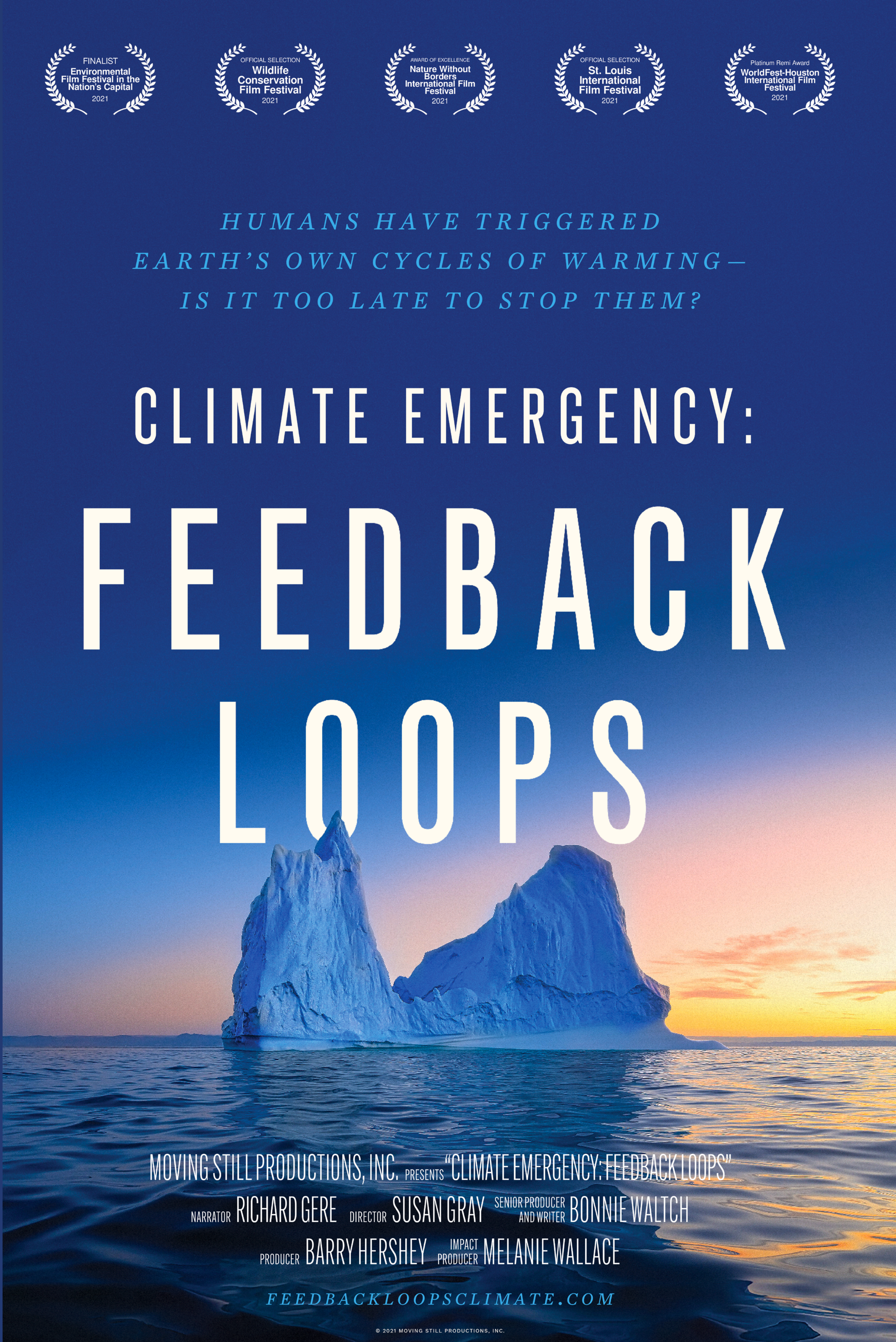
Permafrost



JOURNEYS IN FILM™
educating for global understanding

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.

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.

DIRECTOR: Susan Gray
SENIOR PRODUCER and WRITER: Bonnie Waltch
PRODUCER: Barry Hershey
IMPACT PRODUCER: Melanie Wallace
ASSOCIATE PRODUCER: Talia Sabato
NARRATOR: Richard Gere
FEATURED SCIENTISTS: George Woodwell, Warren Washington, Andrew Tanentzap, Brendan Rogers, Don Perovich, Sue Natali, Beverly Law, Marika Holland, Jennifer Francis, Kerry Emmanuel, Phil Duffy, Mike Coe
CINEMATOGRAPHER: Jesse Beecher
EDITOR: Tim Raycroft
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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 0ºC 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°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°C, 32°C, and 100°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 Science 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

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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 $0^{\circ}C$) 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

<u>Frozen Yeast Culture</u>
Sketch and Observations:

______________ Agar
______________ Hours
______________ °C

<u>Room Temperature Yeast Culture</u>
Sketch and Observations:

______________ Agar
______________ Hours
______________ °C

<u>Boiled Yeast Culture</u>
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.

