Module 1: Activity 4

The Criteria Pollutants & a Closer Look at Ozone

IT'S OUR AIR

SUMMARY

Students will be introduced to the criteria pollutants and will work in groups to make cartoon booklets demonstrating the formation of ground-level ozone and the destruction of stratospheric ozone.

ESSENTIAL QUESTIONS

- What are criteria pollutants and why are they of concern?
- What's the difference between stratospheric ozone and ground-level ozone?
- Why do we sometimes have too much ozone in the troposphere and not enough in the stratosphere?
- How do these problems affect human health?

TIME NEEDED

Highly variable. It's possible to complete this activity in one block period if you just use the background information provided and have students create a comic strip individually. However if you want to give students more time to produce creative products, allow two full days to work on the project in groups, and 30 minutes to present projects in class.

2012 North Carolina ESSENTIAL STANDARDS FOR EARTH/ENVIRONMENTAL SCIENCE

- EEn.2.5.1 Summarize the structure and composition of our atmosphere.
- EEn.2.5.5 Explain how human activities affect air quality.
- EEn.2.7.3 Explain how human activities impact the biosphere.

A product of the NC Air Awareness Program 2014.

MAKING CONNECTIONS

In this activity, students will be learning about ozone depletion. Many people confuse ozone depletion (or the "ozone hole") with global warming. Make sure your students are clear on the difference. The "ozone hole" refers to a thinning of the ozone layer, particularly over Antarctica, as a result of a build-up of molecules called chlorofluorocarbons (CFCs) in the stratosphere. "Global warming" refers to the idea that the Earth's climate is warming. Even though the two concepts are not the same thing, there are some interrelationships between the two issues, not all of which are fully understood.

BACKGROUND

THE SIX CRITERIA POLLUTANTS

EPA sets the standards for six criteria pollutants: ground-level ozone, particle pollution (also called particulate matter), nitrogen dioxide, carbon monoxide, sulfur dioxide, and lead. Nationally, the levels of all of these pollutants have fallen significantly since 1980, despite the fact that the population, gross domestic product, energy use, and vehicle miles traveled have all risen. However, in many urban areas ozone and particulate matter still pose a challenge.

Nitrogen dioxide (NO_2) is a kind of nitrogen oxide (NO_x), a class that also includes nitric oxide (NO). NO_x are formed during combustion in air at very high temperatures (typically 2700°F or higher), such as in a car engine or a boiler at a power plant. NO_x react with other molecules in the air to produce ground-level ozone, ammonia, nitric acid and acid rain. The largest sources of NO_x include cars and other vehicles with internal combustion engines, electrical generation, and industry.

Ground-level ozone is a secondary pollutant that forms when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react in the presence of sunlight and warm temperatures (usually over 75° F). NO_x comes from burning fuels. VOCs are chemicals containing carbon that evaporate easily – which usually means they are smelly. Sources of VOCs include cleaning chemicals, solvents, paints, unburned gasoline, hog waste lagoons, and natural sources such as trees. In North Carolina, almost all VOCs are from plants. Ozone is most likely to form on a hot summer afternoon near cars and in cities.

Particulate matter refers to a size rather than a chemical composition. Particulate matter can be either solid particles (such as dust) or tiny liquid droplets. For example, sulfur dioxide and nitrogen oxides can react with other chemicals in the air to form tiny droplets. Particulate matter is divided into two categories. PM10, or "coarse" particles, refers to particles less than 10 micrometers in diameter. PM2.5, or "fine" particles, refers to particles smaller than 2.5 micrometers. For comparison, fine beach sand is about 90 micrometers in diameter, and a human hair is between 50 and 70 micrometers in diameter. Reactions in the atmosphere among naturally occurring and manmade chemicals (such as sulfur dioxide and nitrogen oxides) are a major source of particulate matter. Other sources include construction sites, unpaved roads, fields, forest fires, and smokestacks.

Carbon monoxide (CO) is a product of incomplete combustion. When inhaled, it reduces oxygen delivery in the body. By far the largest source of carbon monoxide in the atmosphere is vehicles including cars, trucks, construction equipment, airplanes and trains.

