The Greenhouse Effect

Part Two: **The Role of CO_2**

By role-playing various components of Earth's surface, atmosphere and incoming solar radiation, students compare the natural and enhanced greenhouse effects. The warming effect of adding more carbon dioxide (CO_2), a greenhouse gas, to the atmosphere is experienced in this active simulation.

Activity Time
- Warm-up: 10 - 30 minutes, depending on students' prior knowledge
- Activity: 20 - 30 minutes
- Wrap-up: 10 – 20 minutes

Setting
- Large open area in classroom, gymnasium, or outdoor playing area

Materials
- Seven gym vests, arm bands, or belts of one colour to identify one role
- Cones to mark boundaries
- Optional: Gym vests, arm bands, or belts of two other colours to identify all roles

Subjects
Science, Social Studies, Language Arts, Physical Education

Keywords
Visible light, infrared radiation, electromagnetic spectrum, albedo, atmosphere, carbon dioxide, molecule, greenhouse gas, greenhouse effect, climate change

Prescribed Learning Outcomes - Science:
Life Science
- Assess the requirements for sustaining healthy local ecosystems
- Evaluate human impacts on local ecosystems

Physical Science
- Classify substances as elements, compounds, and mixtures

IRP Curriculum Organizers:
Language Arts
- Oral Language
- Reading and Viewing
- Writing and Representing

Social Studies
- Human and Physical Environment

Introduction and Background
The greenhouse effect is a natural phenomenon that helps Earth to maintain an average global temperature that is hospitable for life. The atmosphere of Earth is a gaseous mixture made up primarily of nitrogen (N_2; 78%), oxygen (O_2; 21%) and argon (Ar; 0.9%). The remaining fraction of one percent is a mix of greenhouse gases and trace gases. Greenhouse gases are able to absorb and emit much of the heat energy (i.e., infrared radiation) from Earth's surface and atmosphere before it is lost to space.

In order to understand the greenhouse effect, it is necessary to understand what happens to the energy Earth receives from the Sun (solar radiation). Short-wave energy in the form of visible light reaches the lower atmosphere and surface of Earth. Approximately thirty percent of the visible light is

