# Air pollution: follow the pathway

Air pollution involves gases or suspended particles at levels that can cause harm. Identify the substance, where it comes from, whether it changes in the atmosphere, and what it affects.

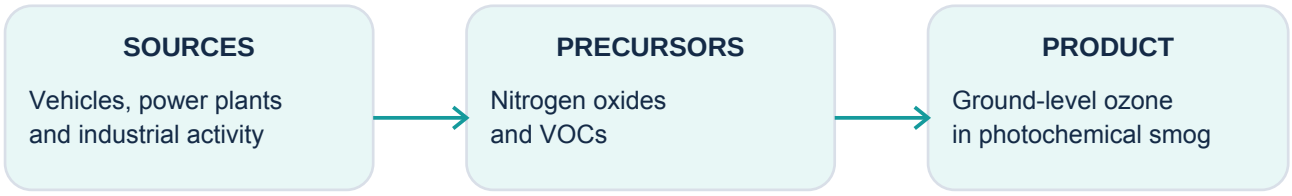
### PRIMARY: EMITTED DIRECTLY

Released from a source into air.
Examples: carbon monoxide in exhaust; sulfur dioxide from burning sulfur-containing fuel.

### SECONDARY: FORMED IN AIR

Produced by atmospheric reactions.
Examples: ground-level ozone; nitric acid; sulfate and nitrate particles.

## 1. EXAMPLE: EMISSIONS CAN BECOME NEW POLLUTANTS




Atmospheric reactions occur in sunlight. VOCs are volatile organic compounds; they include many hydrocarbon vapors. This is a pathway diagram, not a balanced chemical equation.

## 2. PRIMARY AND SECONDARY DESCRIBE ORIGIN

Soot emitted from an engine is primary particulate matter. Sulfate particles formed later from sulfur dioxide are secondary particulate matter. The same broad pollutant category can contain both types.

## 3. LOCATION MATTERS FOR OZONE

Stratospheric ozone helps absorb harmful ultraviolet radiation. Ground-level ozone is a pollutant that can harm lungs and vegetation. The molecule is $O_3$ in both places; its role depends on location.

Ozone formation and atmospheric location: US EPA, Ground-level Ozone Basics.
Direct and secondary particles: US EPA, Particulate Matter Basics.
Nitrogen oxides and acid formation: US EPA, Basic Information about NO2.

Scope: College Board AP Environmental Science CED, Topic 7.1, p. 140.

# Match each pollutant to its effects

Fuel combustion can release several pollutants at once. Their identities and amounts depend on the fuel, combustion conditions and emission controls; their effects are not interchangeable.

### 1. SULFUR DIOXIDE: SULFUR IN THE FUEL

Burning sulfur-containing coal or petroleum fuels, including diesel with sulfur impurities, releases $SO_2$. Power plants and industrial facilities are important sources. $SO_2$ irritates airways and can contribute to acid deposition and secondary particles. Volcanoes are a natural source.

### 2. NITROGEN OXIDES: COMBUSTION PRECURSORS

Combustion in engines and power plants releases nitrogen oxides. $NO_2$ can irritate the respiratory system. Atmospheric reactions involving $NO_x$ help form ground-level ozone, nitrate particles and nitric acid ($HNO_3$), linking emissions to smog, haze and acid deposition.

### 3. CARBON MONOXIDE (CO): LESS OXYGEN DELIVERY

Incomplete combustion of carbon-containing fuel can produce carbon monoxide, a colorless, odorless gas. Vehicles and other fuel-burning equipment are sources. CO reduces the blood's ability to deliver oxygen to organs. Do not confuse CO with carbon dioxide ($CO_2$): they have different properties and major environmental effects.

### 4. PARTICULATE MATTER (PM): NOT JUST VISIBLE SMOKE

PM is a mixture of solid particles and liquid droplets suspended in air. Sources include combustion, fires, road dust and construction, as well as atmospheric reactions. $PM_{2.5}$ describes fine particles generally no more than 2.5 micrometers in diameter. Fine particles can penetrate deeply into lungs, some can enter the bloodstream, and they can reduce visibility.

Sulfur sources, respiratory effects and acid deposition: US EPA, Sulfur Dioxide Basics.
Nitrogen oxides, ozone and acids: US EPA, Basic Information about NO2.
Carbon monoxide and oxygen transport: US EPA, Carbon Monoxide Basics.
Particle composition, size and effects: US EPA, Particulate Matter Basics.

Scope: College Board AP Environmental Science CED, Topic 7.1, p. 140.

# Sources, controls and evidence

Connect a specific source to a specific pollutant and effect. A fuel change or emission control may reduce one pollutant without eliminating every environmental impact.

## 1. COAL COMBUSTION: A MIXTURE OF EMISSIONS

Burning coal can release $CO_2$, $SO_2$, nitrogen oxides, particulate matter and toxic metals such as mercury. Added $CO_2$ contributes to climate warming; particles and irritating gases affect air quality. Mercury can enter ecosystems and food webs. Removing particles from exhaust does not automatically remove $CO_2$.

## 2. LEAD (Pb): AN EXAMPLE OF SOURCE CONTROL

Lead is a toxic metal that can harm the nervous system, particularly children's development. Under the Clean Air Act, EPA controls on lead, including its removal from motor-vehicle gasoline, helped dramatically reduce airborne lead in the United States. This did not remove all sources: metal processing and aircraft using leaded aviation fuel can still emit lead.

## 3. HUMAN AND NATURAL SOURCES CAN OVERLAP

Vehicles, power plants and industry are human sources. Volcanic gases, windblown dust and wildfire smoke can also pollute air. Natural origin does not guarantee safety. A source label alone is not enough: identify the pollutant and the exposure it creates.

## 4. EXTENSION: TEST A CLAIM WITH COMPARABLE DATA

To investigate whether a control reduces nearby PM, compare repeated measurements before and after installation at the same location, with a comparison site if possible. Keep sampling method and duration consistent; record wind and operating conditions. A lower reading on one windy day may reflect dilution rather than a lower emission rate.

Coal emissions, climate and mercury: US EIA, Coal and the Environment.
Lead sources, health effects and regulatory progress: US EPA, Lead Air Pollution Basics.
Natural sulfur emissions: US EPA, Sulfur Dioxide Basics.
Particle sources and atmospheric formation: US EPA, Particulate Matter Basics.

Scope: College Board AP Environmental Science CED, Topic 7.1, p. 140.