Sulfur dioxide (SO_2) is a kind of sulfur oxide (SO_x). The largest source of sulfur dioxide is fuel combustion during generation of electricity, but it can be generated any time sulfur-rich fossil fuels such as coal are burned. Sulfur dioxide causes health problems, contributes to acid rain, and contributes to particle pollution.

Lead in the atmosphere has fallen the most dramatically of the six criteria pollutants, primarily due to the phase-out of leaded gasoline. In addition to breathing lead in the air, lead particles can settle onto surfaces and children can ingest the lead contaminated dust.

OZONE

The ozone layer in the stratosphere protects humans, animals, and plants from the sun's ultraviolet rays. Ozone in the troposphere, called ground-level ozone, causes respiratory distress and damages plants. In either case, ozone (O_3) is the same molecule: three oxygen atoms connected with two single bonds. Ozone in the stratosphere is good for humans and other life, but ozone in the troposphere causes problems for humans and other life. An easy way to remember this is: "Ozone: Good up high, bad nearby."

THE OZONE LAYER IN THE STRATOSPHERE

In the stratosphere, UV radiation knocks oxygen molecules (O_2) apart into two single oxygen atoms. These single atoms combine with oxygen molecules to form ozone (O_3). The ozone in the stratosphere absorbs UV radiation, which is good for us since UV radiation contributes to skin cancer, cataracts, and problems with the immune system.

Chlorofluorocarbons (CFCs) break down ozone in the stratosphere. CFCs, discovered in the 1930s, were once widely used in aerosol sprays, in the production of Styrofoam, and as refrigerants and cleaning solvents. Here are some formulas for CFCs:

- CCl_2F_2 (called CFC 12)
- CCl_3F (called CFC 11)
- $CHClF_2$ (called CFC 22)
- $C_2Cl_3F_3$ (called CFC 113)

Here's how CFCs break down ozone in the stratosphere:

- UV radiation knocks a chlorine atom off a CFC molecule.
- The chlorine atom steals an oxygen atom from an ozone molecule to make chlorine monoxide. It leaves behind a molecule of ordinary oxygen, O_2
- A free atom of oxygen hits the chlorine monoxide and frees the chlorine while forming another molecule of oxygen.
- The free chlorine can then go "attack" another ozone molecule.

In the mid-1980s, scientists discovered that the ozone layer over Antarctica was thinning and that CFCs were causing the problem. In 1987, representatives from 31 countries met in Montreal and signed the Montreal Protocol, which laid out a schedule for reducing and eliminating use of CFCs. Although CFCs can linger in the atmosphere for decades, the amount of CFCs in the stratosphere has slowly decreased since the 1990s and the ozone hole is beginning to shrink as well.

GROUND-LEVEL OZONE

Near the surface of the Earth, ground-level ozone forms when nitrogen oxides (NO_x) and volatile organics (VOCs) combine in the presence of sunlight and heat.

The series of chemical reactions that lead to the formation of ground-level ozone are rather involved and complex, and of course they vary depending on the form of nitrogen oxides and VOCs involved. Help your students focus on the basic recipe of:

NO_x + VOCs + heat + sunlight ⇨ O_3

In North Carolina, ozone is most likely to be a problem on sunny hot days in urban areas where there is a lot of car traffic to produce those nitrogen oxides. Nitrogen oxides are also produced by combustion-based electric generation and burning fossil fuels. Chemical solvents, industrial processes, gasoline, vehicles, and natural sources such as trees are sources of VOCs.

Ozone is very unstable in the troposphere and goes back to being a two-oxygen molecule fairly quickly, so it usually dissipates overnight.

MATERIALS

- Paper and art supplies (colored pencils and markers)
- Worksheets for students about criteria pollutants and ozone (provided)
- Internet connection (optional)
- Molecule-making sets (optional)

WARMUP

Show your students the video to get them thinking about how to define air pollution and some of the chemicals that exist in our atmosphere and which of those are considered "pollutants." Hand out the video checksheet (included) and have them fill in the answers while watching. The video also covers the ozone and the five other criteria pollutants (particulate matter, nitrogen oxides, sulfur dioxide, carbon monoxide, and lead). This information gives a larger context for this activity and sets the stage for future activities.

Ozone is an interesting case, because in the stratosphere it's beneficial. But in the troposphere (at ground level) it is a harmful pollutant. If you have a molecular model set, use it to demonstrate ozone (O_3) and distinguish it from oxygen (O_2).

