earth science

Meteorology

Greenhouse Effect Simulations

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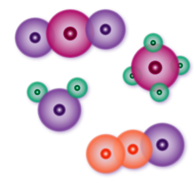
Your Name

What are greenhouse gases? How do greenhouse gases affect the flow of light and heat energy through Earth's atmosphere and affect Earth's climate?

"Without the greenhouse effect, Earth would be a frozen planet."
—NOAA Reports to the Nation, Our Changing Climate

The atmosphere is a mixture of gases, including natural and human-made trace ***greenhouse gases*** such as carbon dioxide, methane, water vapor, nitrous oxide, CFC's, and HC's. These gases interact with infrared heat energy trying to radiate from Earth's surface back into space, keeping the planet warmer than it would be without these gases.



Simulation #1: Molecules and Light

1. Open the Molecules and Light simulation from PhET.
2. Working with your partner, explore all of the controls in the simulation for a few minutes. Click on different things and figure out what each one does. What does the simulation do and show?
3. Use the simulator to specifically examine how two different types of radiation interact with different atmospheric gas molecules. In the data table below, record your observations for each combination — draw a labeled sketch and add a few descriptive words.

Atmospheric Gas	Visible Radiation (Light Energy)	Infrared Radiation (Heat Energy)
Nitrogen (N_2)		
Oxygen (O_2)		
Carbon Dioxide (CO_2)		
Water Vapor (H_2O)		

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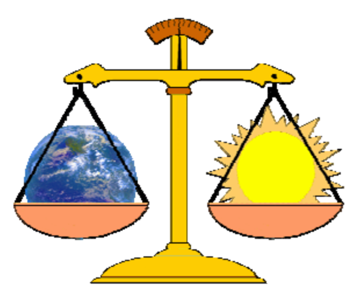
Reflection — based on your observations, answer the questions below.

- Which atmospheric gas molecules ***were not*** affected by the visible or infrared radiation?
- Which atmospheric gas molecules ***were*** affected by the visible or infrared radiation?
- How were these atmospheric gas molecules affected by the radiation?
- How was the radiation affected by these atmospheric gas molecules?

Put all the pieces together — connect what's happening in this simulation to what's happening in the real world.

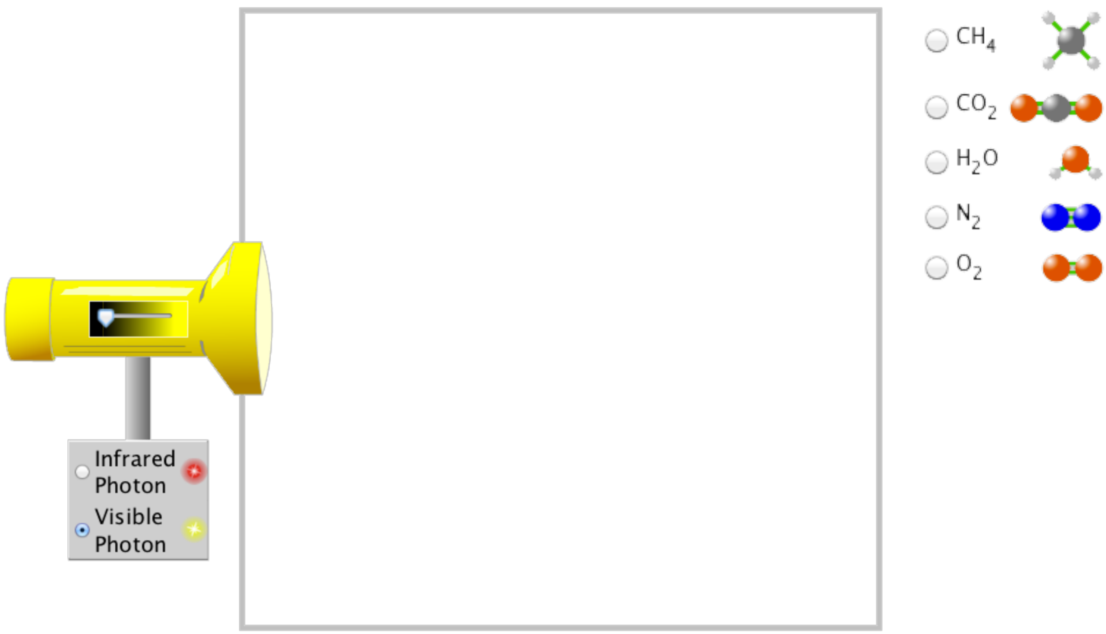
- Based on the simulation, what makes a greenhouse gas a greenhouse gas?
- How does energy flow in and out of Earth's atmosphere, and how might this be related to Earth's climate?
- What is one question that you are still wondering about?

