



7.2 SMOG AND THERMAL INVERSIONS

College Board Topics 7.2 and 7.3

Related Reading page 463 - 468

Learning Objectives and Essential Knowledge

ENDURING UNDERSTANDING

STB-2

Human activities have physical, chemical, and biological consequences for the atmosphere.

LEARNING OBJECTIVE

STB-2.B

Explain the causes and effects of photochemical smog and methods to reduce it.

SUGGESTED SKILL

 *Data Analysis*

5.B

Describe relationships among variables in data represented.

ESSENTIAL KNOWLEDGE

STB-2.B.1

Photochemical smog is formed when nitrogen oxides and volatile organic hydrocarbons react with heat and sunlight to produce a variety of pollutants.

STB-2.B.2

Many environmental factors affect the formation of photochemical smog.

STB-2.B.3

Nitrogen oxide is produced early in the day. Ozone concentrations peak in the afternoon and are higher in the summer because ozone is produced by chemical reactions between oxygen and sunlight.

STB-2.B.4

Volatile Organic Compounds (VOCs), such as formaldehyde and gasoline, evaporate or sublime at room temperature. Trees are a natural source of VOCs.

STB-2.B.5

Photochemical smog often forms in urban areas because of the large number of motor vehicles there.

STB-2.B.6

Photochemical smog can be reduced through the reduction of nitrogen oxide and VOCs.

STB-2.B.7

Photochemical smog can harm human health in several ways, including causing respiratory problems and eye irritation.

ENDURING UNDERSTANDING

STB-2


Human activities have physical, chemical, and biological consequences for the atmosphere.

LEARNING OBJECTIVE

STB-2.C

Describe thermal inversion and its relationship with pollution.

SUGGESTED SKILL

 *Visual Representations*

2.C

Explain how environmental concepts and processes represented visually relate to broader environmental issues.

ESSENTIAL KNOWLEDGE

STB-2.C.1

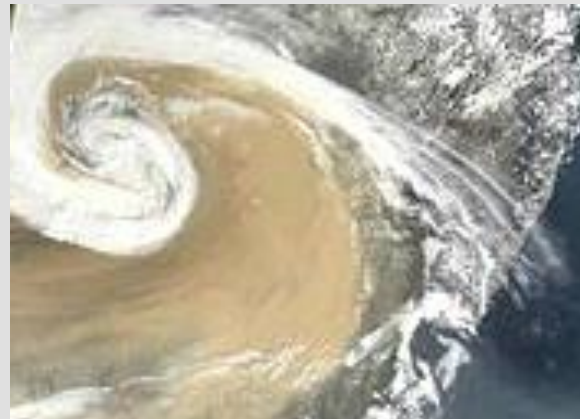
During a thermal inversion, the normal temperature gradient in the atmosphere is altered as the air temperature at the Earth's surface is cooler than the air at higher altitudes.

STB-2.C.2

Thermal inversion traps pollution close to the ground, especially smog and particulates.

Industrializing nations suffer increased air pollution

- Industrializing countries promote economic growth, with little environmental regulation.
 - Proliferation of manufacturing and power plants, along with increased automobile use (1500 new cars /day in Beijing), during this stage of development lead to increasing air pollution.
 - Air quality problems have been especially severe in Asia. China and India, and their large populations, have industrialized, fueled mainly by low grade coal.
- Has resulted in the formation of the **Asian Brown Cloud**.
 - A 2 mile thick haze of pollution over southern Asia which forms annually during the dry season.
 - Reduces sunlight reaching Earth's surface by 10-20% and contributes to thousands of premature deaths each year.
- **Smog** is an unhealthy mixture of air pollutants which typically form over urban areas.
 - **Industrial "Sulfurous" smog** forms primarily as a result of unregulated coal burning from industry and electricity production.
 - **Photochemical Smog** forms primarily as a result of automobile exhaust during hot, sunny weather.