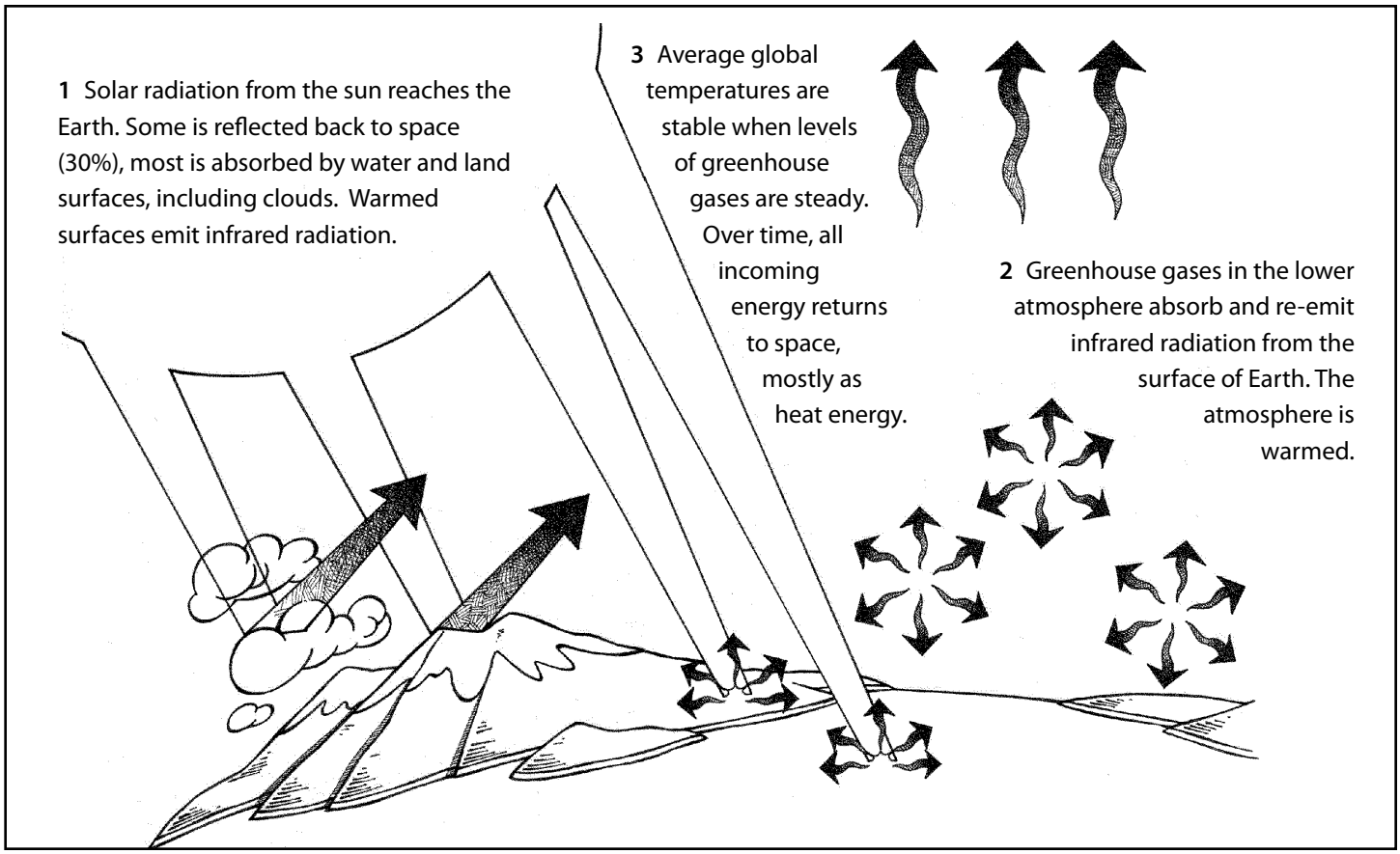
reflected back out to space by clouds and particles in the atmosphere and by snow and ice at Earth's surface. In the atmosphere, clouds, gases and particles absorb twenty percent of the incoming visible light and the remaining fifty percent is absorbed at Earth's surface.

Once absorbed, the visible light energy is transformed into infrared radiation, which warms the surface and atmosphere. Emitted in all directions, some of the infrared radiation (i.e., heat energy) immediately escapes into space, while most is absorbed and emitted back to Earth and into the atmosphere by gases that naturally occur in Earth's atmosphere – the greenhouse gases. This process is known as the natural greenhouse effect and it is responsible for keeping Earth's temperature warm enough to support life. Without it, the average temperature on Earth would be –18°C.

Overall, the energy entering Earth's atmospheric system is balanced by the energy leaving it. The pre-industrial level of atmospheric greenhouse gases kept the average global temperature relatively stable. Unfortunately, human activity is altering the composition of the atmosphere by increasing the amount of greenhouse gases. For example carbon dioxide (CO_2) has increased by approximately 31% since the Industrial Revolution began in the 1750's. The result is that more infrared radiation is retained in Earth's atmosphere for a longer time, leading to an increased average global temperature – this is called the enhanced greenhouse effect. In other words global warming is occurring and it is directly associated with the changes in Earth's global climate system referred to as climate change.

*See the **Primer** and **Resources** for more information.*

Greenhouse Effect Diagram



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Note: This activity is a streamlined explanation of the complex interactions that happen between solar radiation and Earth's surface and atmosphere. It enables students to obtain a basic understanding of the greenhouse effect by having them actively engage in a demonstration of the process.

Procedure

Warm Up

1 If the lesson ***Greenhouse Effect Part One: Warming the Earth Experiment*** has not been done, compare the metaphor of a gardener's greenhouse to the actual phenomena of the natural greenhouse effect of Earth's atmosphere with the students. Remind students that without atmospheric greenhouse gases absorbing and emitting infrared radiation (heat energy) from Earth's surface, the temperature on Earth would be too cold to sustain life. Also remind students that virtually all of the energy utilized in ecosystems on Earth originates from the Sun.