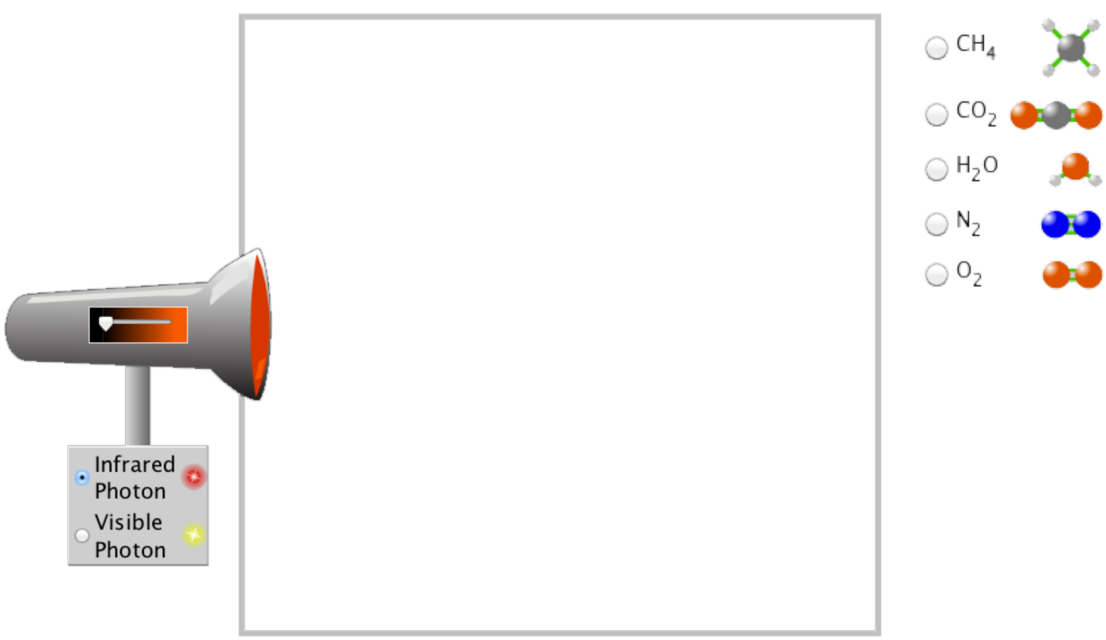


Your Name

Simulation #2: The Greenhouse Effect

- Use PhET's Greenhouse Effect simulation to explore and explain the role of greenhouse gases in Earth's atmosphere and climate. Show what happens in each situation below.





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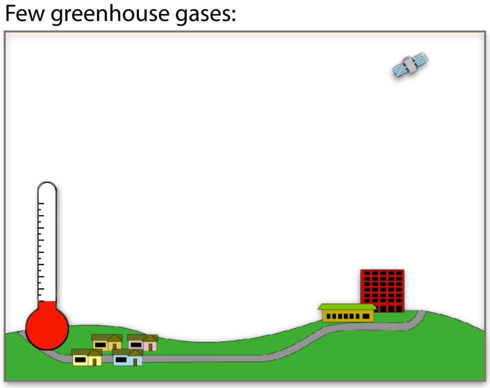
Fill in the data table below:

