Air Pollution and the Environment

Matthew Williams • Chemistry • May 15, 2026

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Human activity, primarily the combustion of fossil fuels, has changed the composition of the atmosphere in ways that drive three linked environmental problems: climate change, acid rain, and ozone depletion. Understanding the chemistry behind each is required for CSEC and increasingly relevant to the world these topics describe.

Composition of Clean Air

Clean, dry air is approximately:

Gas	Percentage by volume
Nitrogen (N_2)	~78%
Oxygen (O_2)	~21%
Argon and other noble gases	~1%
Carbon dioxide (CO_2)	~0.04%

Variable components — water vapour, dust, and pollutants — are not included in these figures.

Air Pollution

That is clean air. Combustion and industry have added significant amounts of other substances, each with its own sources and effects.

Pollutant	Sources	Effects
Carbon monoxide (CO)	Incomplete combustion (cars, gas appliances)	Binds haemoglobin; fatal in enclosed spaces
Sulfur dioxide (SO_2)	Burning fossil fuels containing sulfur; volcanic eruptions	Causes acid rain; respiratory irritant
Oxides of nitrogen (NO_x)	High-temperature combustion in engines	Cause acid rain; contribute to smog

Carbon dioxide (CO_2)	All combustion, deforestation, respiration	Greenhouse effect; climate change
Chlorofluorocarbons (CFCs)	Refrigerants, aerosols (now banned in most countries)	Ozone layer depletion
Particulates / soot	Diesel engines, coal combustion	Respiratory disease; reduces visibility
Unburnt hydrocarbons	Inefficient combustion	Contribute to photochemical smog

Greenhouse Effect and Global Warming

Carbon dioxide is in the table above, but its effect works differently from SO_2 or soot. Rather than causing direct local damage, it gradually changes how the atmosphere retains heat across the whole planet.

The **greenhouse effect** is a natural process essential for life on Earth. Greenhouse gases (CO_2, methane, water vapour, and others) in the atmosphere absorb infrared radiation emitted by the Earth's surface after it is warmed by sunlight. These gases then re-radiate the energy in all directions, including back toward Earth's surface. Without this effect, Earth's average temperature would be about −18 °C instead of the current +15 °C.

Enhanced greenhouse effect (global warming) results from increasing concentrations of CO_2 and other greenhouse gases from human activity. Consequences include:

- Rising sea levels (thermal expansion of seawater and melting of land ice)
- More frequent and intense extreme weather events
- Shifts in climate zones affecting agriculture
- Loss of polar ice and associated habitat

Main human sources of CO_2; burning fossil fuels (coal, oil, natural gas) and deforestation (fewer trees means less CO_2 is absorbed by photosynthesis).

Acid Rain

Sulfur dioxide and nitrogen oxides have a more direct and faster effect: they dissolve in rainwater and make it acidic.

Sulfur dioxide and nitrogen oxides dissolve in rainwater to form acids. Normal, unpolluted rain has a pH of about 5.6 (slightly acidic due to dissolved CO_2 forming carbonic acid). Acid rain can have a pH as low as 4 or below.

$$SO_2 + H_2O \rightarrow H_2SO_3 \quad \text{(sulfurous acid)}$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad \text{(sulfuric acid)}$$

$$2NO_2 + H_2O \rightarrow HNO_3 + HNO_2 \quad \text{(nitric and nitrous acids)}$$

Effects of acid rain:

- Damages and kills trees and plants (leaches nutrients from soil)
- Acidifies lakes and rivers, killing fish and aquatic life
- Corrodes limestone buildings, concrete, and metal structures (statues and monuments)

Catalytic converters in cars convert harmful exhaust gases to less harmful ones before they leave the exhaust pipe:

$$2CO + 2NO \rightarrow 2CO_2 + N_2$$

Unburnt hydrocarbons are also oxidised to CO_2 and H_2O. The catalyst is typically a mixture of platinum and rhodium on a ceramic support.

Ozone Layer Depletion

A separate problem plays out much higher up. In the stratosphere, CFCs have been breaking down ozone, which is the gas that filters UV radiation before it reaches the surface.

The ozone layer (O_3) in the stratosphere absorbs harmful ultraviolet (UV) radiation from the sun, protecting living organisms from DNA damage, skin cancer, and cataracts.

CFCs (chlorofluorocarbons) — once widely used in refrigerants and aerosol propellants — rise into the stratosphere and react with ozone in the presence of UV light. Free chlorine radicals break down ozone in a chain reaction:

$$CF_2Cl_2 \xrightarrow{UV} CF_2Cl^\bullet + Cl^\bullet$$

$$Cl^\bullet + O_3 \rightarrow ClO^\bullet + O_2 \quad \text{(ozone destroyed)}$$

One chlorine radical can destroy thousands of ozone molecules before it is deactivated. The **Montreal Protocol** (1987) committed nations to phasing out CFC production. Even so, CFCs

already in the stratosphere continue to damage the ozone layer, particularly over the polar regions (the "ozone hole" over Antarctica).

Green Chemistry

All three problems above came from chemical processes that were never designed with their environmental effects in mind. Green chemistry is the field that tries to prevent this from the start rather than manage the consequences after.

Green chemistry is the design and application of chemical processes that reduce or eliminate the use and generation of hazardous substances during the manufacture and use of chemical products.

Core principles include:

- Using **renewable feedstocks** (plant-derived rather than petroleum-derived)
- Designing processes that produce **little or no waste** (atom economy)
- Replacing **toxic reagents** with safer alternatives
- Using **catalysts** rather than stoichiometric reagents (a catalyst is reused; a stoichiometric reagent is consumed)
- Designing products that are **biodegradable** after use

Green chemistry represents a shift in how chemists think: rather than disposing of hazardous waste safely after it is made, the goal is to design processes that do not generate hazardous waste in the first place.