2 Ensure students are familiar with the concepts covered in the lesson ***Greenhouse Effect Part One***, especially:

- visible light energy (one part of the electromagnetic spectrum) easily penetrates the upper atmosphere and can reach Earth's surface,

Table: Summary of the Sources and Sinks of the Main Greenhouse Gases

Greenhouse Gas	Released into atmosphere by…	Removed from atmosphere by…
Carbon Dioxide (CO_2)	***Human Activity:*** burning and production of fossil fuels, clearing of land using fire (combustion) ***Natural Activity:*** Volcanic activity, forest fires, respiration by organisms, decomposition	***Human Activity:*** less CO_2 is removed by natural activity because of deforestation, degrading of soils, and wetland destruction ***Natural Activity:*** Plants and algae (photosynthesis); oceans (go into solution)
Methane (CH_4)	***Human Activity:*** Digestive processes of grazing domestic animals, decomposition (anaerobic or without air) in solid waste landfills, fossil fuel production ***Natural Activity:*** Decomposition in swamp and wetland areas, melting of permafrost, digestive process of grazing animals	***Human Activity:*** Burning as a source of energy, forms carbon dioxide (CO_2) and water (H_2O) ***Natural Activity:*** chemical reactions in the upper atmosphere, soil, ocean sediments
Nitrous Oxide (NO_2)	***Human Activity:*** Agriculture, especially the use of synthetic nitrogen fertilizers and raising of cows, pigs and chickens; burning of fossil fuels; creation of synthetic nitrogen based fabric (e.g., nylon) ***Natural Activity:*** Emitted by bacteria in soils and oceans	***Natural Activity:*** Bacteria (especially nitrogen fixing bacteria)

- visible light energy is absorbed by objects, then transformed and emitted as infrared radiation (heat energy),
- objects of different colour and composition reflect or absorb visible light energy differentially; generally, the darker the object, the more visible light energy is absorbed, and
- this results in variable warming of the surface of different objects and the atmosphere close to them.

3 Ask the students to give an example of the above phenomena that they have experienced. Possible examples include: 1) feeling heat coming from something exposed to direct sunlight such as dark cloth, pavement, or sand and 2) a top few centimeters of water in a small lake being warmer than lower layers in the summer.

4 Ask the students, "What is the atmosphere composed of?" Ensure students understand that the "air" of our atmosphere is made up of matter (atoms and molecules) in the gas phase. Explain that the composition of the atmosphere is mostly nitrogen (78%), oxygen (21%), and argon (0.9%). Greenhouse gases such as the naturally occurring carbon dioxide, methane, and nitrous oxide, along with man-made gases (e.g., halocarbons), make up less than 0.1%. The percentage of water vapour, another naturally occurring greenhouse gas in the atmosphere, varies over place and time. Also, ensure students understand there are different layers of the atmosphere, noting it is in the lower layers that most of the gases are concentrated and where most weather occurs.

5 Introduce the concept that atoms or molecules of matter interact with heat differentially. Ensure students understand that in the Earth-Atmosphere system, greenhouse gases are all able to absorb and re-emit infrared radiation, including that coming from Earth's surface, but some have a greater ability to do this than others. Another way of saying this is that relative to carbon dioxide, methane and nitrous oxide are more "potent".

6 Inform the students that this lesson is a whole class role-play activity that will help them understand the greenhouse effect by experiencing the interactions amongst visible light from the sun, infrared radiation, and the greenhouse gas, carbon dioxide.

Activity

1 Set out cones to **mark boundaries**. The size of the playing area should be approximately 20m wide and 30m long. Adjust the playing area size to fit class numbers as indicated below.

2 **Assign** the following **roles** to the indicated number of students*.

- Light Surfaces: 5 students
- Dark Surfaces: 10 students
- Carbon Dioxide (CO_2): 6 students
- Visible Light (part of the radiant energy from the sun): 7 students.