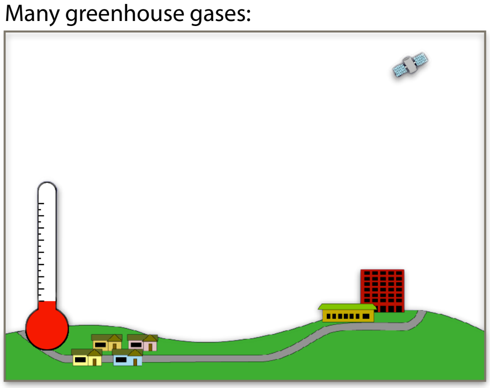
Atmospheric Gas: What is the name of each gas?	Is it a greenhouse gas?	Does it absorb visible energy?	Does it absorb infrared energy?
N_2			
O_2			
CO_2			
CH_4			
H_2O			

In the diagrams below, draw and explain how both the flow of visible (solar) and infrared (heat) energy and the temperature of Earth's atmosphere are affected by greenhouse gases.

Few greenhouse gases:

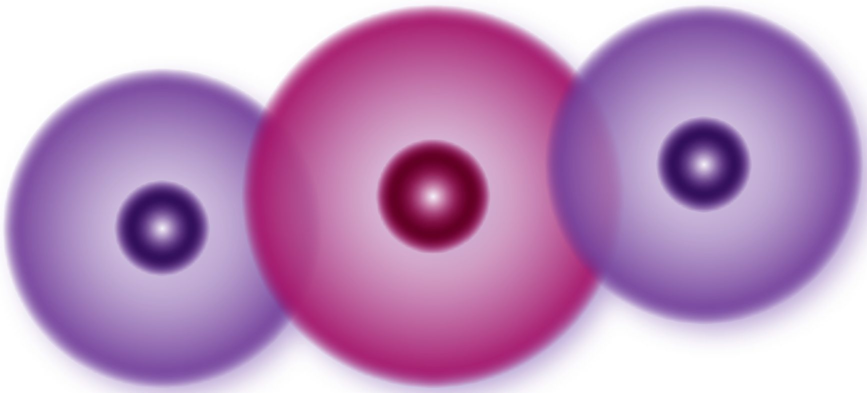


Many greenhouse gases:

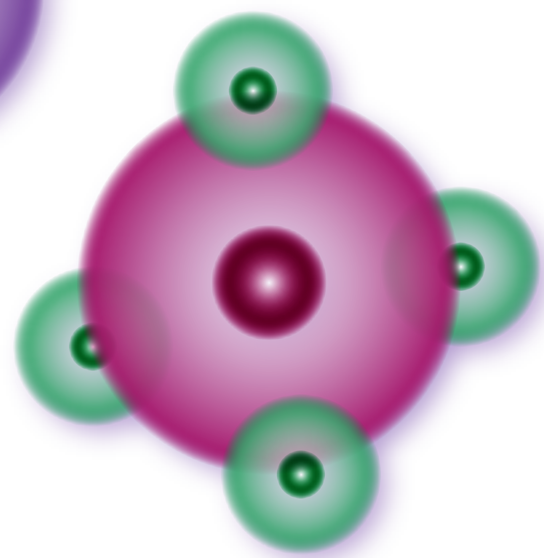


The Greenhouse Gases

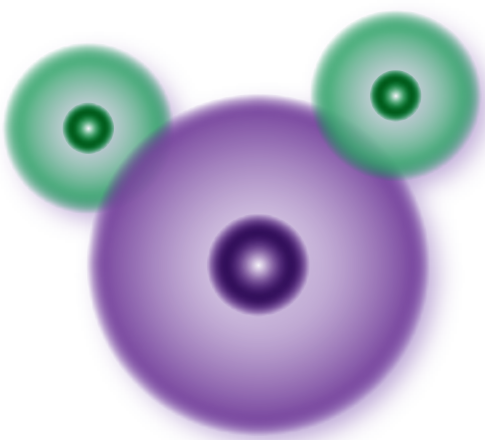
"Without the greenhouse effect, Earth would be a frozen planet."
–NOAA Reports to the Nation, Our Changing Climate