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):

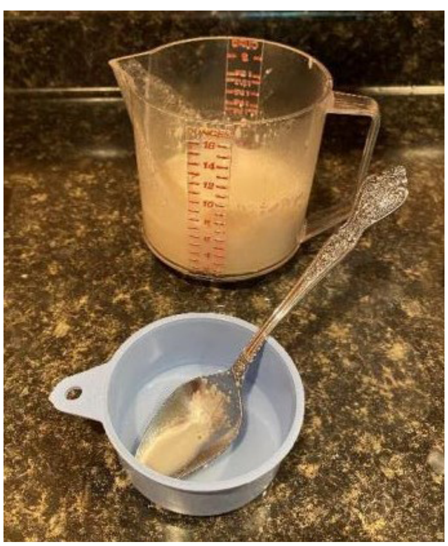
Use the materials provided to design an experiment to simulate the effects of gas emission on the permafrost landscape at various temperatures.

Teacher Resource 3

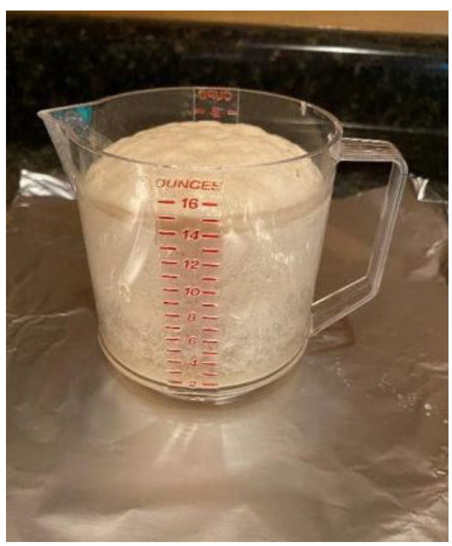
Answer Sheet for Handout 3: Simulating the Effect of Microbial Decomposition and Gas Release on the Landscape of Thawing Permafrost

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.



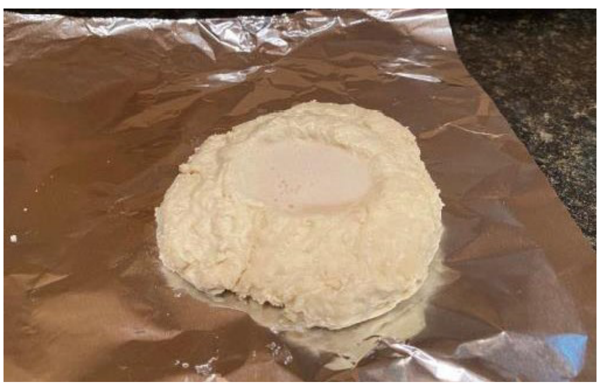
The mixture will expand as more gases are released over a short period of time.

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.

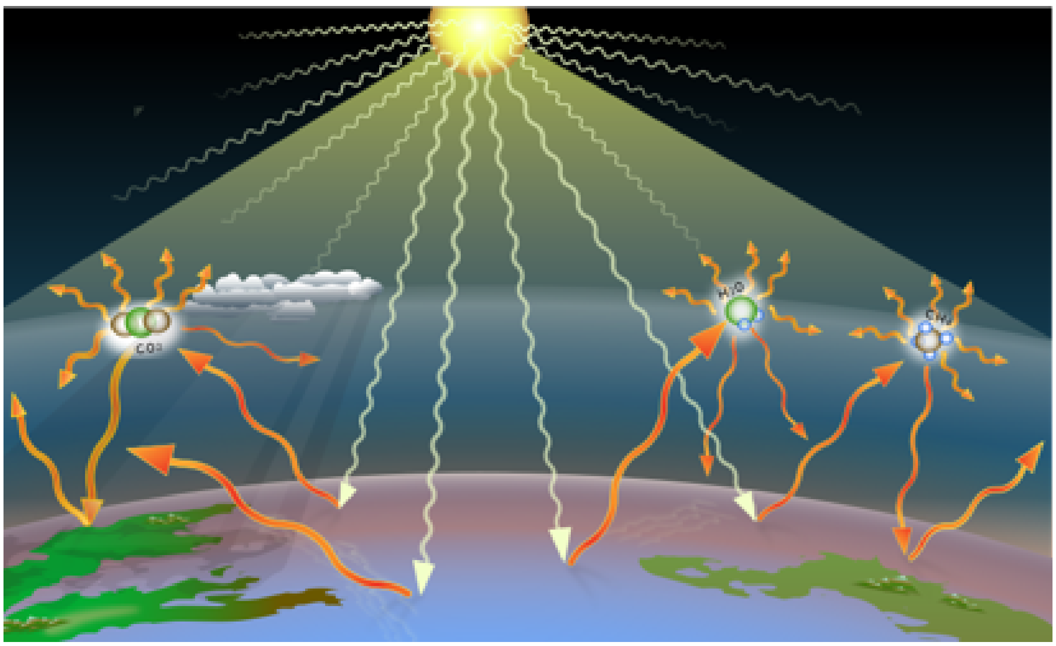
Additionally, the poster should have arrows showing relationships (feedback loops) between the various sketches or pictures presented on the poster.