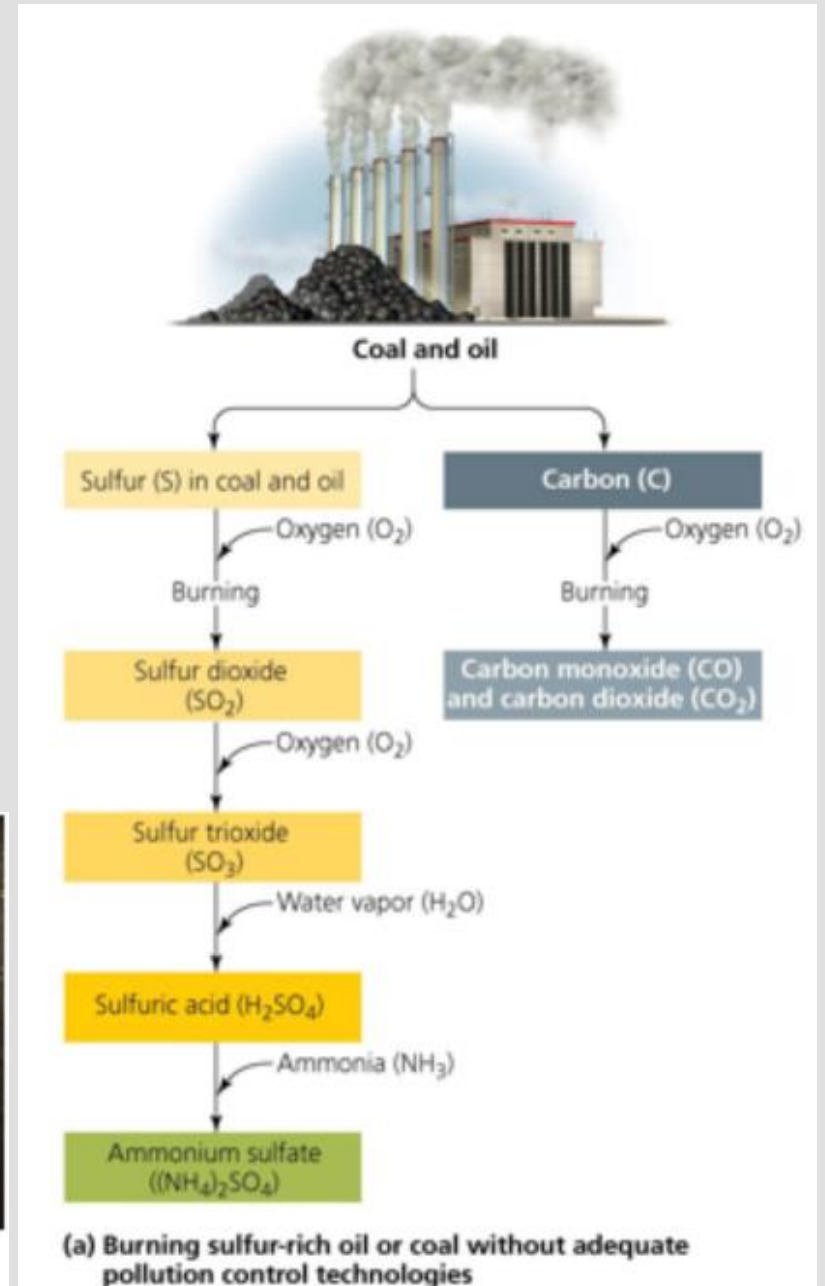


Smog poses health risks

- **Industrial smog** is smog created by combustion of coal and crude oil, especially coal.
 - Carbon monoxide, sulfur dioxide, nitrogen dioxide, and particulate matter are produced.
 - Sulfur reacts with water vapor to form sulfuric acid which condenses on particulate matter to form the aerosolized particles which are the main component of sulfurous smog.
 - Nitrogen compounds also contribute.
- Industrial smog combined with a thermal inversion killed 21 and sickened 6000 people in Donora, PA in 1948.
- Industrial smog is now rare in most developed nations, but a growing concern in industrializing nations.