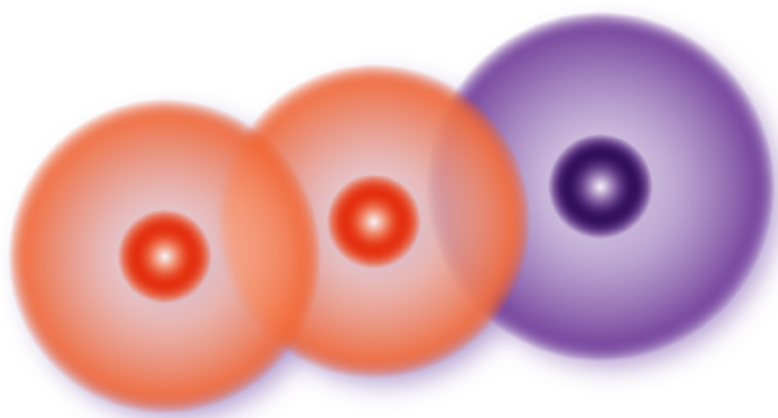
Carbon Dioxide, CO_2



Methane, CH_4



Water Vapor, H_2O



Nitrous Oxide, N_2O

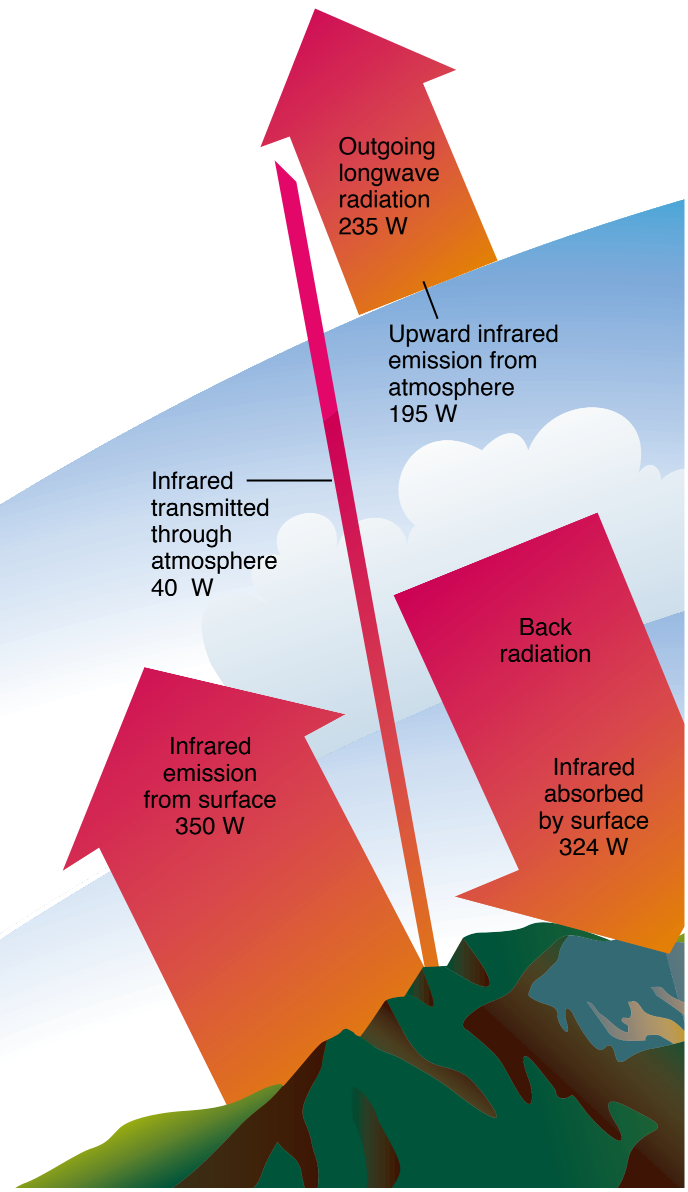
Within Earth's atmosphere, these naturally occurring greenhouse gases interact with heat energy trying to radiate from the Earth back into space, slowing the process down. But what happens to the energy balance when humans add even more of these (and other) gases to Earth's atmosphere?

