# Air Pollution Learning Module

*Figure 1. Air pollution in Hong Kong.*

Source

Understanding and monitoring air quality is essential to atmospheric scientists to help reduce emissions, protect human health and the environment. In this learning module, we will learn about air pollutants, their sources, and the effects on the environment and our respiratory systems.

## Composition of the Atmosphere

The air is made up of many different gases. To give you an idea of what air actually consists of watch this video!

**Composition of Air** (2:37 – 6:33)

The first, **nitrogen**, is the largest constituent of the atmosphere. If the air were made of 1000 parts, nitrogen would call for 780 parts, or 78%. Nitrogen is really important to us because it helps plants to gain minerals from the soil for plant growth. The next most common gas that is in air is **oxygen**. Oxygen makes up 209, or 20.9% of our air. Oxygen is important for many things. We need it to breath, but it is also needed for fires. The only problem is with oxygen, if you have too much of it, oxygen is extremely reactive. Things could combust if you have an oxygen-rich environment, so having the nitrogen in our air balances it out and gives us the right percentage of oxygen and nitrogen together to make air safe to breath and be around.

The next gas in the air is called **argon**. Argon does not do much for us in the atmosphere, but we have 9 parts, or 0.9% in the air. Argon is a gas that can be placed in a tube with an electric current to create a purple hue in a neon sign. Next, we have a gas that we hear a lot about these days, which is **carbon dioxide**. This gas is one of the trace gases and is found in small concentrations in the atmosphere. Carbon dioxide is a gas that we exhale when we breathe. It is also taken in by plants to create the plant's structure. Recall from the temperature learning module that carbon dioxide is a greenhouse gas and allows incoming solar radiation to pass through the atmosphere, but traps outgoing or reflected sunlight to cause a warming effect in our atmosphere. **Trace gases**, including carbon dioxide, make up 1 part, or 0.1% of the air. Other trace gases include ozone, nitrous oxide, methane, helium, neon, water vapor, and several others.

Created by Tyra Brown, Nicole Riemer, Eric Snodgrass and Anna Ortiz at the University of Illinois at Urbana-Champaign. 2015-2016. Supported by the National Science Foundation CAREER Grant #1254428.

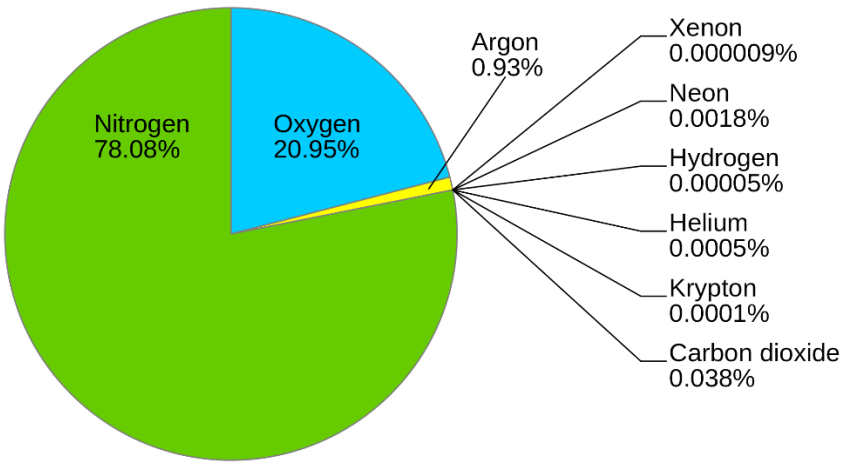



*Figure 2. Composition of the Atmosphere*

Source

**Video Lecture Notes** [1]

- 99% of our atmosphere is made of oxygen ($O_2$) at 21% and 78% nitrogen ($N_2$). These gases are transparent to both visible light from the sun and thermal infrared light from the earth.
- **Greenhouse gases**, like water vapor, carbon dioxide and methane, are vitally important for keeping our planet warm.
- Although these gases are found in small concentrations, they are vitally important in maintaining a globally averaged temperature of 59°F.

## Pollutants

When we think of air pollution today, we think of cities like Beijing. In Figure 3, you can see a view of the city before and after it rained, which removed a lot of the pollution from the atmosphere. These pollutants have adverse health effects. In London in 1952, they had the Great Smog of 1952. It was difficult to see and thousands of people died, which led to legislation to reduce the pollution. We had the same problems in North America.

**Air Pollution** (9:24)

*Figure 3. Beijing before (left) and after (right) rain.*

Source

So, what is air pollution? It is not only chemicals in the atmosphere, but chemicals that have bad health effects. Since we are breathing it in, it is going to affect our lungs and can lead to increased cancer risks.

So if they are affecting us negatively, we call them pollutants. The following are **primary pollutants**, which means they are emitted directly into the atmosphere by a particular source.