(b) Donora, Pennsylvania, at midday in the 1948 smog event

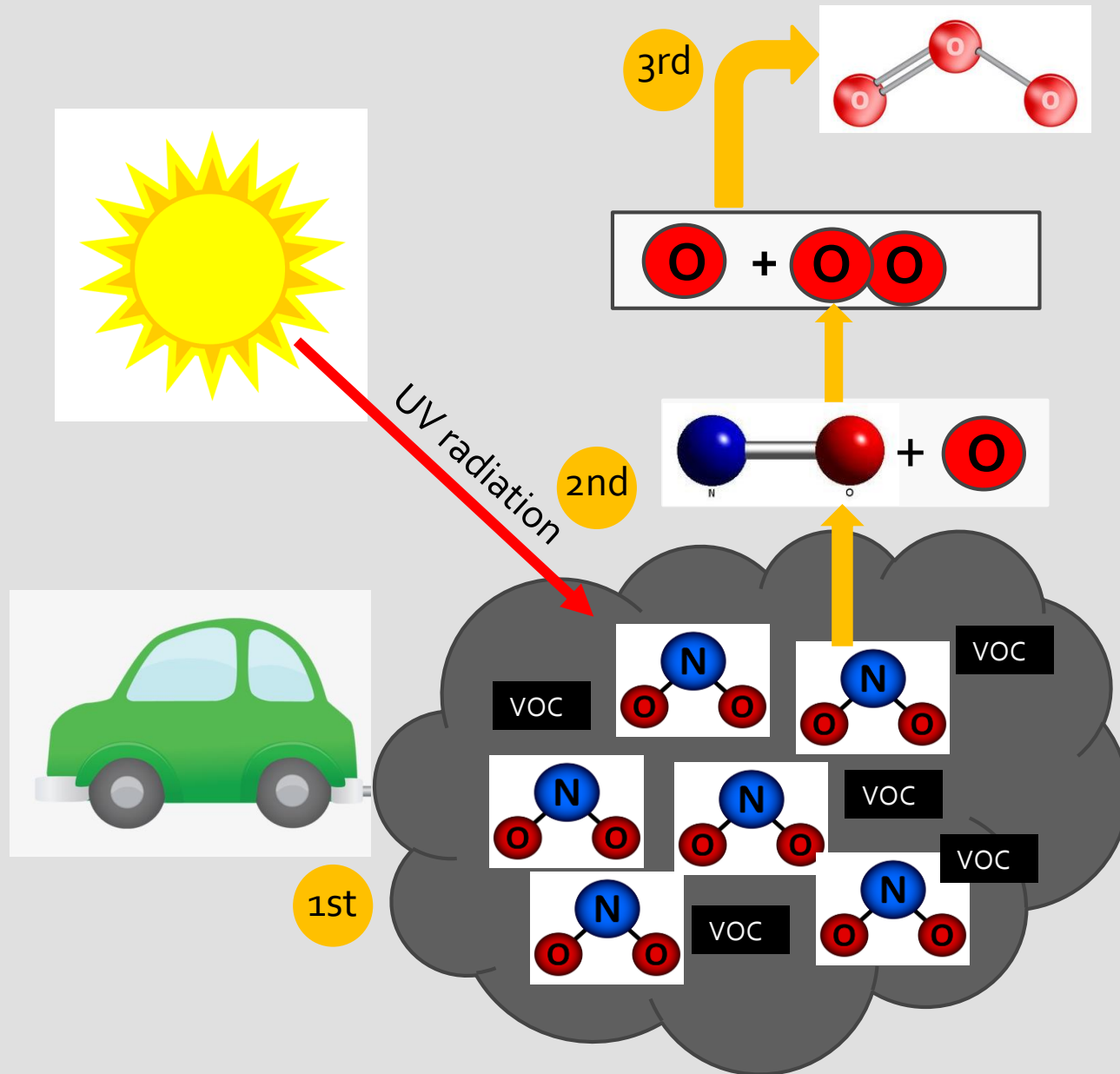


Photochemical Smog

- **Photochemical smog** is smog produced when sunlight drives a series of reactions involving primary pollutants.
 - The primary pollutants most responsible for photochemical smog are **Nitrogen Dioxide (NO₂)**, **Volatile Organic Compounds (VOC's)** and **Carbon Monoxide (CO)**
 - NO₂ results primarily from combustion of gasoline in engines.
 - Nitrogen (N₂) and oxygen (O₂) are the two most abundant gases in the atmosphere
 - Normally they are stable and do not react with each other.
 - Under the high temperatures of a cars engine or during electricity production in a power plant, O₂ and N₂ react to form NO₂ as follows:
 - $N_2 + O_2 \rightarrow 2NO$
 - $2NO + O_2 \rightarrow 2NO_2$
 - VOC's are carbon-based chemicals that volatilize (evaporate) easily.
 - Numerous chemicals classified as VOC's are produced by gasoline vapors, combustion of gasoline, dry cleaning, petrochemical and plastic manufacturing, as well as natural sources such as pine trees.