Without the greenhouse effect, Earth would be a frozen planet.

The Greenhouse Effect

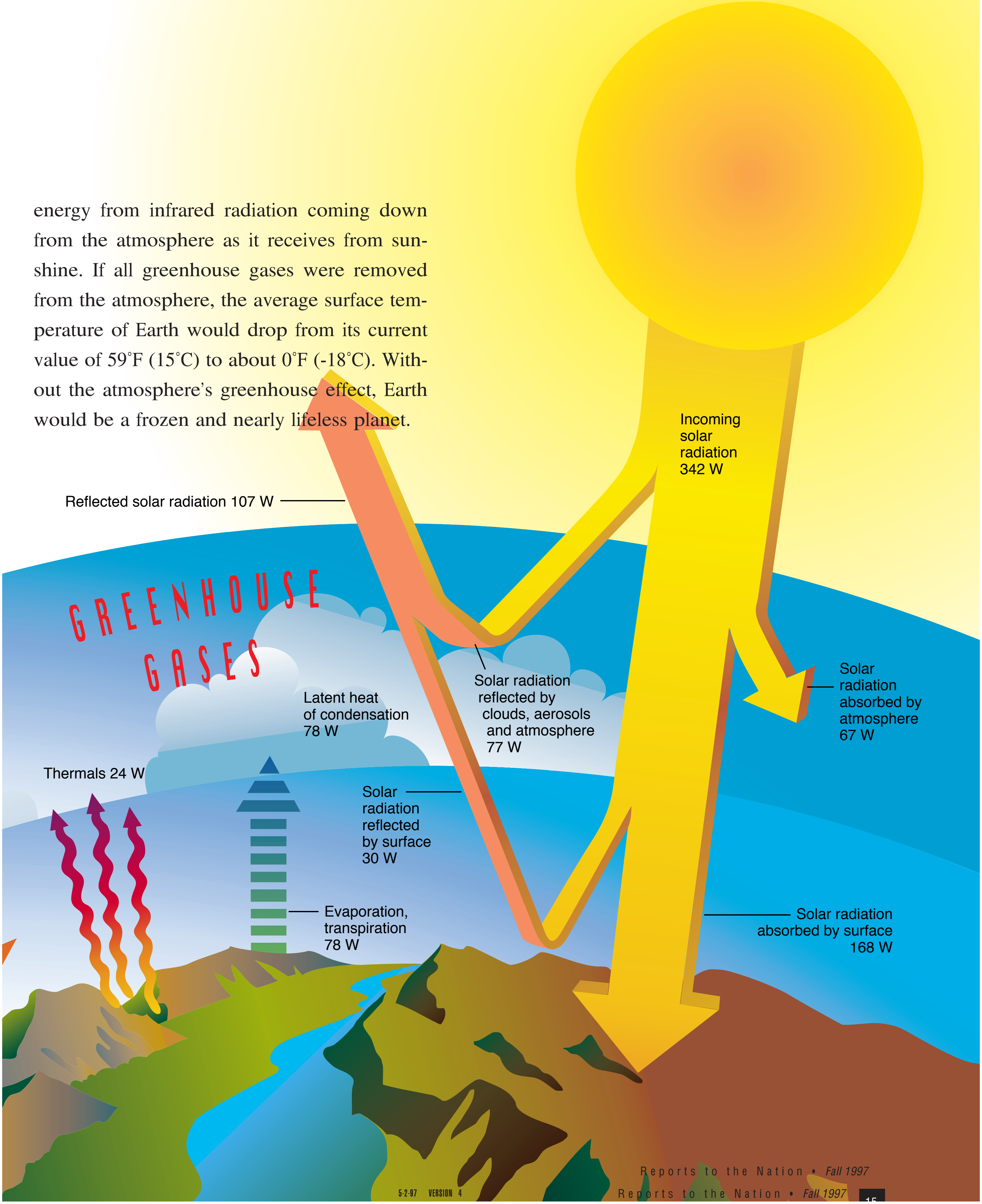
Carbon dioxide gas constitutes a tiny fraction of the atmosphere. Only about one air molecule in three thousand is CO_2. Yet despite their small numbers, CO_2 molecules can have a big effect on the climate. To understand why they are so important, we need to know about the greenhouse effect of the atmosphere. Earth's atmosphere lets in rays of sunshine and they warm the surface. The planet keeps cool by emitting heat back into space in the form of infrared radiation—the same radiation that warms us when we sit near a campfire or stove. But while the atmosphere is fairly transparent to sunshine, it is almost opaque to infrared radiation. Much like a garden greenhouse, it traps the heat inside.