**Primary Pollutants**

- **Volatile organic compounds (VOCs)** such as gases from evaporating gasoline.
- **Carbon monoxide (CO)**, which is an odorless gas that is produced by combustion.
- **NOx**, which includes nitric oxide (NO) and nitrogen dioxide ($NO_2$).
- **Sulfur dioxide ($SO_2$)**, which is produced through the combustion of coal.
- **Particulate matter (PM)**, which are small suspended particles.
- **Lead**, which we used to add to our gasoline.

Primary pollutants can combine with other chemicals in the atmosphere and produce **secondary pollutants**.

**Secondary Pollutants** [1]

- NOx can produce **nitric acid ($HNO_3$)**.
- Sulfur dioxide ($SO_2$) can produce **sulfuric acid ($H_2SO_2$)**.
- **Ozone ($O_3$)**, which is produced through chemical reactions between nitrogen dioxide, VOCs, and sunlight.

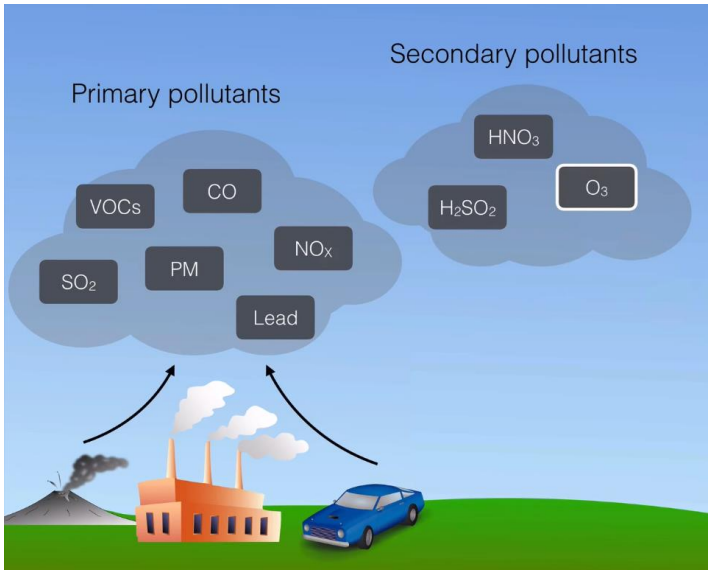



*Figure 4. Primary and secondary pollutants.*

Source

Ozone can be helpful or harmful to our health and the environment. In the stratosphere, ozone is produced naturally to block harmful ultraviolet rays from the sun [1]. This is an example of "good" ozone. In the troposphere, ground-level ozone largely contributes to smog. This is "bad" ozone.

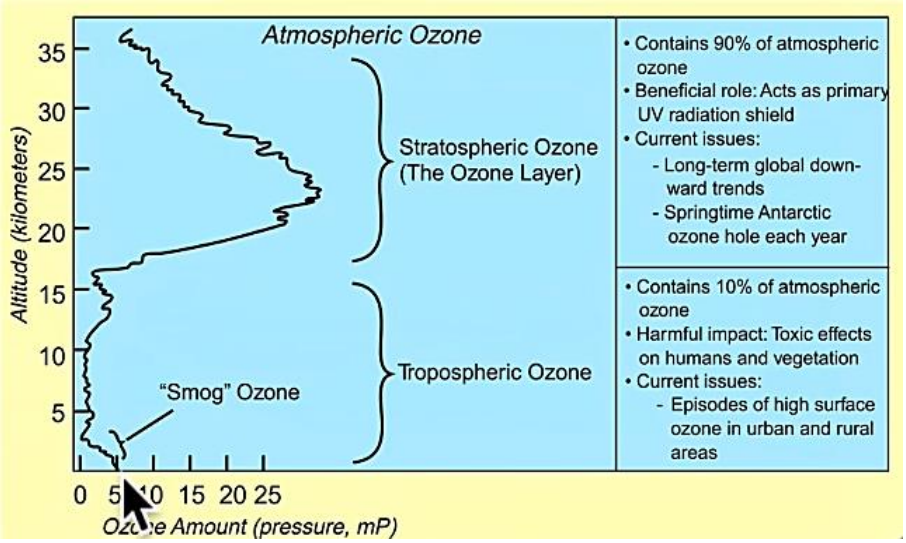



*Figure 5. A vertical profile showing atmospheric ozone, which includes tropospheric and stratospheric ozone.*

Source

## Aerosols

Trillions of tiny particles are floating in the air. Volcanic eruptions, wildfires, sandstorms, and other natural causes are sources of those tiny particles [4]. There are also be man-made sources such as controlled burning, car exhaust fumes, and industrial pollution. These particles in our earth's atmosphere are called **aerosols**. To learn more, watch this next video!

**Aerosols** (1:38)

Our weather, climate, the whole thermal state of our planet, and of course our health is influenced by aerosols [1]. Satellites continuously provide us with massive amounts of aerosol data, which need to be processed to provide us with important information about the spatial distribution and concentration of aerosols [4].

*Figure 7. Sources of aerosols including volcanic eruptions (left), wildfires (center), and sandstorms (right)* **4**.