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

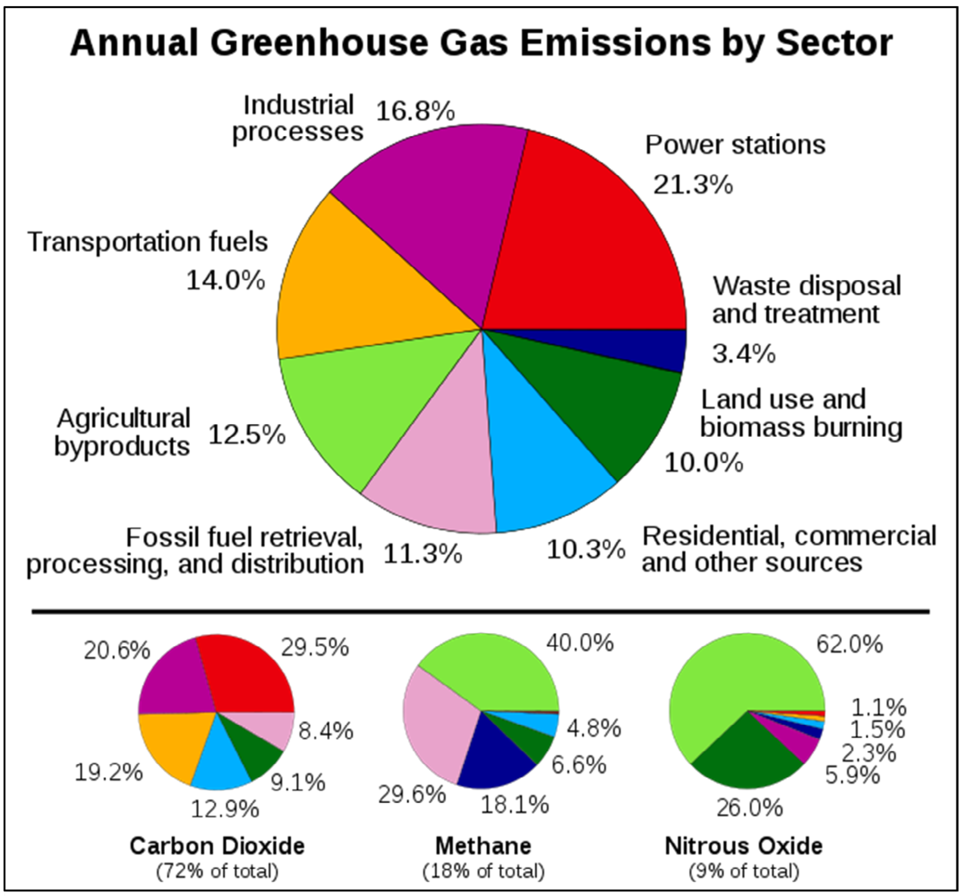
Greenhouse gases trap heat in the atmosphere, which leads to changing climate patterns on Earth. The burning of fossil fuels releases greenhouse gases into the atmosphere. The greatest percentage of greenhouse gas emission from fossil fuel burning is carbon dioxide. However, the greenhouse gases methane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

