

STUDENT GUIDE

EXPLORE 1 LESSON 8



Part 1: Our Motivation

Record what we were trying to figure out that led to this investigation.

- How do cow burps influence climate?
- What is climate change?
- What do greenhouse gases have to do with climate change?



Part 2: Analyzing Data on Human Activity and Climate Change

In the space below, describe the general trends that you observe in each data set.

| Name of Data Set: | My Notes: |
|-------------------------------|--|
| Greenhouse Gas Concentrations | The amount of greenhouse gases in the atmosphere has increased significantly over time. As shown on the graph, from 1950 to 2020, global atmosphere concentrations of carbon dioxide went from just over 300 ppm to 400 ppm. |
| Our World in Data | Humans are contributing more carbon dioxide and methane into the atmosphere every year. From 1979 to 2023, global atmospheric CO ₂ concentration went from just under 340 ppm to approximately 420 ppm. From 1983 to 2023, methane increased from just under 1,650 ppb to over 1,900 ppb. |
| Global Temperatures | As shown on the graph, average temperature anomalies have increased since 1890. As CO ₂ concentrations in the atmosphere have risen, so have global temp anomalies. |

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In the space below, describe the general trends that you observe in each data set. (Cont.)

| Name of Data Set: | My Notes: |
|----------------------|--|
| Economic Output | Since industrialization (just before 1800), the world gross domestic product (GDP) has drastically risen to just over 6,000 from just above 0. |
| Emissions Impossible | Fig 3: Dairy production and consumption have both increased, and projected production is predicted to increase to over 1,000 million tons by 2040. Fig. 11: Global greenhouse gas emissions from beef is increasing. However, emissions in developed countries is decreasing dramatically. It has gone from approximately 1,500 million tons to 700 million tons. It has also dropped in emissions intensity from approximately 75 to 35. |
| GHG From Livestock | From 1960, dairy cattle greenhouse gas emissions has decreased in developed countries (from just under 400 to 200) but is increasing in developing countries (from around 100 to 300). For dairy milk, greenhouse gas emissions are decreasing in both developed and developing countries, leading to overall intensity of GHG to be decreasing (from 1.5 to less than 1). |

Evaluate the impact of this new data on our working explanation of how cow burps cause climate change. What ideas do you still agree with? What would you revise or add? Use evidence from the data sets above to support your suggestion.

The amount of greenhouse gases in the atmosphere has increased over time since the Industrial Revolution, likely due to human activity. For carbon dioxide this increase was from approximately 315 ppm to 420 ppm. Methane saw an increase to approximately 1,900 ppb from under 1,650 ppb since 1983 according to the Our World in Data graphs. At the same time, increases in average atmospheric temperatures have occurred, rising by approximately 1.3°C according to the Global Temperatures data. The cow burps are one part. Emissions from the dairy industry have overall increased somewhat since 1960 especially in the developing world, rising to approximately 300 MtCO₂eq from around 100 MtCO₂eq. But it is not just dairy that is influencing the climate. Many different human activities may be influencing the climate.

What are limitations of these data? Can they help us determine the causes of climate change?

These data are only showing us the general industrial trends, not those specific to cow burps. They are also only showing us a correlation between several variables – as the industrial activity in the world has increased, so have global average temperatures and the amount of greenhouse gases in the atmosphere. We know that correlation does not necessarily imply causation.

What do you want to figure out next to help us improve our working explanation?

Because we know that correlation is not causation, we'll need some additional evidence that demonstrates a mechanism that describes how the increase in greenhouse gases could cause climate change.



Part 3: Using a Series of Models of the Greenhouse Effect

Record the strengths and limitations of each computer model.

| Computer Model: PhET | | |
|--|--|---|
| Define the System Shown in the Model | Strengths/Merits of How the Model Shows Matter and Energy Changes | Weaknesses/Limitations of How the Model Shows Matter and Energy Changes |
| Earth's surface and Earth's atmosphere, including clouds and just before space | <ul style="list-style-type: none"> Shows sunlight and infrared energy as waves Shows the change in surface temperature Shows balance of energy in vs. energy out Can change time period of GHG emissions (which also changes background) Shows how some infrared radiation leaves to space. | <ul style="list-style-type: none"> Can set GHG concentration to lots or none (no actual value shown) Doesn't show exactly how greenhouse gases and infrared or sunlight energy interact |