Source

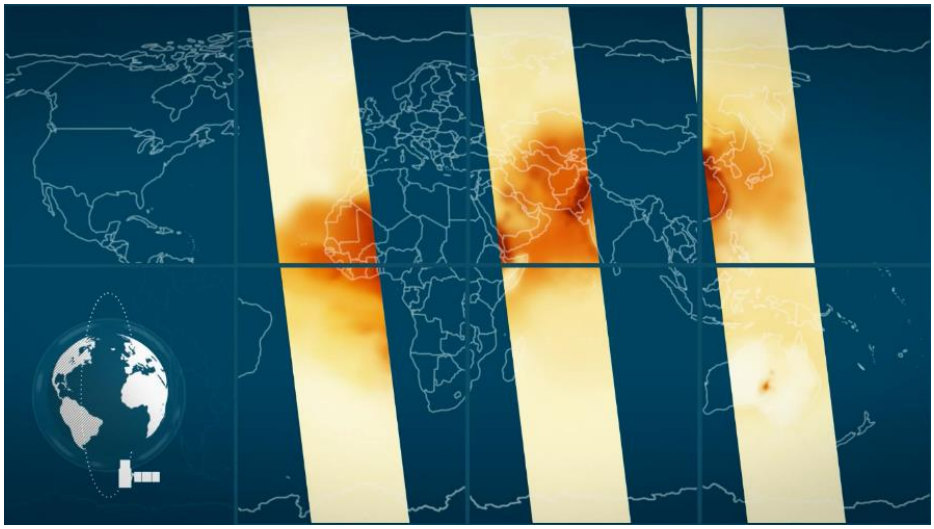


*Figure 8. Satellite data of aerosols across the globe* **4**.

Source

## Sources of Pollution

Where are these chemicals coming from? They can be produced naturally such as from forest fires, volcanoes, and sandstorms. They can also come from stationary sources. You can think of those as industrial such as factories. Finally, we have mobile sources such as cars and buses.

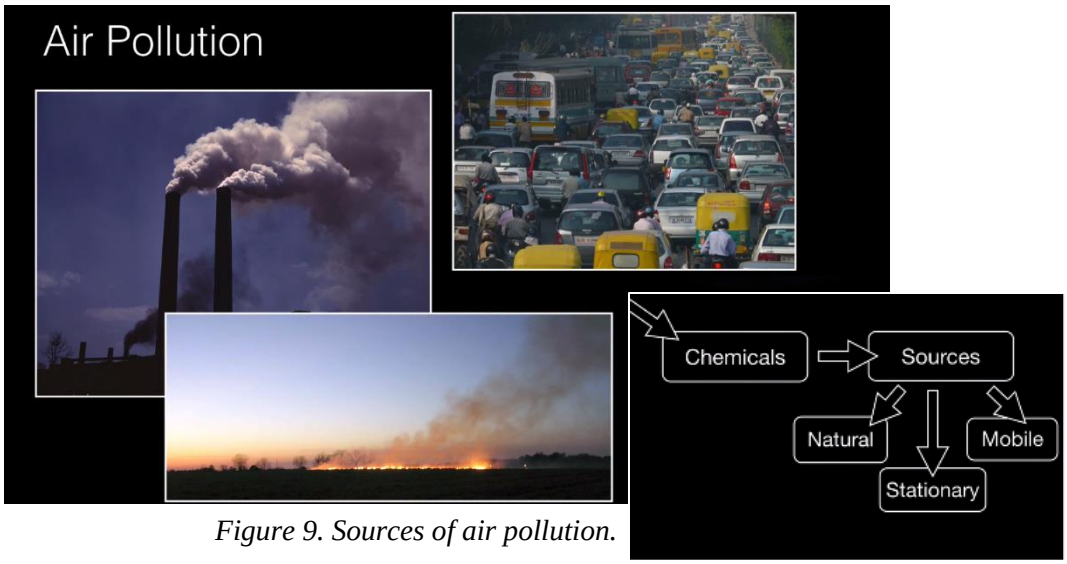



*Figure 9. Sources of air pollution.*

Source

## Improving Air Quality

We can control air pollution through regulation. The **Clean Air Act** (1970) in the United States was able to reduce pollutants and save lives. Technology is able to scrub those pollutants out of the air before it is released. The Clean Air Act put strict standards on certain pollutants so that industries are limited on how many pollutants they can put into the atmosphere **2**.

The Clean Air Act requires the **Environmental Protection Agency (EPA)** to set National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment.

The EPA has set standards for the six **criteria pollutants** which include

1. Carbon Monoxide (CO)
2. Lead (Pb)
3. Nitrogen Dioxide ($NO_2$)
4. Ozone ($O_3$)
5. Particulate Matter (PM)
6. Sulfur dioxide ($SO_2$)

To learn more about the criteria pollutants and the concentrations at which they are considered by the EPA to be unsafe, **click here**.

