought
- sea-level rise
- coastline destruction
- human health concerns
- climate refugees

Extension Activity 4: Carbon Footprint Awareness

Students could calculate their own carbon footprint, research ways of reducing their footprints, and design engagement campaigns to help members of their communities do the same. This digital Carbon Footprint Calculator from the U.S. Environmental Protection Agency may be helpful: https://www3.epa.gov/carbon-footprint-calculator/.

Additional Resources

Climate Change Basics

NASA Global Climate Change
https://climate.nasa.gov/

How to Talk to Kids About Climate Change
https://www.npr.org/2019/10/22/772266241/how-to-talk-to-your-kids-about-climate-change

EPA Climate Change
https://www.epa.gov/climate-change

Climate Reality Project
https://www.climaterealityproject.org/

EPA: Calculating a Carbon Footprint
https://www3.epa.gov/carbon-footprint-calculator/

Climate Change Data

NASA Climate Change: How Do We Know?
https://climate.nasa.gov/evidence/

NOAA Data Snapshots: Reusable Climate Maps
https://www.climate.gov/maps-data

National Science Foundation: Climate Reanalyzer
https://climatereanalyzer.org/

National Snow & Ice Data Center
https://nsidc.org/

Climate Change Impacts

NASA: The Effects of Climate Change
https://climate.nasa.gov/effects/

World Wildlife Foundation: Effect of Climate Change
https://www.worldwildlife.org/threats/effects-of-climate-change

CDC: Climate Effect on Health
https://www.cdc.gov/climateandhealth/effects/default.htm

JOURNEYS IN FILM educating for global understanding

Handout 1

Thinking About Systems

Directions: Please read the examples of environmental systems provided in the table below. For each system, state whether it is an example of a positive or negative feedback loop. Then, for each scenario, provide an explanation for your answer in the space below and illustrate the feedback loop as a cycle on the blank paper provided.

Environmental System	Type of Feedback Loop (Positive or Negative)	Explanation
A population of turtles is critically endangered. Because the population has become so small, finding a mate has become a challenge. The number of births has since declined, and the turtle population continues to decrease.		
A native grass species has covered a meadow. Some larger plants and shrubs are present but have grown slowly due to longer roots with less access to water. Because the grass is smaller and has shorter roots, it has more access to water and grows more consistently.		
The warming of Earth's climate has caused an increase in atmospheric water vapor, resulting in more precipitation. More precipitation has caused a shift in the movement of ocean currents, distributing water to new locations on Earth. This, in turn, increases the amount of atmospheric water vapor and precipitation in parts of the world that are typically dry.		
As a population of mountain goats has increased, so has their consumption of food. As a result, increasing food scarcity has led to the starvation and death of some of the population.		
As Earth's climate warms in response to climate change, an increase in water vapor contributes to increased cloud formation. Increased cloud cover can have a cooling effect by reflecting heat from the sun but can also absorb and trap heat from the Earth's surface.		

Teacher Resource 1

Thinking About Systems (Suggested Answers)

Environmental System	Type of Feedback Loop (Positive or Negative)	Explanation
A population of turtles is critically endangered. Because the population has become so small, finding a mate has become a challenge. The number of births has since declined, and the turtle population continues to decrease.	Positive	The turtle population decrease due to fewer births will further perpetuate the challenge in mating and producing offspring. This will cause the population to drop further.
A native grass species has covered a meadow. Some larger plants and shrubs are present but have grown slowly due to longer roots with less access to water. Because the grass is smaller and has shorter roots, it has more access to water and grows more consistently.	Negative	Due to consistent water access, the grass would grow at a balanced rate while inhibiting the growth of the larger plant cover. In doing so, the grasses would provide habitat for insects, birds, and small mammals.
The warming of Earth's climate has caused an increase in atmospheric water vapor, resulting in more precipitation. More precipitation has caused a shift in the movement of ocean currents, distributing water to new locations on Earth. This, in turn, increases the amount of atmospheric water vapor and precipitation in parts of the world that are typically dry.	Positive	Increased precipitation in places which are typically less dry could lead to continued changes to the movement of ocean currents and additional precipitation elsewhere. In this case, the cycle of increasingly erratic weather would strengthen over time.
As a population of mountain goats has increased, so has their consumption of food. As a result, increasing food scarcity has led to the starvation and death of some of the population.	Negative	A decrease in population size would give surviving members access to more food while also decreasing food scarcity. The population size would eventually stabilize.
As Earth's climate warms in response to climate change, an increase in water vapor contributes to increased cloud formation. Increased cloud cover can have a cooling effect by reflecting heat from the sun but can also absorb and trap heat from the Earth's surface.	Positive	When heat from the sun is absorbed by the clouds, Earth's temperature will increase. This would increase the amount of atmospheric water vapor, further warming Earth's climate.