About half of the solar energy that reaches Earth passes through the atmosphere and is absorbed at the surface. In contrast, about 90% of the infrared radiation emitted by the surface is absorbed by the atmosphere before it can escape to space. In addition, greenhouse gases like CO_2 as well as clouds can re-emit this radiation, sending it back toward the ground. The fact is, Earth's surface receives almost twice as much



The Greenhouse Effect
The atmosphere allows solar radiation to enter the climate system relatively easily, but absorbs the infrared radiation emitted by the Earth's surface. Although about half of the energy coming from the sun is absorbed at the surface of the Earth, almost twice as much surface heating is provided by downward infrared emission from the atmosphere as from sunshine. This "greenhouse effect" causes the surface of Earth to be much warmer than it would be without the atmosphere. The graphic on this page shows the flow of solar (yellow) and infrared (red) radiative energy through the climate system in watts per square meter of surface area. On average, 168 watts of solar radiation energy reach each square meter of the surface area, but the heating of the surface from the downward infrared radiation emitted by the atmosphere is almost twice that, 324 watts per square meter.

energy from infrared radiation coming down from the atmosphere as it receives from sunshine. If all greenhouse gases were removed from the atmosphere, the average surface temperature of Earth would drop from its current value of 59˚F (15˚C) to about 0˚F (-18˚C). Without the atmosphere's greenhouse effect, Earth would be a frozen and nearly lifeless planet.

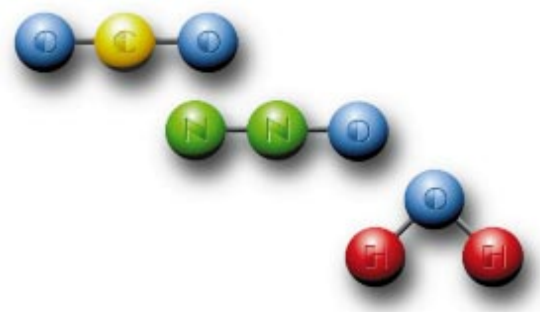


Reports to the Nation • *Fall 1997*

Denali National Park, Alaska.

It is the distinctive molecular structures of the greenhouse gases that make them strong absorbers and emitters of infrared radiation. About 99% of air molecules are nitrogen and oxygen, which have a simple structure consisting of two identical atoms. Because of this simple structure, they have a relatively minor effect on the transmission of solar and infrared radiation through the atmosphere. Molecules with three or more atoms like water vapor, carbon dioxide, ozone, and a host of other trace gases can efficiently absorb and emit infrared energy by storing and releasing it in molecular vibration and rotation. Though some of these gases constitute only a tiny fraction of the atmosphere, they can nevertheless make significant contributions to the greenhouse effect.