| Computer Model: The Concord Consortium | | |
|---|---|--|
| Define the System Shown in the Model | Strengths/Merits of How the Model Shows Matter and Energy Changes | Weaknesses/Limitations of How the Model Shows Matter and Energy Changes |
| Just under Earth's surface and Earth's atmosphere, ending just before space | <ul style="list-style-type: none"> • Shows solar radiation, infrared radiation, carbon dioxide, and heat as small moving dots • Shows a graph of temperature change and graph of CO₂ concentration over time • Shows a graph of the historical atmospheric CO₂ over time • Demonstrates how solar radiation interacts with Earth's surface and atmosphere • Shows how the accumulation of infrared radiation can lead to increased temperatures. | <ul style="list-style-type: none"> • Large number of moving model components is somewhat difficult to interpret |

| Computer Model: HHMI BioInteractive | | |
|--|---|---|
| Define the System Shown in the Model | Strengths/Merits of How the Model Shows Matter and Energy Changes | Weaknesses/Limitations of How the Model Shows Matter and Energy Changes |
| Earth's surface and Earth's atmosphere, at the edge of space | Explains different greenhouse gases in the atmosphere, how energy moves through the atmosphere, and how GHGs radiate heat | <ul style="list-style-type: none"> • Is a video, so you cannot manipulate any of the input variables • Says that global temperatures are rising, but does not show this on the model • Says that humans are impacting the rising temperatures and climate, but does not show this on the model |

Prepare an explanation of the mechanism for how Earth's average temperature increases, including the following:

- How greenhouse gases like methane and carbon dioxide influence Earth's average temperature.
- How energy moves into and out of the Earth system, and what this has to do with the Earth's average temperature.
- The specific features from one model you found most useful in helping you understand the mechanism.

As energy from the Sun comes down from the edge of the atmosphere, that sunlight energy is transformed into thermal energy. Some of the heat it brings is reabsorbed by gases at the edge of the atmosphere, causing it to warm. What remains radiates down to warm Earth's surface as well. The energy that is reflected by Earth's surface goes back into space and some is not reflected and is absorbed by interacting with the greenhouse gas molecules, warming the Earth. As sunlight is reflected as infrared waves into the atmosphere, the molecules at Earth's surface heat up, causing a rise in temperature. When there is a greater amount of GHG in the atmosphere, less infrared radiation can pass outside of the system. The combination of all these factors causes Earth's average temperature to rise.

The PhET Greenhouse Effect simulation showed actual surface temperature as more or less infrared radiation was absorbed by Earth, which explains how electromagnetic energy from the sun comes down from the edge of the atmosphere and is transformed into thermal energy. The other models had limitations because they did not demonstrate this in any way. The Concord Consortium Tool was helpful in showing what is happening with the actual molecules as sunlight is reflected into the atmosphere.



Part 4: Sharing Explanations

In the space below, note the similarities and differences in the explanations that your peers share. Be sure to record:

- Which of the models your peers thought had the most merits/strengths.
- How your peers describe the movements of energy and matter into and out of the Earth system.

| Similarities | Differences |
|--|--|
| One of my peers agreed that one of the strengths of the Concord Consortium Tool was in showing how greenhouse gases increase global temperatures. They agreed that the graphs were useful in showing the changes in greenhouse gas emissions over time and throughout history, which was another strength. | One of my peers thought BioInteractive HHMI video had limitations because it did not rely on numerical values, but I thought it had a strength of explaining how solar radiation is absorbed or reflected and how the different molecules in the atmosphere absorb them. |

**Part 5: Revise the Class Working Explanation**

Based on what you figured out about the mechanism of the greenhouse effect, revise our working explanation in the space below.

As energy from the Sun comes down from the edge of the atmosphere, that electromagnetic energy is transformed into thermal energy. Incoming thermal energy from the Sun passes through the atmosphere and warms the Earth. The Earth emits thermal radiation as well, which re-enters the atmosphere. Greenhouse gases like methane and CO₂ in the atmosphere absorb infrared radiation. When GHG absorb infrared radiation, they radiate heat in all directions, causing surface temperatures to rise. The amount of greenhouse gases in the atmosphere has increased over time since the Industrial Revolution, likely due to human activity. At the same time, increases in average atmospheric temperatures have occurred. The methane from cow burps are only one part. There are other greenhouse gases in the atmosphere, such as carbon dioxide. But it is not just dairy that is influencing the climate. Many different human activities may be influencing the climate. Emissions from the dairy industry have increased somewhat since 1960, especially in the developing world.