Handout 2

How Does the Albedo Effect Work?

Instructions: Please answer the following questions to the best of your ability after watching the *Climate Emergency: Feedback Loops* film "Albedo" (https://feedbackloopsclimate.com/albedo/).

1. This film argues that Earth's equilibrium is at risk. What does "equilibrium" mean? Why is the concept of equilibrium used here in reference to Earth?

2. In your own words, how would you describe the albedo effect?

3. What happens when the Earth loses its ability to reflect sunlight? Is this an example of a positive or negative feedback loop? Please explain.

4. Snow and ice reflect a large percentage of the sun's rays. Do snow and ice have a *high* or *low* albedo? Please explain.

5. In the film, Don Perovich from Dartmouth College references the yearly growth and melting of Arctic ice as a natural cycle. He then goes on to say this cycle is changing. What about this yearly cycle is changing?

6. According to the film, heat-trapping gases like carbon dioxide, methane, and nitrous oxide from human-caused greenhouse emissions are responsible for increasing the temperature in the Arctic two to three times faster than anywhere else on the planet. This warming is then amplified by the loss of albedo as the reflective Arctic ice and snow disappear, exposing the dark ocean beneath. Why is this a problem?

7. Studies suggest that the melting of Arctic sea ice and snow cover on land are responsible for a 40% loss in Earth's reflectivity. Climate model projections suggest that Arctic sea ice will be lost in the summer months altogether by the end of this century. The added contribution of greenhouse gases to the equation may dictate the additional loss of the winter sea ice. Using the film as reference, how might the changing climate of the Arctic relate to temperature elsewhere on Earth?

8. According to the film, we have the technology and knowledge to move toward sources of energy that do not produce heat-trapping gases but we are not making this a priority. Why do you think this is the case?

Teacher Resource 2

How Does the Albedo Effect Work? (Suggested answers)

Instructions: Please answer the following questions to the best of your ability after watching the *Climate Emergency: Feedback Loops* film "Albedo" (https://feedbackloopsclimate.com/albedo/).

1. This film argues that Earth's equilibrium is at risk. What does "equilibrium" mean? Why is the concept of equilibrium used here in reference to Earth?

The word equilibrium refers to a state of balance.

2. In your own words, how would you describe the albedo effect?

The albedo effect refers to the ability of a surface to reflect sunlight.

3. What happens when the Earth loses its ability to reflect sunlight? Is this an example of a positive or negative feedback loop? Please explain.

As it loses its ability to reflect sunlight, the climate of Earth warms. Positive feedback loop.

4. Snow and ice reflect a large percentage of the sun's rays. Do snow and ice have a *high* or *low* albedo? Please explain.

Snow and ice have a high albedo due to their light color. The lighter the color of the surface, the larger the percentage of reflection.

5. In the film, Don Perovich from Dartmouth College references the yearly growth and melting of Arctic ice as a natural cycle. He then goes on to say this cycle is changing. What about this yearly cycle is changing?

The timing when different elements of this cycle occur. For example, the ice is melting earlier, the freezing is starting later, the ice coverage decreases every month of the year, etc.

6. According to the film, heat-trapping gases like carbon dioxide, methane, and nitrous oxide from human-caused greenhouse emissions are responsible for increasing the temperature in the Arctic two to three times faster than anywhere else on the planet. This warming is then amplified by the loss of albedo as the reflective Arctic ice and snow disappear, exposing the dark ocean beneath. Why is this a problem?