Photochemical Smog forming primary pollutants



Photochemical Smog and the formation of tropospheric O_3

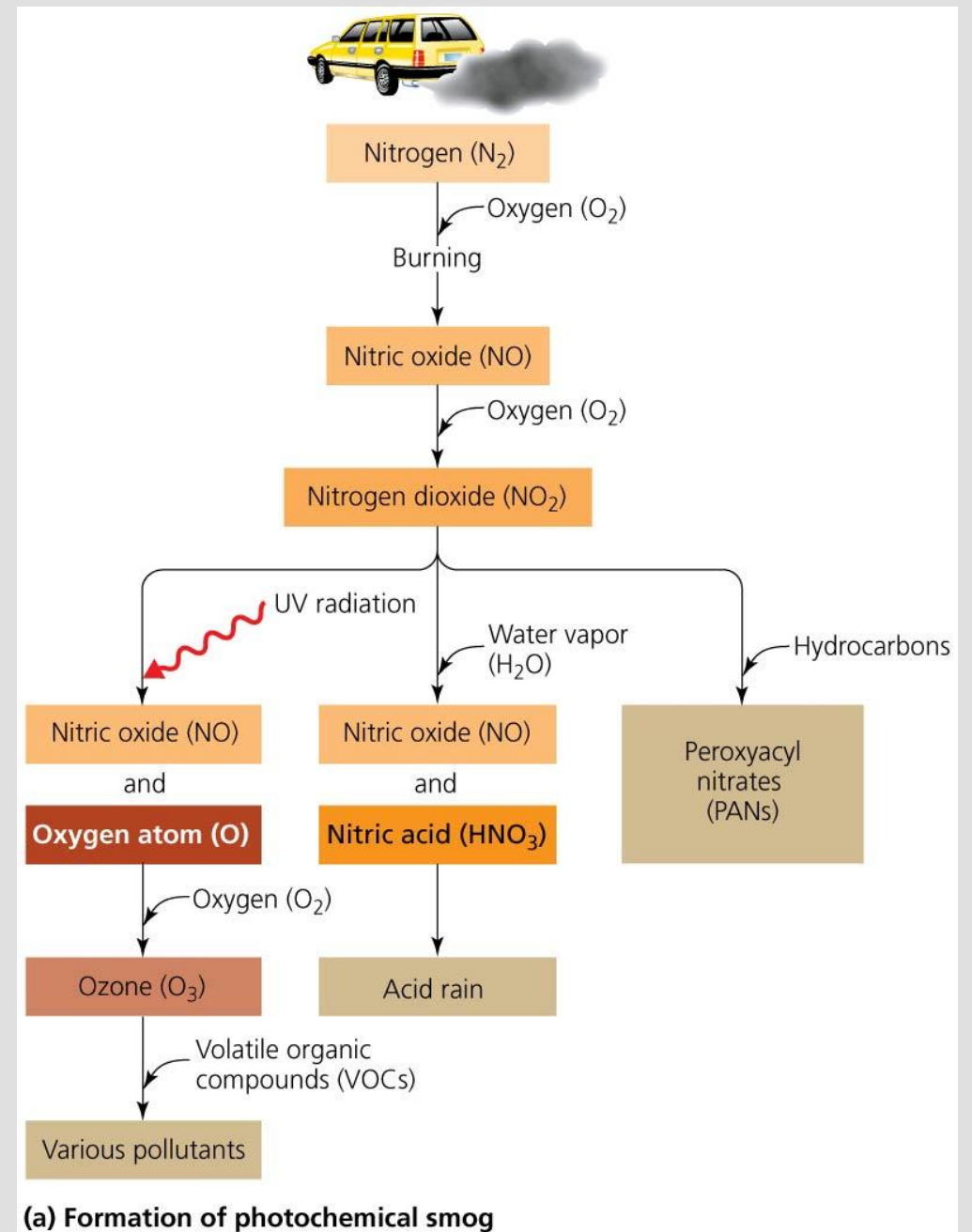
- 1st:** Exhaust from morning traffic releases NO_2 and VOC's
- 2nd:** Day time temperatures rise, splitting NO_2 to form NO and O
- 3rd:** The O atom reacts with O_2 to form O_3 (*tropospheric or ground-level ozone*)
- 4th:** By now, the afternoon commute is beginning and NO_2 and VOC levels increase further, as O_3 peaks.