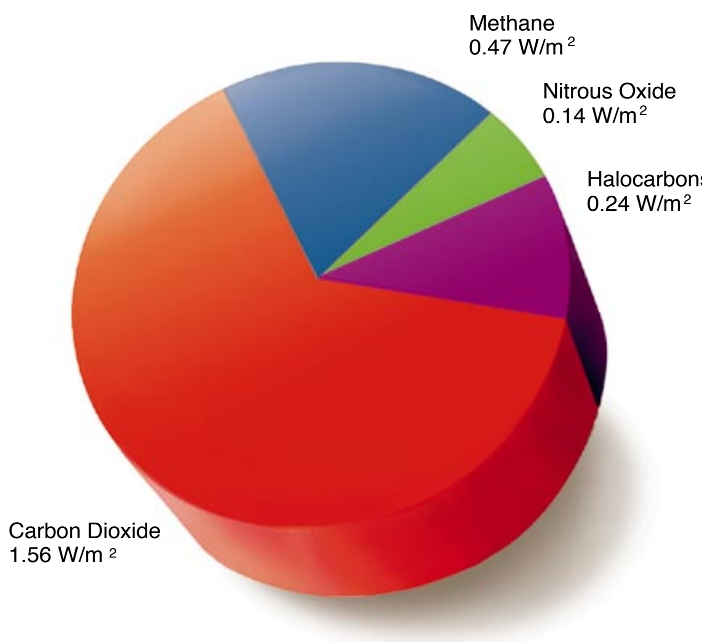
The molecule that makes the largest contribution is water vapor, which is a relatively abundant greenhouse gas. An average water molecule stays in the atmosphere only a few days from the time it evaporates from the surface to the time it falls out of the atmosphere as precipitation, so the water vapor content of the atmosphere adjusts quickly to changes in surface temperature. Humanity can do little to directly control the global amount of atmospheric water vapor. Because atmospheric water vapor tends to increase with increasing temperature, however, it can amplify climate changes produced by other means—a process called water vapor feedback.



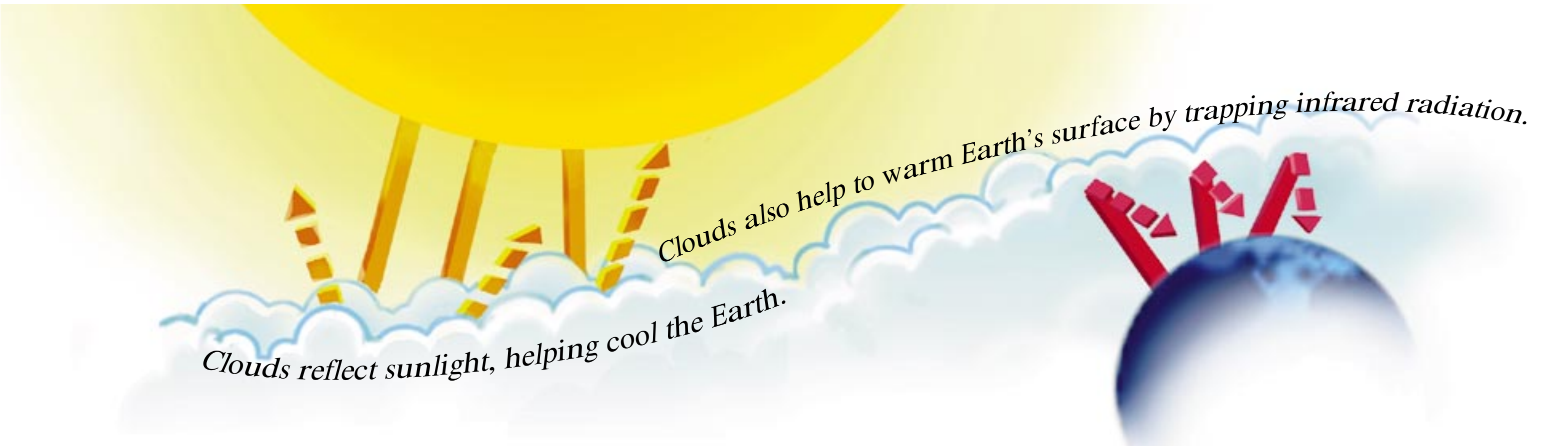
Why Are Greenhouse Gas Amounts Increasing?