One of the best natural reflectors (snow) is being replaced by one of the worst (the open ocean). The ocean will absorb the sunlight, heat up, and melt more ice. The continued increase in melting ice will further perpetuate the cycle. As the darker waters warm, they emit carbon dioxide and water vapor and further warming the system.

7. Studies suggest that the melting of Arctic sea ice and snow cover on land are responsible for a 40% loss in Earth's reflectivity. Climate model projections suggest that Arctic sea ice will be lost in the summer months altogether by the end of this century. The added contribution of greenhouse gases to the equation may dictate the additional loss of the winter sea ice. Using the film as reference, how might the changing climate of the Arctic relate to temperature elsewhere on Earth?

Warming patterns in the Arctic may contribute to the movement of warm air around the planet. This could cause crop reduction, global increases in food pricing, erratic weather/increased precipitation, excessive drought, sea-level rise, coastline destruction, human health concerns, climate refugees, etc.

8. According to the film, we have the technology and knowledge to move toward sources of energy that do not produce heat-trapping gases but we are not making this a priority. Why do you think this is the case?

Answers may vary.

Handout 3

Turn Up the Heat—Investigating the Albedo Effect

Objective

To develop and test hypotheses about the effect of albedo on the temperature of different surfaces.

Background Information

Albedo generally refers to the amount of energy reflected by a surface. Surfaces on Earth with a higher albedo are bright and reflect more/absorb less of the sun's energy. Surfaces of this nature include ice caps, glaciers, seasonal snow cover, and deserts. Conversely, surfaces with a lower albedo are darker and reflect less/absorb more of the sun's energy. Surfaces of this nature include open water, forests, concrete, and soil. The angle at which the sunlight hits a surface relative to its texture can also affect the albedo of the surface.

Understanding the fate of sunlight arriving to Earth is crucial to how we interpret and respond to our planet's changing climate. For this investigation, you will design two setups to explore the role of albedo in determining the amount of energy absorbed by different surfaces. For each setup, you will measure the change in temperature over a 20-minute period.

Materials

- 2 clear containers with lids
- 2 thermometers
- cardboard
- scissors
- tape
- marker
- light source with incandescent or heat bulb
- timer
- assortment of materials to represent Earth's surfaces (provided by the teacher)

Procedure

1. Using the tape and marker provided, label your containers **Setup 1** and **Setup 2.** Add the initials of your group members to each label.

2. Flip one container upside down and trace its perimeter on the cardboard provided. Do this twice. Cut each shape out. Then, use the scissors to poke a hole in the center of each piece large enough to accommodate a thermometer. Set the cut pieces aside.

3. Design your experimental setups using the materials provided by your teacher to represent different surfaces on Earth. Consider the role of albedo in choosing your materials for each setup.

a. Setup 1 should reflect a high albedo system and demonstrate the least amount of temperature change as possible during the 20-minute period.

b. Setup 2 should reflect a low albedo system and demonstrate the greatest amount of temperature change as possible during the 20-minute period.

4. Add the materials you have chosen to each container.

5. In the spaces provided below, (1) create a labeled diagram of each setup and (2) describe the types of surfaces your materials represent. *Hint: Be sure to consider color and texture here!* <u>Your teacher must approve your setup before moving onto the next step.</u>

Setup 1:	**Setup 2:**

6. For each setup, design a hypothesis predicting what you think will happen to the temperature over the 20-minute period.
   a. Hypothesis for **Setup 1:**

   b. Hypothesis for **Setup 2:**

7. Position the cardboard cutouts you made in Step 2 on the top of each container, sealing the edges with the tape provided. Insert one thermometer into each hole, ensuring the thermometers are placed in such a way to be easily read through the clear sides of each container.

8. Place your containers beneath your light source (do not turn it on yet). Set your timer for 20 minutes. Allow your containers to sit for 60 seconds. Record the temperature for each and enter this number as Time 0 for both setups in the table below.

9. Turn your light source on and begin the time. Record temperature readings for both setups every minute for the 20-minute duration. When time stops, calculate the total change in temperature for each setup and record this value in the space provided at the bottom of each table.