Photochemical Smog also contains Nitric Acid and PAN's

- Nitrogen Dioxide (NO_2) from exhaust also reacts with water vapor in the air (or which results from combustion) to form additional molecules of NO and **Nitric Acid (HNO_3)**

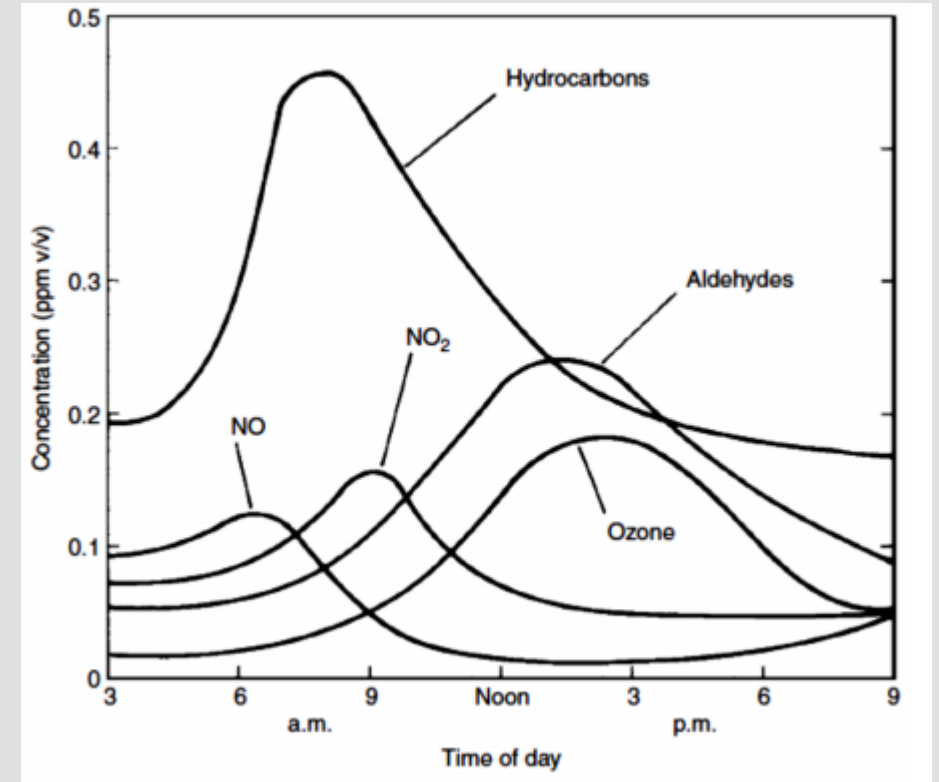


- NO_2 also reacts directly with the VOC's produced during combustion to produce **peroxyacyl nitrates (PAN's)**
 - PAN's are powerful eye and respiratory irritants, causing irritation at only a few parts per billion (ppb).
 - At higher concentrations, PANS cause significant damage to vegetation.
 - PAN's are very stable and persist in the atmosphere.