**The above numbers are based on a class size of 28 students; adjust the number of students playing each role as necessary for your class size. The roles of Light Surfaces and Dark Surfaces should have a 1:2 ratio (one-third of the total should be Light Surfaces, two-thirds Dark Surfaces). The total number of students role-playing surfaces should be more than those role-playing visible light.*

3 Ensure students understand conceptually that all the surfaces on Earth absorb some visible light and vary in the degree in which they reflect visible light. For the purposes of this activity, the role "Light Surfaces" represents those surfaces on Earth that are light coloured and highly reflective such as snow and ice. The role "Dark Surfaces" represents Earth surfaces that are darker in colour and readily absorb visible light such as water, rocks, soil, and vegetation.

4 **Identify** the students playing the Light Surfaces role with light coloured gym vests, arm bands, belts, or clothing. Optional: Also identify students playing the Dark Surface, Carbon Dioxide and Visible Light roles with appropriate colours (e.g., darkly coloured vests for Dark Surfaces).

During the activity, the position and/or actions of these roles will help to identify them.

5 **Arrange** the students so that:

The Visible Light players form a line at one end of the playing area, facing the opposite end. This area represents the sun in space.

Light and Dark Surface Players form a single line at the other end of the playing area, representing the surface of Earth. Order does not matter. Each student should extend their arms out to the side and be able to touch the fingers of the next student, ensuring there are no gaps between students or at the edges. Adjust the size of the playing area accordingly to work with your class size.

Carbon Dioxide players are scattered in the third of the playing area closest to the Light and Dark Surfaces. This area represents Earth's lower atmosphere; the rest of the area is the upper atmosphere and space.

6 Inform the students of the **actions for each role** as follows:

Visible Light players must walk slowly forward to the other end in a straight line while extending their arms out forward and wiggling their fingers. Once they reach the other end, their actions may change depending on what player they encounter.

If they encounter a Light Surface player, they are **reflected** back to space. They return to the starting spot (the Sun) and wait for the next round.

If they encounter a Dark Surface player, they are **transformed and become Infrared Radiation**, warming up the surface and atmosphere. Infrared Radiation players now wrap their arms around their upper body in a loose hug.

Dark Surface players simulate the absorption and transformation of visible light into infrared radiation by gently moving the Visible Light player's extended arms so that they now wrap around the upper body of the player (i.e., a self hug). The now Infrared Radiation player is then released into the atmosphere in any direction. To indicate **heat energy being released** to the surface and warming it up, the Dark Surface player now rocks from one foot to the other, swaying side to side but staying in one spot.

Light Surface players use their bodies and arms to gently "bounce" (reflect) Visible Light players back into space at the same angle as they arrived (like a ball bouncing off a wall).

Dark Surface and Light Surface players, when approached by an Infrared Radiation player from the atmosphere, simulate the interaction with and re-emission of infrared radiation by gently turning and re-directing the Infrared Radiation player back into the atmosphere. To indicate heat energy being released, the Dark Surface or Light Surface player should gently rock side to side.

Carbon Dioxide players must allow Visible Light players to easily pass by, including stepping to one side if necessary. When an Infrared Radiation player approaches either from Earth's surface or atmosphere, Carbon Dioxide players stay in place, but extend their arms and "capture" the Infrared Radiation player by placing their hands on the shoulders of that player. The pair spin in place slowly with their eyes closed for a count of 5, then stop and open their eyes. The Carbon Dioxide player releases the Infrared Radiation player and steps to one side so that the Infrared Radiation player can walk straight ahead in whatever direction they are now pointing. To indicate **heat energy being released** from infrared radiation and absorbed by carbon dioxide, the Carbon Dioxide player now rocks from one foot to the other, swaying side to side but staying in one spot.

Infrared Radiation must walk slowly forward, with their arms around themselves in a hug, after an encounter with another player. Once released by another player, they continue moving straight ahead in the direction indicated until they are either again absorbed and re-emitted by a Carbon Dioxide, Light Surface or Dark Surface player or

finally leave the atmosphere. Once in space, they should return to a corner of the playing area near the sun. If they reach a playing area boundary within the atmosphere zone, they should "bounce" off and resume a straight path. Reminder: each time an Infrared Radiation player encounters a Light Surface, Dark Surface or Carbon Dioxide player, heat energy is released and the other player should rock from side to side.