Time (min.)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Setup 1: High Albedo Temperature											
Time (min.)		**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Setup 1: High Albedo Temperature											
Total Change in Temperature											

Time (min.)	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Setup 2: High Albedo Temperature											
Time (min.)		**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Setup 2: High Albedo Temperature											
Total Change in Temperature											

10. Graph the temperature data you collected as function of time for **Setup 1** and **Setup 2** below using different colors. Label your axes, including appropriate units of measurement. Include a title and key to distinguish between the lines for each setup.

11. When you are finished, clean up your station and answer the *Reflection Questions* below.

Reflection Questions

1. How did the data you collected compare to your original hypothesis for each setup? Be specific for each.

2. List the materials you used for **Setup 1** and **Setup 2.** Then, describe the type of Earth's surface each material represented.

3. How did the total change in temperature for **Setup 1** compare to **Setup 2**? How would you explain this observation?

4. How does your data for each setup compare to other groups in class? Please be specific.

5. Were any sources of error present in your setups for this investigation? Please explain.

6. If you were to conduct this investigation again, how would you modify **Setup 1** to produce a total change in temperature over the 20-min period that is greater than what was observed here?

7. If you were to conduct this investigation again, how would you modify **Setup 2** to produce a total change in temperature over the 20-min period that is lower than what was observed here?

8. Are the results of this investigation consistent with your prior knowledge of the role of albedo in determining the amount of energy absorbed by different surfaces? Please explain.

9. In what ways did this investigation help improve your understanding of the albedo effect?

Lesson 5

Regreening the Earth

Enduring Understandings

- The climate crisis, magnified by feedback loops, is impacting the Earth and will continue to impact and endanger life in the future unless actions are taken to reverse the causes of the crisis immediately.
- There are multiple ways to alleviate these issues, and many organizations and individuals are currently working around the world to bring about a regreening of the Earth. Creative solutions will be needed to reverse the damage already caused.
- Students can impact the world around them in both large and small ways.

Essential Questions

- What does it mean to regreen the Earth?
- Who is trying to regreen? What are they doing? What impacts are they having?
- What is one way that students can participate in bringing about environmental change locally and globally?

Notes to the Teacher

Analysis of feedback loops shows us how the environment replicates both positive and negative phenomena to intensify solutions and failures. While one problem can cause many more, one solution can also trigger many others. What are some possible action steps humans can take? The films from *Climate Emergency: Feedback Loops* stress the need to act now, and students will be challenged to do that in this lesson as they carry out a research project that is designed to help them regreen the Earth.

In 2015, the journal *Science* estimated that there were approximately 3 trillion trees on the planet. A 2019 follow-up found that there was room for approximately 1 trillion more. The generally accepted key to regreening the Earth is maintaining existing forested areas and adding more trees. While any kind of green space is helpful, trees sustainably absorb carbon over time. Action in this lesson will be focused on ways to regreen locally to contribute to regreening globally.

This lesson will introduce students to possible solutions to global warming that have been suggested or implemented by young environmental activists. Students will learn more deeply about one of the solutions, be asked to explore and evaluate its outcomes, brainstorm ways to enhance the solution, and participate in implementing one of these processes.

In Part 1 of this lesson, students consider what is meant by "regreening" the Earth. They brainstorm a list of the reasons for climate change based on the films from *Climate Emergency: Feedback Loops,* and they consider how they could have an impact on one or more of these issues in their own community.

Part 2 introduces students to young activists around the globe. **Handout 1** is a chart designed for students to record information about these young people. Students will need access to the Internet to complete it. Once it is completed, students consider the impact of these teen activists and consider whether any of their efforts could be applied to the community your students live in. Student groups complete **Handout 2** to formulate an action plan and present their plan to the group.

In Part 3, students plan a viable project that they can carry out in their community. They outline their goals and generate a list of steps they will have to take. They consider what resources and permissions they will need and think about possible partnerships that would help them meet their objectives.