To restrict the amount of pollutants that are emitted from vehicles into the atmosphere, we can use a device called a **catalytic converter**. This technology grabs onto the nitrogen dioxide and carbon monoxide that is produced during combustion. We can also use **mechanical or electrostatic filters** that produce a gradient and it grabs onto some of these pollutants. Finally, we can use **wet scrubbers**, which bring in polluted air and a mist eliminator grabs onto a lot of those chemicals to remove them from the air [2].

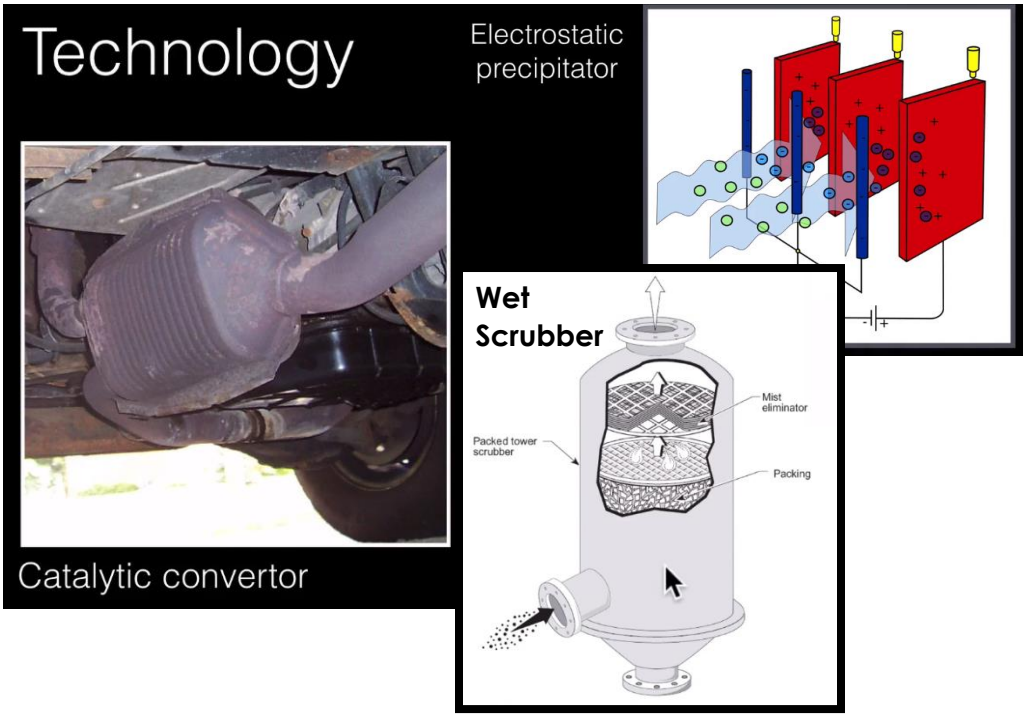



*Figure 10. Technology to reduce air pollution including a catalytic converter for vehicles, an electrostatic precipitator, and a wet scrubber.*

Source

## Air Quality Index

The **Air Quality Index (AQI)** is a color-coded scale showing us if the air around us is good, poor, or extremely unhealthy. To learn more about the AQI, watch this next video [2]!

**Air Quality Index** (0:50)

Each color indicates the level of pollutants in the air. Green represents good air quality. When the AQI reaches orange, it is unhealthy for sensitive groups such as children, the elderly, and those with respiratory illness. When it reaches red or higher, the air quality is unhealthy for everyone. The AQI also has a number scale. An AQI value above 100 means sensitive groups need to reduce outdoor activity. When the AQI reaches 150, everyone should go indoors.

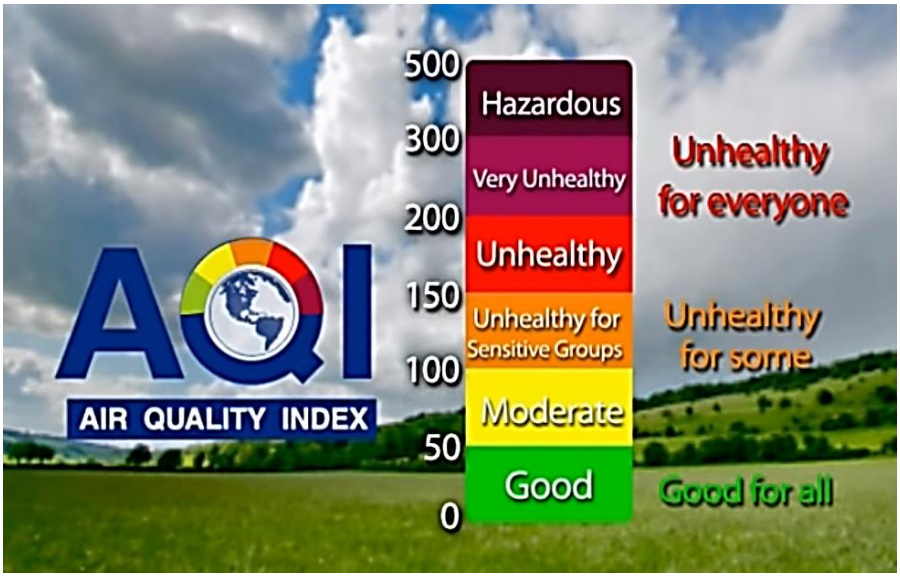



*Figure 11. The color-coded Air Quality Index.*

Source

## Health Effects

When air pollution worsens, it can be harmful to health. Studies show that even small increases in air pollution can cause increases in emergency room visits, hospitalizations, and deaths. In this next video, we will learn about the links between air quality and your health.

