How the atmosphere warms Earth

The greenhouse effect involves the absorption and emission of infrared radiation. The natural effect helps keep the surface warm enough for liquid water and life as we know it.

1. FOLLOW THE ENERGY

SUNLIGHT ARRIVES

Absorbed shortwave solar energy warms the surface.

→

SURFACE EMITS

The warmed surface emits longer-wave infrared radiation.

→

GASES ABSORB

Greenhouse gases absorb some infrared wavelengths.

The atmosphere emits infrared in all directions: some travels toward space and some toward the surface. Downward radiation makes the surface warmer than it would be with solar heating alone. Energy still escapes to space.

2. NATURAL VERSUS ENHANCED

The natural greenhouse effect is not itself pollution. Human activities increase concentrations of long-lived greenhouse gases and strengthen the effect. With more greenhouse gases, less infrared initially escapes to space at the same temperature. The Earth system gains energy and warms toward a new balance.

3. ABSORPTION IS NOT A SOLID LID

Greenhouse gases do not form a sealed barrier, stop all cooling or simply reflect heat like a mirror. Different gases absorb different infrared wavelengths. Most atmospheric nitrogen and oxygen do not absorb strongly in these thermal infrared bands, so abundance alone does not determine greenhouse activity.

Keep the radiation distinct: ozone-layer protection mainly concerns incoming ultraviolet; greenhouse warming concerns outgoing thermal infrared. An ozone hole is not the explanation for CO_2-driven warming.

Energy transfer and radiative balance: NASA, Climate and Earth's Energy Budget.
Natural and human-enhanced greenhouse effect: NASA, Causes of Climate Change.

Scope: College Board APES CED, Topic 9.3, STB-4.C and STB-4.D, p. 184.

Know the gases and their sources

The five principal gases named in Topic 9.3 are carbon dioxide, methane, water vapor, nitrous oxide and CFCs. Both natural processes and human activities can supply greenhouse gases.

1. MATCH EACH GAS TO A SOURCE

Carbon dioxide CO_2	Fossil-fuel burning, cement production and deforestation; also respiration, decomposition and ocean exchange.
Methane CH_4	Wetlands; livestock digestion, rice cultivation, landfills and leaks during fossil-fuel production or transport.
Nitrous oxide N_2O	Microbial activity in soils and waters; nitrogen fertilizer use, manure management and some industrial processes.
Water vapor H_2O	Evaporation and plant transpiration add vapor; condensation and precipitation return water to the surface.
CFCs Chemical family	Human-made chemicals formerly used in cooling, foam production and aerosols; old equipment and materials can still release them.

Additional examples: ozone and HFCs also absorb infrared. The syllabus list is not a list of every greenhouse gas.

2. WATER VAPOR: SHORT-LIVED, BUT IMPORTANT

Water vapor cycles out of the atmosphere rapidly, so direct additions do not build up like long-lived CO_2. However, warming allows more water vapor in the air, which strengthens infrared absorption and amplifies the initial warming.

Feedback: warming → more atmospheric water vapor → additional warming. Its short residence time does not mean it has little climate influence.

Human sources of CO2, CH4 and N2O: US EPA, Overview of Greenhouse Gases.
Natural sources and CFCs: NASA, Causes of Climate Change.
Short residence time and feedback: NASA, Steamy Relationships.

Scope: College Board APES CED, Topic 9.3, STB-4.C and STB-4.D, p. 184.

Compare potency, not just presence

Global warming potential (GWP) compares the integrated warming impact of equal masses of emitted gases over a specified period. Carbon dioxide is the reference, with GWP = 1.

1. A COMMON 100-YEAR COMPARISON

CO_2	1	Reference gas
CH_4	About 27-30	More warming per unit mass than CO2
N_2O	273	Higher GWP than methane
CFCs	Typically thousands	Very high GWP; value depends on the compound

Among these examples: CFCs > N_2O > CH_4 > CO_2. Values depend on the time horizon and scientific assessment; do not mix incompatible comparisons.

2. SUPPORTING CALCULATION: CO2 EQUIVALENT

$$CO_2 \text{ equivalent} = \text{mass emitted} \times \text{GWP}$$

Illustrative exercise: use a given 100-year methane GWP of 28.

$$2 \text{ kg } CH_4 \times 28 = 56 \text{ kg } CO_2 \text{ equivalent}$$

This compares warming impact, not conversion of methane into CO2.

3. HIGHER GWP DOES NOT MEAN LARGEST TOTAL EFFECT

A gas's overall contribution also depends on how much is emitted, its atmospheric abundance, lifetime and absorption properties. CO_2 remains a major driver of human-caused warming despite GWP = 1. Methane has a higher GWP over 20 years than over 100 years because much of its influence occurs relatively early.

100-year GWP values, timescales and CO2 equivalents: US EPA, Understanding GWPs.
CFC ranking among syllabus examples: College Board APES CED, STB-4.D.1.
Abundance, lifetime and heat absorption: US EPA, Overview of Greenhouse Gases.

Scope: College Board APES CED, Topic 9.3, STB-4.C and STB-4.D, p. 184.