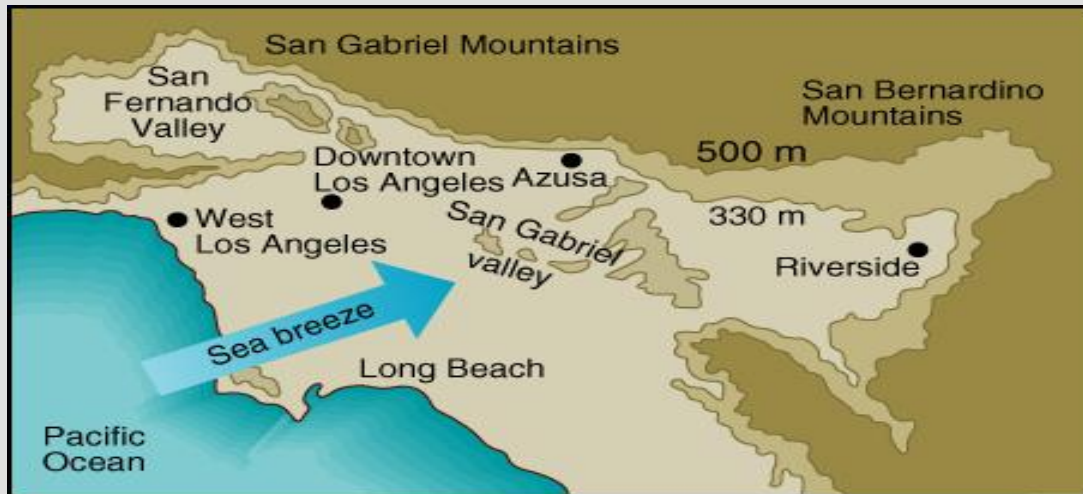
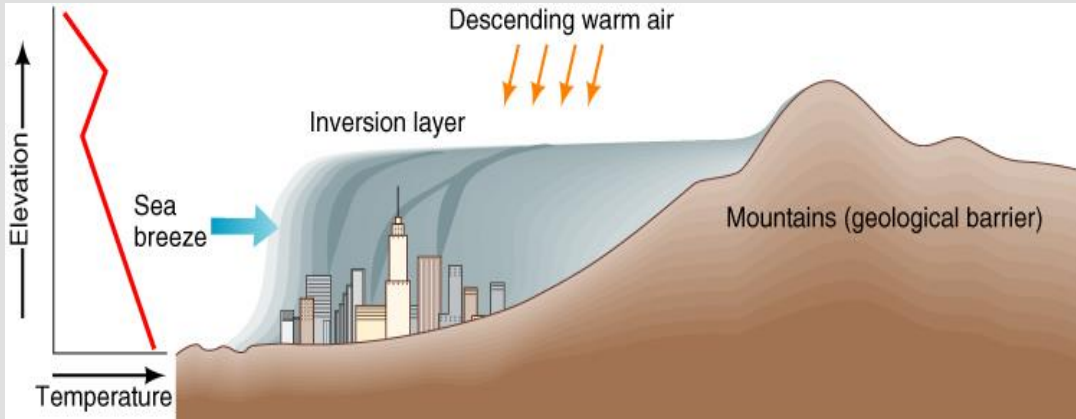
A Summary of Photochemical Smog

- Conditions that increase smog
 - Traffic releasing NO_2 and VOC's
 - Sunlight (\uparrow intensity and \uparrow duration)
 - Summer afternoons in warm climates, especially urban areas (urban heat island effect)
- Primary Pollutants (precursors)
 - NO_2 and VOC's, as well as CO and PM
- Secondary Pollutants
 - Tropospheric Ozone (O_3)
 - Ozone is the criteria pollutant of the Clean Air Act that is most often exceeded.
 - Ozone in the troposphere is harmful to the environment and human health. Ozone in the stratosphere is required for life on Earth.
 - Nitric Acid (HNO_3)
 - Peroxyacyl nitrates (PAN's)



- Ozone levels decrease overnight without sunlight to drive these photochemical reactions, but may not return completely to previous levels.
 - Smog events often lead to deteriorating air quality over several days, before weather patterns shift and allow pollutants to fully dissipate.

Inversion layers amplify ground level pollution



- Under most conditions, air in the troposphere becomes cooler as air rises.
- **Thermal Inversion layers** form when cold air gets trapped beneath a layer of warm air.
 - Thermal inversions trap pollution close to the ground, especially particulate matter and smog.
 - As a result, concentrations of pollutants increase during a thermal inversion.
- Coastal Inversion (Ex: Los Angeles)
 - Air over land heats faster than air over the ocean. (land radiates more heat, warming the air faster)
 - Cool ocean air blows onshore, under the layer of warm air.
 - Coastal mountains can prevent the cool, ocean air from spreading inland.
- Mountain Inversion (Ex: Salt Lake City)
 - Cold air sinks into valleys at night.
 - When a warm front approaches, it moves over the top of the mountains, capping the cold air trapped in the valley.

Impacts of Smog

• Environmental

- Particulate matter in smog reduces sunlight reaching the ground; limiting photosynthesis.
- O_3 produced during photochemical smog enters stomata and is a strong oxidizers; interferes with photosynthesis and cellular respiration.
- H_2SO_4 from industrial smog and HNO_3 from photochemical smog result in acid deposition.