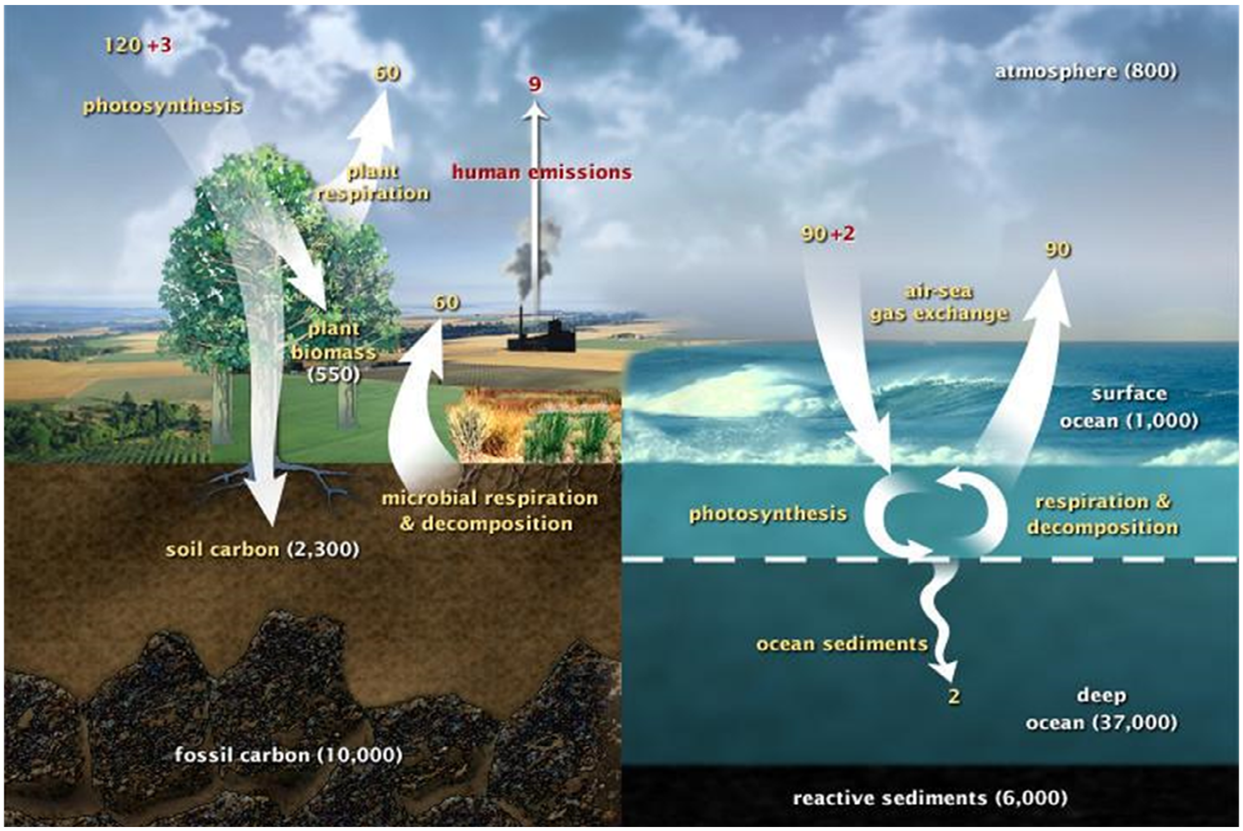
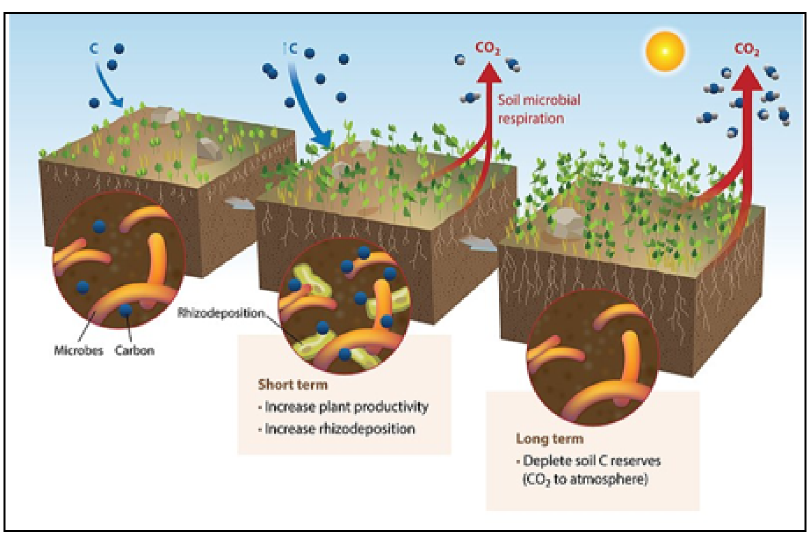


Diagram adapted from U.S. DOE, Biological and Environmental Research Information System.
https://www.flickr.com/photos/atmospheric-infrared-sounder/8263944907



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.

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