**Air Quality and Your Health** (2:12)

Pollution affects our health through our cardiovascular system, just like smoking. It can lead to lung and heart diseases, and increase the risk of cancer. We see health effects most wherever we have industrialization such as places like China. In eastern Europe, there is a huge amount of industrialization and not a lot of regulation.

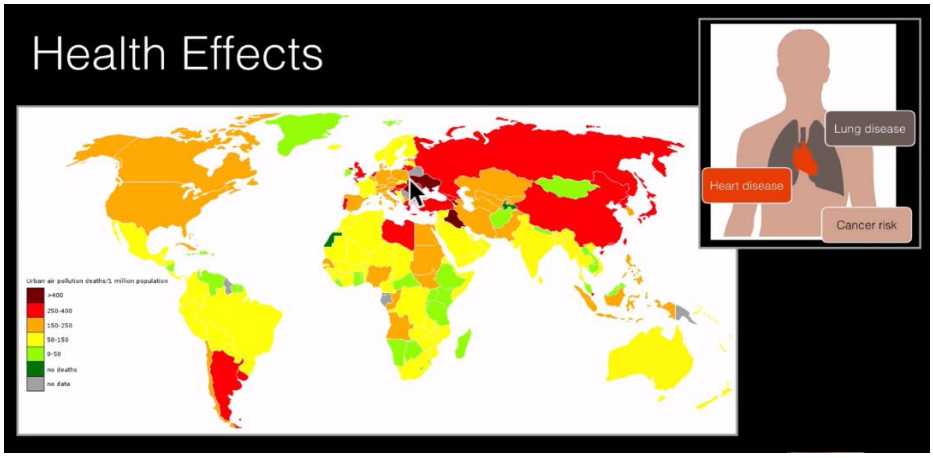



*Figure 12. Global air quality (left) and the health effects associated with poor air quality (right).*

Source

Specifically, particulate matter are small particles that as you breathe them in, the hairs in your nose and respiratory tract do not trap them. PM goes into your lungs and just like smoking, it is stuck there and can lead to other types of diseases. Lead, which we used to add to our gasoline, has huge neurological impacts. Nitrogen and sulfur can lead to nitric acid and sulfuric acid and these contribute to acid rain. Acid rain can dissolve statues, but more importantly, it changes the acidity (or pH) in the food web and can impact living systems.

To learn more about outdoor air quality and how it affects your health, **click here** and find the answers to the following questions!

**Q: How does air pollution affect your health?**

**A**: Air pollution affects your health based on the length of time you are exposed, your health status, and the concentration of pollutants. Air pollution can

- Make it harder to breath.
- Irritate your respiratory system.
- Aggravate asthma symptoms or heart conditions.

**Q: Who is at risk of negative health effects from bad air quality?**

**A**: Everyone. Sensitive groups include newborns and young children, pregnant women, the elderly, and people with pre-existing health conditions.

**Q: Can air pollution affect asthma and allergies?**

**A**: Pollution can make asthma symptoms worse. It can reduce somebody's lung functions, as well as, increase respiratory infections. Pollution can also make children more sensitive to allergens. In fact, people who have asthma need to make sure they manage their asthma much more carefully when air quality is poor.

**Q: How should you make use of the Air Quality Index (AQI) to protect your health?**

**A**: It should be used to plan ahead because it can tell you the best time of day to be outside and when to reduce your outdoor activity. It is also a good reminder of the need to protect the environment. For example, cars are a major source of air pollution and if we reduce driving, we can reduce the number of bad air quality days.

**Q**: **What can you do to protect your health?**

**A**: There are several ways to protect your health including

- Watch for air quality advisories.
- Schedule outdoor activities for early in the day.
- Protect sensitive groups.
- Avoid busy streets when jogging/running outside.

## Reducing Air Pollution

Now that we have learned about all the impacts of poor air quality, let's discuss a few steps that you can take to reduce the amount of pollution that is released into the atmosphere. To learn more about reducing air pollution, **click here** and find the answers to the following questions **2**!

**Q**: **What can you do to reduce your contribution to air pollution?**

**A**: There are several ways to reduce air pollution including

- Carpool, take public transportation, bike or walk.
- Turn down the air conditioner during the summer.
- Avoid using the fireplace during the winter.
- Turn lights off and use low energy bulbs.
- Purchase a fuel-efficient or electric car.