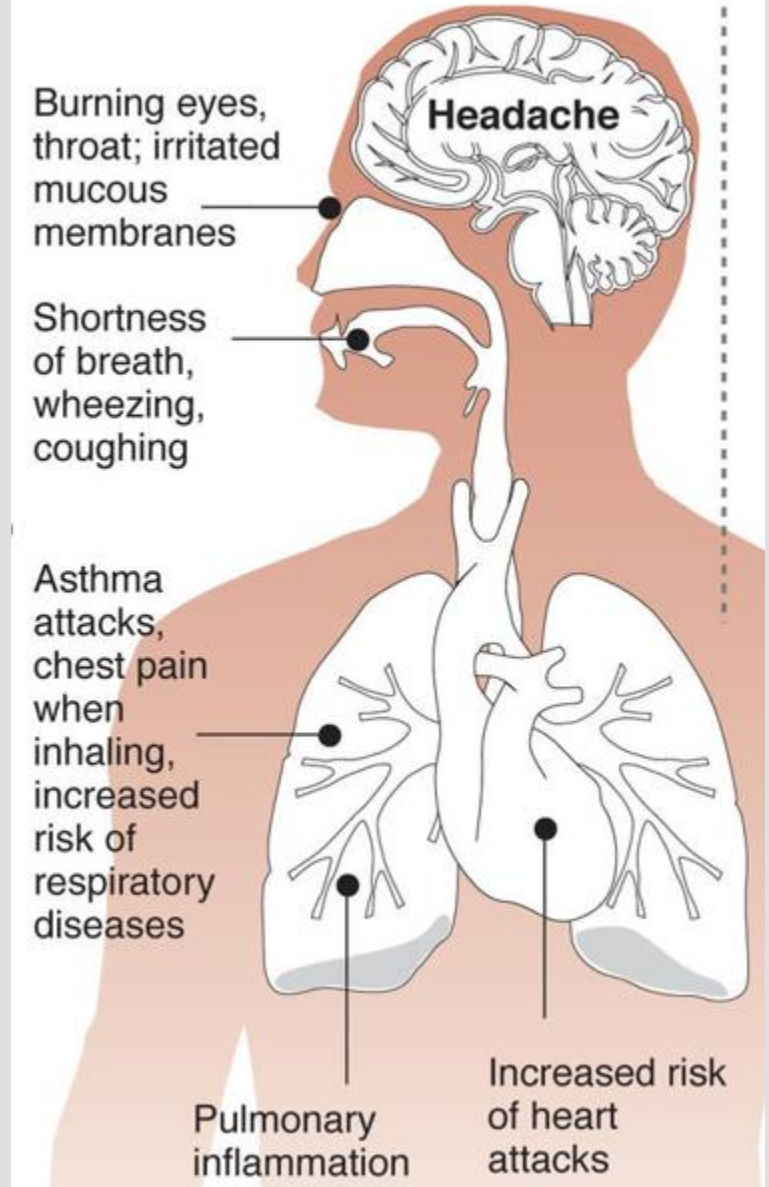
• Human Health

- PAN's and O_3 are eye and respiratory irritants; causing or worsening asthma, bronchitis, COPD, pneumonia.