7 **Round One: Natural Greenhouse Effect.** Before beginning the activity, **review the roles** of each player by **walking through a demonstration** with one player. To avoid Visible Light players from seeking a specific spot at the Earth's surface, ask the Visible Light players to turn so they are initially facing away from the playing area. Encourage the Dark Surface and Light Surface players to switch positions along the line.

8 **Start the activity** by asking all the Visible Light players to turn and walk in a straight line toward the Earth's surface at the opposite side of the playing area. Remind the Visible Light/Infrared Radiation players that once they return to space, they go and stay at the starting place (the area representing the sun).

9 Allow the activity to continue for five minutes or until all the Visible Light/Infrared Radiation players return to the starting place; record this time. Count and record the number of Visible Light players and Infrared Radiation players in space, as well as the number of Infrared Players still in the atmosphere.

10 Briefly **debrief** what the students observed and experienced. Remind the students that all radiant energy eventually leaves Earth and enters space. Also discuss how the atmosphere is kept at a life-sustaining temperature because carbon dioxide, and other greenhouse gases, retains infrared radiation (heat energy) in the atmosphere. Repeat the first round if desired.

11 **Round Two: Enhanced Greenhouse Effect.** Tell the students that for the next round, there will be **more Carbon Dioxide players** in the atmosphere. Ask the students why this might happen. Possible answers include the burning of fossil fuels, thus releasing more carbon dioxide, and/or decreasing forest size, which results in less carbon dioxide being removed from the atmosphere through photosynthesis. **Re-assign** one Dark Surface player and one or two Light Surface players to become Carbon Dioxide players, thus increasing the amount of carbon dioxide in the atmosphere.

12 Repeat the activity, continuing it for the same length of time as before. At the end, **record the numbers** of Visible Light and Infrared Radiation players reflected directly back to space, as well as the number of Infrared Radiation players in the atmosphere. Repeat if desired.

Wrap-up

1 Compare the outcomes of the natural and enhanced greenhouse rounds of the activity by analyzing the recorded numbers. To prompt discussion, ask the students the following questions:

- What was the impact of more Carbon Dioxide players in Round Two? *(A: More Infrared Radiation players were captured initially and they were kept in the atmosphere for a longer period of time.)*
- What was the impact of less Light Surface players in Round Two? *(A: Proportionately more Visible Light players were absorbed by Dark Surface players and transformed into Infrared Radiation players. As Earth is warmed, there is a decrease in the total amount of ice and snow, especially in the summer, as seen by the decreasing amount of sea ice in the Arctic Ocean).*

2 Lead a discussion of how more carbon dioxide results in an increase in the average global temperature of Earth's atmosphere and that this phenomena is called the Enhanced Greenhouse Effect. Connect how this atmospheric warming has an impact on other components in Earth's global climate system, causing a period of significant climate change. Explore with the students the possible impact on ecosystems due to changes in abiotic

(non-living) conditions if global and regional climates continue to change. For example, what might happen to populations of various species of trees if there is an increase in average summer temperatures in a region? *(A: Some species have limited tolerance to changes in temperatures of even a few degrees and may experience die-offs while other species may thrive under these new conditions. The range of tree populations may shift over time.) See the **Primer** and **Resources** for some specific observed changes in abiotic conditions in British Columbia and predicted impact on species populations.*

3 Ask the students why two-thirds of Earth's surface was "Dark Surfaces" and one-third was "Light Surfaces" in the activity. Encourage students to explore possible answers, guiding them to understand that Earth has an **albedo** of approximately 30%; in other words, roughly one third of incoming solar radiation is directly reflected back to space due to reflective components in Earth's surface and atmosphere (*see below for the role played by clouds*). Ensure students understand all surfaces both reflect and absorb visible light, but to different degrees.

4 Ensure the students understand that all objects, regardless of colour or composition, interact with infrared radiation (heat energy), but in different manners. This interaction was simulated in the activity by the rocking of Light Surface, Dark Surface, and Carbon Dioxide players after interacting with an Infrared Radiation player. (Discussion of this concept could lead to the introduction of specific heat and transfer of energy).