**Q**: **What other things can you do to improve air quality in your community?**

**A**: There are several ways to improve air quality including

- Drive less, walk and bike more, and make use of public transit.
- Encourage development of community walking and biking paths.
- Get involved in planting trees and community gardens.

**Pre-Class Activity** 2, 7

**Instructions**: Before teaching about air pollution, have the students answer the questions below, followed by a question for in-class discussion between you and your students.

1. What is the largest constituent gas of the atmosphere?
    a. Oxygen
    b. Nitrogen
    c. Carbon dioxide
    d. Argon
    e. Ozone

2. Which of the following is not a source of air pollution?
    a. Volcanic eruptions
    b. Dust storms
    c. Hurricanes
    d. Combustion of fossil fuels
    e. Forest fires

3. What does EPA stand for?
    a. Environmental Prediction Association
    b. Environmental Protection Agency
    c. Environmental Pollution Act
    d. Extreme Polluted Air

4. What negative health effects are associated with poor air quality?
    a. Lung disease
    b. Cancer risk
    c. Heart disease
    d. Asthma
    e. All of the above

5. Which of the following is not a primary pollutant?
    a. Particulate matter
    b. Lead
    c. Nitrogen
    d. Carbon monoxide

**Discussion Question**: Air pollution can be harmful to human health and the environment. Discuss some of your everyday activities that cause air pollution and ways to reduce your contribution to air pollution.

**In-Class Activity**

## Part 1. Smog City Activity 2, 3, 4

**Instructions**: **Click here** to learn what controls pollution emissions and our air quality. Follow each step and answer the questions below.

Step 1: Before moving the controls, record the current temperature and air quality index below.

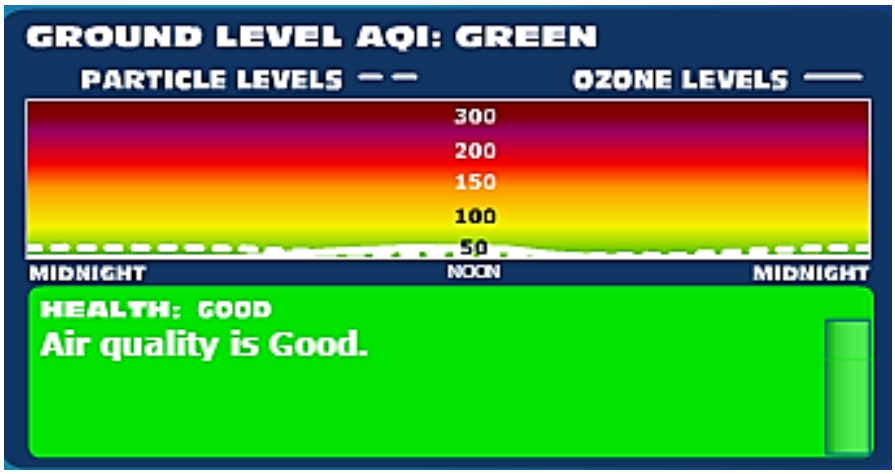
Temp =

AQI =

Step 2: List the 10 controls that affect air quality on the left side of the page.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____
10. _____

At the bottom right of the Smog City 2 Experience, you will see an Air Quality Index (AQI) chart like the one below. The top panel shows the AQI by color and number. The dashed line represents the particle levels by the time of day, and the solid line represents ozone by the time of day.




Step 3: Move the emissions and population controls to the maximum settings. Change the wind speed to calm (far left).

**Questions**

1. What happens to ground-level ozone and particle levels?

2. What time(s) of day would particle pollution levels be the highest?

3. Without altering the weather conditions, how can you reduce particle pollution?

Step 4: Set the temperature to 110°F (far right).

**Questions**

1. What happens to the ground-level ozone and particle pollution?

2. At what time of day would ground-level ozone levels be the highest?

3. Move the population slide. What effect does the population control have on air pollution?

Step 5: Check the Random Events box (lower left). As you use the weather, emissions, and population controls, watch the cityscape for wildfires and dust storms.

**Questions**

1. How do wildfires and dust storms affect air quality?

## Part 2. The Air Quality Index [2]

**Instructions**: **Click Here** to learn more about the current and forecasted air quality in the U.S. Scroll over the colored tabs below the map to review the air quality index (AQI) and finish filling in the table below. Summarize the health effects in one sentence.

| Color | AQI Rating | Health Effects |
|---|---|---|
| Green | Good (0 – 50) | Air quality is considered satisfactory, and air pollution poses little or no risk. |
| | | |
| | | |
| | | |
| | | |
| | | |

Click the 'Current AQI' tab above the map and determine the current state of our air quality. Draw on the map below and label areas where air quality is good, unhealthy, etc.

**Questions**

1. Which states have the highest AQI? Check your answer by clicking on 'Current AQI' under the 'Highest 5' tab below the map.