Prior to teaching the lesson, teachers should photocopy handouts, reserve library/computer lab space if required for using Internet-connected devices, and talk with their school librarian about any resources that students may use to complete their handouts and prepare for their presentations. The implementation of the solution may require additional resources depending on the project students choose, and therefore the teacher may also wish to talk with school or local officials about resources that can be made available to students. If resources are limited, teachers are encouraged to provide parameters to students up front. Students can then plan creatively within these limitations.

The time required for carrying out the project will vary widely based on the project selected. Teachers may wish to provide specific options that will best fit the time allowed; if more time is available, teachers may wish to allow students more agency in determining the direction and scope of the project.

Some additional resources for you and your students are:

https://www.nrdc.org/stories/global-warming-101
https://www.rock-your-world.org/environment
https://www.un.org/en/climatechange/youth-in-action

It is vitally important that students not feel discouraged or hopeless as they contemplate the feedback loops that are accelerating climate change. In addition to Lesson 5, you may wish to encourage them to explore Project Drawdown (https://drawdown.org/). "Drawdown" is defined on this website as "the future point in time when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline." This non-profit organization reviews and evaluates potential climate solutions, advances communication about such solutions, and works with partners to accelerate climate solutions. Your students will find many suggestions here for ways in which climate change can be slowed or stopped.

Laurie David and Heather Reisman's *Imagine It: A Handbook for a Happier Planet* (New York: Rodale Books, 2020) provides suggestions for individuals and families to change their own habits in order to reduce their use of natural resources.

Common Core Standards addressed by this lesson

CCSS.ELA-LITERACY.CCRA.SL.1
Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

CCSS.ELA-LITERACY.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.

CCSS.ELA-LITERACY.CCRA.W.8
Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.

CCSS.ELA-LITERACY.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.

Duration of Lesson

This is a three-part lesson. The first two parts make up the research and presentation components and require three to four hours of class time. If only three hours are available, work may need to be assigned as homework. The third part includes planning and implementation of the regreening project and will add additional time to the lesson, depending on the extent and goals of the project. If there are resource or time limitations, explain those at the beginning of Part 2.

Assessments

Class discussions
Handouts
Group presentations
Project outcomes
Reflection

Materials

Climate Emergency: Feedback Loops films
Access to library or devices with Internet connection for research
Handout 1: Young Environmental Activists
Handout 2: Problem Profile
Handout 3: Regreen Your World

Procedure

Part 1: What does it mean to "regreen the Earth"?

1. Prior to watching the films, ask students what they think the term "regreen" means. After they have responded, share that according to the Merriam-Webster Dictionary, to regreen means "to make green again, *especially*: to restore (barren, degraded, or deforested land) to a healthy ecological state by planting vegetation (such as trees, shrubs, grasses, or sustainable crops) often in conjunction with improvements in soil fertility and water retention." Write this definition on the board and discuss it to be sure students understand it completely.

2. After viewing the *Feedback Loops* films, ask students to identify the causes of global warming noted throughout the films. Brainstorm a list on the board. Are there other issues that were implied but not directly referenced in the film? Add these issues to the list. If you notice there are causes missing, or to expand your list, ask students to use their devices to research causes of global warming. The brainstormed list should include at least the following:

- Deforestation
- Reliance on fossil fuels
- Greenhouse effect
- Industrial practices
- Transportation
- Agricultural practices
- Consumer practices
- Pollution
- Humans' lack of desire to change

3. As a class, discuss which of these causes students believe they can impact and how much they can impact them. Students should consider the livelihoods that are most important in their local communities, as well as their ability to reach people within and beyond their school. Consider the ways in which regreening the Earth would impact their community. What changes would have to happen to limit their production of greenhouse gases, for example? After the discussion, make a list of the causes and rank them according to where students believe they have the most impact to those where they believe they could have the least.

Part 2: Who is trying to regreen? What are they doing? What impacts are they having?

1. Tell students that you are going to introduce them to young people who may have thought they had a limited voice and small impact, but who are now known for their environmental activism. Distribute copies of **Handout 1: Young Environmental Activists** and give students time to research each of the activists. You may wish to divide the students into research teams or give this as an assignment for them to complete for homework.

2. Lead a discussion with the following questions: How did each of these young activists impact their community, region, country, continent, world? What actions have they taken to regreen the world? Discuss the kind of results they have had. How long did it take them to achieve these results?