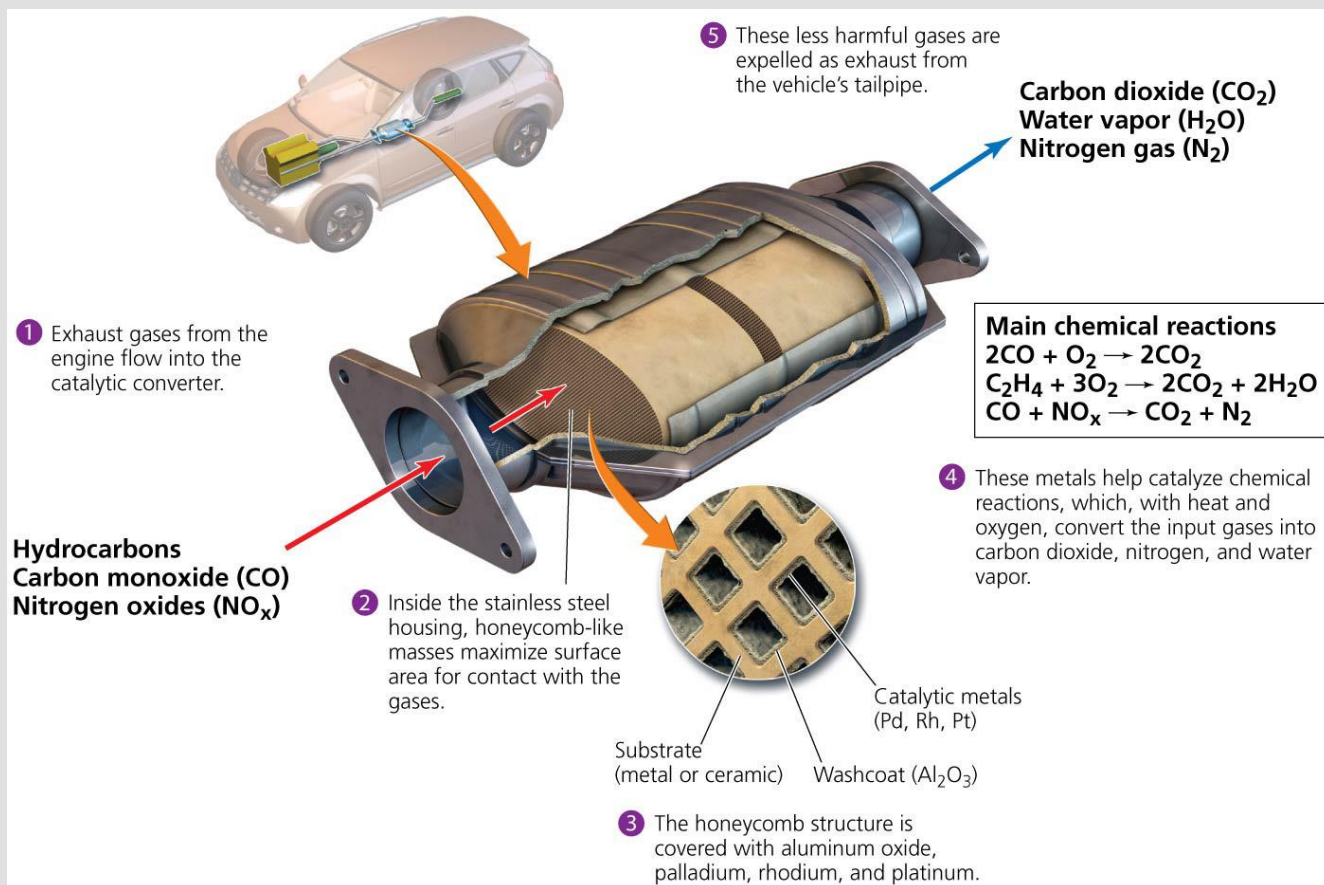
• Economic

- Increased health care costs for chronic and acute respiratory conditions.
- Lost productivity due to missed work days.
- Decreased agricultural yields.

Effects on health



Reduction of Smog



• Vehicles

- New cars emit 1% of the smog forming emissions a 1960's car did.
- Reduce the number of vehicles, especially older vehicles, on the road (improve/increase public transit, car pool, bike, create walkable cities through urban planning, "Cash-for-Clunkers").
- Require *vapor recovery nozzles* on gas pumps.
- Require vehicle emission control equipment such as *catalytic converters*.
- Smog inspection required to register vehicles in some states.

• Electricity and Energy generation

- Convert to natural gas power plants instead of coal. (good)
- Increase electricity production from renewable sources. (better)
- Practice energy conservation. (best)

Video Resources

- Bozeman Science "Air Pollution"
 - https://www.youtube.com/watch?v=_dTvtlctgk&t=1s
- National Geographic "Air Pollution 101"
 - <https://www.youtube.com/watch?v=e6rglsLy1Ys&t=1s>
- Ted Ed: "The Science of Smog"
 - <https://www.youtube.com/watch?v=CdbBwlgq4rs>
- "With Every Breathe We Take; The Health Effects of Smog"
 - <https://www.youtube.com/watch?v=4oKL33ZAs9Q&t=4s>
- "Clearing California Skies"
 - <https://www.youtube.com/watch?v=k2Ra8PRtXSU&t=1s>