    1) _____

    2) _____

    3) _____

    4) _____

    5) _____

2. Which regions of the U.S. (i.e., northeast, southwest) have good air quality?

3. Based on what you have learned about how the weather affects air pollution, if the air quality is good, what type of weather conditions would you expect to be present? How about if the air quality is poor? You may use the exercise from Part 1: Smog City to help you answer this question. (Hint: Consider precipitation, clear vs. cloudy days, etc.)

**Air Quality**: Good **Weather Conditions**:

**Air Quality**: Poor **Weather Conditions**:

## Part 3. Supplemental Exercise 5

**Instructions**: Review scientific notation with these practice problems.

The Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards (NAAQS) that restrict the emissions of six criteria pollutants believed to be harmful to human health and the environment (shown below). To learn more about NAAQS, **click here**.

| Pollutant [links to historical tables of NAAQS reviews] | | Primary/ Secondary | Averaging Time | Level | Form |
|---|---|---|---|---|---|
| Carbon Monoxide (CO) | | primary | 8 hours | 9 ppm | Not to be exceeded more than once per year |
| | | | 1 hour | 35 ppm | |
| Lead (Pb) | | primary and secondary | Rolling 3 month average | 0.15 µg/m$^3$ (1) | Not to be exceeded |
| Nitrogen Dioxide ($NO_2$) | | primary | 1 hour | 100 ppb | 98th percentile of 1-hour daily maximum concentrations, averaged over 3 years |
| | | primary and secondary | 1 year | 53 ppb (2) | Annual Mean |
| Ozone ($O_3$) | | primary and secondary | 8 hours | 0.070 ppm (3) | Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years |
| Particle Pollution (PM) | $PM_{2.5}$ | primary | 1 year | 12.0 µg/m$^3$ | annual mean, averaged over 3 years |
| | | secondary | 1 year | 15.0 µg/m$^3$ | annual mean, averaged over 3 years |
| | | primary and secondary | 24 hours | 35 µg/m$^3$ | 98th percentile, averaged over 3 years |
| | $PM_{10}$ | primary and secondary | 24 hours | 150 µg/m$^3$ | Not to be exceeded more than once per year on average over 3 years |
| Sulfur Dioxide ($SO_2$) | | primary | 1 hour | 75 ppb (4) | 99th percentile of 1-hour daily maximum concentrations, averaged over 3 years |
| | | secondary | 3 hours | 0.5 ppm | Not to be exceeded more than once per year |

1. Express the levels of carbon monoxide (CO) shown on the table above in scientific notation. Units should remain in parts per million (ppm).

$$9 \text{ ppm} \rightarrow \_\_\_\_\_ \times 10^0 \text{ ppm}$$

$$35 \text{ ppm} \rightarrow \_\_\_\_\_ \times 10^1 \text{ ppm}$$

2. Express the levels of nitrogen dioxide ($NO_2$) shown on the table above in scientific notation. Units should remain in parts per billion (ppb).

$$100 \text{ ppb} \rightarrow \_\_\_\_\_ \times 10^2 \text{ ppb}$$

$$53 \text{ ppb} \rightarrow \_\_\_\_\_ \times 10^1 \text{ ppb}$$

**Take Home Assignment**

## Part 1. True/False (Circle One) 6

1. Earth's atmosphere is made up of mainly nitrogen and oxygen. T F
2. Air pollution affects the respiratory system and can lead to increased cancer risks. T F
3. Particulate matter is considered a secondary pollutant. T F
4. The ozone layer is harmful to humans. T F
5. Aerosols in the atmosphere are monitored using satellites. T F

## Part 2. Short Answer 2

**Instructions**: Answer the following questions in 1 – 2 sentences.

1. List the three ingredients necessary for ozone formation.

    1) _____

    2) _____

    3) _____

2. What is the difference between “good” and “bad” ozone?

3. Name three devices that are used to reduce air pollution. Choose one to describe how the device works to remove pollutants from the air.

    1) _____

    2) _____

    3) _____

Device: _____

Description:

## Part 3. Matching 3, 4

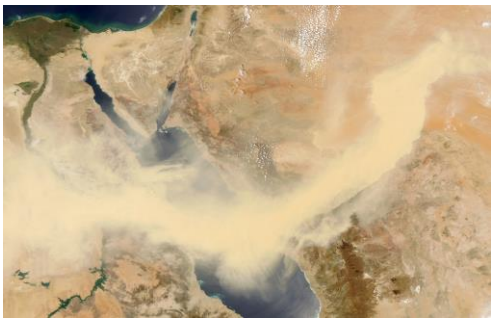
**Instructions**: Identify which of the following are sources of air pollution. Put a check mark in the box next to sources of air pollution.