3. Ask students if any of these activists' solutions to regreening the world seem possible for students to replicate or learn from to regreen your own community. What would be required to do that? Create groups of 3–5 students. Ask each group to choose one of the youth activists and consider how their work could be adapted to work in your school or community.

4. Using the Internet, ask students to begin their research on ways to regreen their school or community. Distribute copies of **Handout 2: Problem Profile** to create a basic plan for this work. (If students need additional time, the work in steps 3 and 4 can be completed as homework or in an additional class period.)

5. When students have had sufficient time to work out a plan, direct each team to prepare a two- to four-minute presentation based on the worksheet. Schedule time for each group to present.

Part 3: How do YOU want to change the world? What is one way that students can participate in the regreening of the Earth?

1. Jigsaw students into groups of 6–8 so that there are people from several groups represented. Discuss the presentations and decide on a project to carry out. Give students the choice to accept a project as it was presented, modify a project and use it, take parts from multiple projects and combine them, or create a new solution altogether that was inspired by one or more presentations. The goal is to create a project that regreens AND contributes to a positive feedback loop.

2. Direct each group to complete **Handout 3: Regreen Your World.** Unless your goal is to create a long-term program, require students to consider a project that can be completed by the group in the time you have allotted.

3. As groups consider where their efforts would be best applied, encourage them to consider the following questions: What resources will they need? Do they have the access to those resources? Students should consider if the resources that they have access to are sufficient to carry out their project. If the answer is no, then they need to develop a different idea.

4. Have each group present its idea to the class. Then, as a class, discuss whether the plan can be executed with the time and resources that are available. Develop consensus around one plan where there are available resources, the ability to contribute to a positive feedback loop, and student enthusiasm. Appoint student leaders and develop committees tasked with completing specific tasks. Use **Handout 3** to guide work on the project, paying specific attention to the goals and outcomes in order to ensure that the project stays on target.

5. Once the project is complete, ask each student to write a reflection on their work within the group and on the project outcomes. Do they feel that they made a difference? Are they inspired to do more? How important is continuing this work for them?

Handout 1

Young Environmental Activists

Directions: Complete the chart for each student activist. If you find resources that are specifically helpful, add them in the Notes section to use in the next part of this lesson.

Name	Organization	Actions	Notes
Yusuf Baluch			
Kehkashan Basu			
Felix Finkbeiner			
Sarah Goody			
Isra Hirsi			
Ann Makosinski			
Xiuhtezcatl Martinez			
Autumn Peltier			
Greta Thunberg			
Melati and Isabel Wijsen			

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Handout 2

Problem Profile

Provide answers that are as specific as possible.

Names of research team members:

Using the work of a youth activist as inspiration, describe a project that the class could complete to help regreen the Earth.

What are the most successful methods the activist used? Did they need help from another organization to get the resources they needed to make a difference? What can you learn from this for your project?

Are there parts of their work that you think you could use in your project? Why? What are they? Are there things that you don't think would work? Why? What are they?

What resources will you need to complete your project?

What steps would you need to take to complete this project? Be specific.

How will this project contribute to the regreening of the Earth?

How will you measure your success?

Now use this information to prepare a two- to four-minute presentation on your proposal.

Handout 3

Regreen Your World

It's now time to carry out a project of your own that will help to regreen the Earth. As you learned in the *Feedback Loop* films, it is necessary for us to take immediate action to stop the destructive feedback loops that are currently present throughout the world.

Based on the solutions you heard groups propose, what is your plan for regreening your world? (Remember that you may choose to accept any single plan or to modify or create other plans based on what you have learned in this process.)

What resources will you need to complete your project?

How can you secure access to these resources? Be creative as you consider the answer to this question. Remember that you may use resources from within your school or from local governments and environmental groups as well as from organizations created by the youth activists you studied in the research part of this project.

Do you need to seek permission or a local partnership before you begin? If yes, who will do this?

How will you know that you have successfully completed the project? What are your target outcomes?

What steps will need to be taken to complete the project? Include specific tasks. You may need to continue on a separate sheet.

Be ready to discuss your plan with the class.

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