Carbon dioxide has a much longer lifetime in the atmosphere than water vapor. If CO_2 is suddenly added to the atmosphere, it takes 100 to 200 years for the amount of atmospheric CO_2 to establish a new balance, compared to several weeks for water vapor. That's because the carbon in CO_2 is cycled between the atmosphere and the ocean or land surface by slow chemical and biological processes. Plants, for example, use CO_2 to produce energy in a process known as photosynthesis. Through millions of years of Earth's history, trillions of tons of carbon were taken out of the atmosphere by plants and buried in sediments that eventually became coal, oil, or natural gas deposits. In the last two centuries humans have used these deposits at an increasing rate as an economical energy source. In a similar way, cement manufacture releases carbon atoms buried in carbonate rocks. Today humanity releases about 5.5 billion tons of carbon to the atmosphere every year through fossil fuel burning and cement manufacture. Approximately another 1.5 billion tons per year are released through land use changes such as deforestation. These releases result in an increase of atmospheric CO_2 of about one-half percent per year.

Other naturally occurring greenhouse gases such as methane and nitrous oxide have also been increasing, and entirely man-made greenhouse gases such as halocarbons have been introduced into the atmosphere. Many of these gases are increasing more rapidly than carbon dioxide. The amount of methane, or natural gas, in the atmosphere has doubled since the Industrial Revolution. Although its sources are many, the increase is believed to come mainly from rice paddies, domestic animals, and leakage from coal, petroleum, and natural gas mining. Halocarbons are a family of industrial gases that are manufactured for use in refrigeration units, as cleaning solvents, and in the production of insulating foams. They were first manufactured in the 1940s, and because they do not readily react with other chemicals



Climate Forcing by Greenhouse Gas Increases Since the Industrial Revolution. Changes in the atmospheric concentration of CO_2, methane, nitrous oxide, and halocarbons that have occurred since the Industrial Revolution have altered the energy budget of Earth. The difference is about 2.4 watts per square meter, or roughly 1% of the energy flow through the global climate system.



they can have a lifetime in the atmosphere of more than 100 years. Halocarbons are also responsible for the Antarctic ozone hole and a more general decline in global stratospheric ozone, but this is a separate problem from the greenhouse warming contributed by the halocarbons. Production of some of the halocarbons that are important greenhouse gases has been regulated by international agreements to preserve Earth's protective ozone layer, so their influence on climate should decline in the future. Nearer to Earth's surface, in the troposphere, ozone amounts have been increasing because of human activities. Ozone at the surface has harmful effects on the health of plants, animals, and humans.

Aerosols: Sunscreen for the Planet?

Although raising the levels of greenhouse gases in the atmosphere is our most important direct influence on the global climate, human actions also contribute to the aerosol content of the atmosphere. Aerosols are tiny particles of liquid or solid matter that are suspended in air. They are different from water cloud droplets or ice particles in that they are present even in relatively dry air. Atmospheric aerosols have many sources and are composed of many different materials including sea salt, soil, smoke, and sulfuric acid. Although aerosols have many natural sources, it is estimated that aerosols resulting from human activities are now almost as important for climate as naturally produced ones. Most of the human-induced aerosols come from sulfur released in fossil fuel burning and from burning vegetation to clear agricultural land. Human production of sulfur gases accelerated rapidly in the 1950s.

It appears that the cooling effect of aerosols has canceled out part of the warming that might have been associated with recent greenhouse gas increases. Aerosols can reflect solar radiation or absorb and emit infrared radiation, and are often visible as haze or smog. By reflecting sunlight, they cool the climate. The human-induced increase in atmospheric aerosols since preindustrial times is believed to have reduced the energy absorbed by the planet by about half a watt per square meter, enough to offset about 20% of the greenhouse gas warming effect.

The aerosols produced by humans could also have a significant effect on the amount or properties of clouds. Every cloud droplet or ice particle has at its center an aerosol called a cloud condensation nucleus, on which the water vapor collected to form the cloud droplet. Aerosols that attract water, such as those composed of salt or sulfuric acid, are particularly effective as cloud condensation nuclei. The increased number of aerosols produced by humans could cause the water in clouds to be distributed into more, but smaller, cloud droplets. With their water spread more diffusely, the clouds would reflect more solar radiation. The existence of