5 Ask the students "What components of the atmosphere are missing from this simulation of the greenhouse effect?" There are several possible answers, but the most important component that was not included is **clouds.** They play a significant role in reflecting and absorbing visible light coming from the sun, as well as absorbing infrared radiation. In the activity, approximately 70% of visible light is absorbed by "Dark Surfaces" at Earth's surface; in reality approximately 20% of incoming visible light is actually absorbed by clouds and other components of the atmosphere before reaching Earth. Also, water vapour in the atmosphere is another greenhouse gas, which absorbs infrared radiation from Earth's surface. The presence of water vapour is variable over location and amounts, making its impact difficult to model.

6 Using the ***Greenhouse Effect Diagram***, summarize the concept of the solar radiation balance with the students, ensuring they understand that 30% of incoming visible light is reflected back to space by clouds, snow and ice, 20% is absorbed by clouds, and 50% is absorbed by non-reflective, dark surfaces on Earth. Connect this to the concept of the natural greenhouse effect, where visible light is absorbed by dark surfaces such as land, liquid water, and vegetation, transformed, and emitted as infrared radiation (heat energy). Most of this infrared radiation is then absorbed by greenhouse gases such as carbon dioxide and re-emitted in all directions, including back into the atmosphere and toward Earth.

7 Ensure students also understand that close to 90% of the infrared radiation from Earth is absorbed by carbon dioxide in the natural greenhouse effect. In this activity, a large increase in carbon dioxide was used to ensure a quick, significant noticeable effect; in reality the increased level of carbon dioxide in the atmosphere has been building up slowly over the past 150 years. End the discussion by informing students of the other natural and human-made greenhouse gases. *See the **Table** provided for information regarding sources of natural greenhouse gases.*

Assessment

1 Ask small groups of students to draw a diagram illustrating the natural greenhouse effect based on their experiences in the role-play. Look for evidence of an understanding of the interactions between visible light, dark and light surfaces, infrared radiation, and greenhouse gases in the atmosphere.

2 Ask each student to write a story from the point of view of a ray of visible light from the sun hurtling toward Earth with some friends (other rays of visible light), describing what

happens to the group when they reach Earth. Students should include specific examples (e.g., the ray of light is absorbed by a rock in a field, while one of the friends is reflected back to space from a polar ice cap). Look for evidence of the understanding of the possible outcomes when visible light reaches Earth.

3 Have students re-design the natural greenhouse effect part of the activity to include clouds. Based on their understanding of what happens to incoming visible light and Earth's albedo, students should determine the proportion of students should role-play clouds as part of the Light Surfaces role. The activity should also include instructions as to happens to incoming Visible Light and Infrared Radiation from the Earth when they encounter a cloud.

4 Ask students to predict, with an explanation, what would happen to the temperature of Earth's atmosphere if the amount of CO_2 decreased below pre-industrial revolution levels. The paragraph should also include a short discussion of the potential impact on ecosystems throughout the world, based on their understanding of what has happened in the past geological record, for example during the ice age. Look for evidence of an understanding of the role of CO_2 in the atmosphere in maintaining a life-sustaining global temperature and how some species within ecosystems may not be able to tolerate shifts in abiotic conditions such as precipitation patterns or temperatures.

Extensions

1 Conduct the role-play again, varying the numbers in each role to observe outcomes. Possible scenarios include increasing Light Surface players to simulate more clouds due to increased temperatures causing more evaporation from water bodies on Earth's surface.

2 Ask small groups of students to research one of the greenhouse gases to determine the natural processes and human activities that release it to the atmosphere as well as remove it from the atmosphere. The research could be presented as a skit or poster and should highlight the ecosystem processes that contribute/remove their greenhouse gas to the atmosphere in the natural greenhouse effect, as well as human activities that contribute their greenhouse gas.

3 Have students research the atmospheres of all the planets in our solar system. Why is Earth's atmosphere the only one capable of supporting life as we know it?