Volcanic Eruption ☐

Motor Vehicle ☐

Forest Fire ☐

Industry ☐



Sand Storm ☐

Evaporating Gasoline ☐

Fireworks ☐

Planting Trees ☐

Bicycle ☐


Lawn Mower ☐

Grill ☐

Acid Rain ☐

**Student Evaluation** 2, 5, 7

**Instructions**: After completing the lesson on air pollution, please have the students answer the following questions.

1. What is the major difference between primary and secondary pollutants?
    a. Primary pollutants are harmful to the environment, while secondary pollutants are only harmful to human health.
    b. Primary pollutants are emitted directly from a source, while secondary pollutants are those that are formed through chemical reactions with primary pollutants in the atmosphere.
    c. Primary pollutants are emitted from cars and trucks, while secondary pollutants are emitted from natural sources such as forest fires and dust storms.
    d. There are no differences between primary and secondary pollutants.

2. In which layer of the atmosphere is ozone harmful to human health?
    a. Troposphere
    b. Stratosphere
    c. Mesosphere
    d. Thermosphere
    e. None of the above

3. Which of the following is not a source of aerosol pollution?
    a. Forest fires
    b. Dust storms
    c. Volcanic eruptions
    d. Motor vehicles

4. What is the name of the agency that sets air quality standards?
    a. Clean Air Agency
    b. Environmental Protection Agency
    c. National Weather Service
    d. International Panel on Climate Change

5. Which scale is used to determine how clean or polluted the air is?
    a. Air Quality Index
    b. Smog Index
    c. Saffir-Simpson Scale
    d. Enhanced Fujita Scale

6. Which of the following is <u>not</u> a health effect associated with breathing in polluted air?
    a. Asthma
    b. Respiratory infections
    c. Difficulty breathing
    d. Hearing loss
    e. Irritation to heart conditions
    f. Increased risk of cancer

7. Who is at risk of negative health effects from air pollution?
    a. Children
    b. Elderly persons
    c. People with asthma
    d. People with heart conditions
    e. Everyone

8. What can you do to reduce your contribution to air pollution?
    a. Carpool to school/work
    b. Walk or ride your bike
    c. Plant a tree/garden
    d. All of the above

9. Air quality is greatly affected by the concentration of air pollutants and the weather. Assume that you experienced an unhealthy air quality day yesterday (Day 1) and the air quality greatly improved today (Day 2). Write a short weather discussion describing how you think the weather changed between yesterday and today to improve the air quality. *(Hint: Recall what type of weather aids in ozone formation and what types of weather cleans the air)*

Day 1 Weather (Unhealthy AQI):

Day 2 Weather (Good AQI):

10. The EPA measured 0.05 parts per million (ppm) of ozone in Los Angeles, CA. What is the concentration of ozone in Los Angeles written in scientific notation?
    a. $5 \times 10^{2}$ ppm
    b. $5 \times 10^{-5}$ ppm
    c. $5 \times 10^{-2}$ ppm
    d. $50 \times 10^{-2}$ ppm

**Common Core State Standards (CCSS) Initiative**

To learn more, visit http://www.corestandards.org

**Next Generation Science Standards (NGSS)**

To learn more, visit http://www.nextgenscience.org

The following standards are met in this learning module:

1. **NGSS.MS-PS4-2**

| **MS-PS4-2. Waves and Electromagnetic Radiation** |
|---|
| Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials. |
| Lecture: Composition of the Atmosphere, Pollutants: Ozone, Aerosols |

2. **NGSS.MS-ESS3-3**

| **MS-ESS3-3. Human Impacts** |
|---|
| Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment. |
| Lecture: Improving Air Quality, Air Quality Index, Reducing Air Pollution; Pre-Class Activity; In-Class Activity: Parts 1 & 2; Take Home Assignment: Part 2; Student Evaluation |

3. **NGSS.MS-ESS3-4**

| **MS-ESS3-4. Human Impacts** |
|---|
| Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems. |
| In-Class Activity: Part 1; Take Home Activity: Part 3 |

4. **NGSS.MS-ESS3-2**

| **MS-ESS3-2. Human Impacts** |
|---|
| Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects. |
| Lecture: Aerosols; In-Class Activity: Part 1; Take Home Activity: Part 3 |

5. **CCSS.MATH.CONTENT.8.EE.A.4**

| **Grade 8. Expressions & Equations** |
| --- |
| Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose appropriate size for measurements of very large or very small quantities. Interpret scientific notation that has been generated by technology. |
| In-Class Activity: Supplemental Exercise; Student Evaluation |

6. **CCSS.ELA-LITERACY.RST.6-8.8**

| **Grade 8: Science and Technical Subjects** |
| --- |
| Distinguish among facts, reasoned judgment based on research findings, and speculation in a text. |
| Take Home Assignment: Part 1 |

7. **CCSS.ELA-LITERACY.RST.6-8.4**

| **Grade 6-8: Science and Technical Subjects** |
| --- |
| Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific science or technical context relevant to grades 6-8 texts and topics. |
| Lectures: Bolded text; Pre-Class Activity; Student Evaluation |

8. **CCSS.ELA-LITERACY.RST.6-8.7**

| **Grade 6-8: Science and Technical Subjects** |
| --- |
| Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). |
| Video lectures |