Ask students these questions after the video:

- What are some of the characteristics of an air pollutant? [Answer: causes harm to people, animals, plants and/or environment; usually manmade, often from combustion; may disrupt visibility, but not necessarily]
- How did the U.S. dramatically reduce the amount of lead in our air? [Answer: through federal regulation requiring the phase out of lead in gasoline]
- What are the ingredients of ground-level ozone pollution? [Answer: nitrogen oxides and VOCs plus heat and sunlight]
- What are some health problems caused or made worse by ozone? [Answer: the video mentions breathing problems and premature death from heart or lung disease; students will learn about more health problems caused by ozone in future activities]

CRITERIA POLLUTANTS VIDEO

THE VIDEO:

- Asks the question, "How do you define air pollution?" then gets definitions from experts;
- Reviews the criteria pollutants (ground-level ozone, particulate matter, nitrogen oxides, sulfur dioxide, carbon monoxide, and lead) showing the sources and problems caused by each of these air pollutants.
- Presents data showing how, since the Clean Air Act, the U.S. has lowered emissions of air pollution, while our population, gross domestic product, energy use, and vehicle miles traveled have all risen.

Video Length: 13 minutes
Key elements: interviews, video footage, animation

Teacher Tips

Set-up Time: 15 Mins.
Activity Time: 45 Mins.

Consider requiring a certain number of scenes and the use of color in the cartoon booklets so that students don't rush through their projects. I require a minimum of six panels for each comic strip. My grading rubric for this activity assigns 20 points for each of the four questions and 20 points for creativity and presentation.

I spread the activity over a week, giving students about 20 minutes at a time to work on their comic. I have found that some of my more artistically motivated students get more of an opportunity to create something special when given this extra time. Students have created 3D books, computer animations, and other neat products as a result.

– Mark Townley

THE ACTIVITY

Have students work in pairs or trios to produce cartoon booklets explaining either the destruction of ozone in the stratosphere OR the production of ground-level ozone. Encourage students to personify the molecules, making them into characters.

If you have the capability to do so, show your students one of the carbon videos on this website: www.npr.org/news/specials/climate/video/. While the videos on this site are about global warming, not ozone, they may inspire students to convey chemical concepts through animation and humor. The fourth episode shows how carbon likes to make bonds with oxygen, personifying both kinds of atoms.

Here are the concepts that students must cover in their cartoon booklets, not necessarily in this order:

Formation of ozone at ground level:

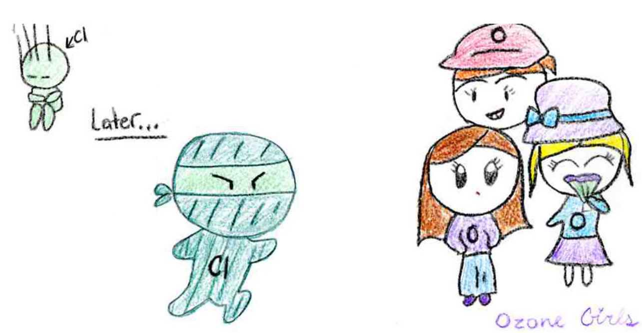
- What is ozone? [a molecule made of three oxygen atoms]
- What are the necessary ingredients for ground-level ozone? [nitrogen oxides, volatile organics, sunlight, heat]
- Where do these ingredients come from? [nitrogen oxides come from car exhaust, industrial processes, coal-fired electricity generation; volatile organics come from man-made sources such as industrial processes and gas stations and from natural sources such as trees; sunlight and heat come from the sun]
- What are some of the problems caused by ground-level ozone? [respiratory problems, damage to plants and crops]

Destruction of ozone in the stratosphere:

- What is ozone? [a molecule made of three oxygen atoms]
- How does the ozone layer in the stratosphere protect us? [absorbs damaging UV radiation from the sun]
- What are CFCs and where do they come from? [chlorofluorocarbons; they were used in aerosols and as refrigerants; although they aren't used anymore, it will take years for them to break down in the stratosphere]
- How do CFCs destroy ozone in the stratosphere? [UV radiation knocks a chlorine atom off a CFC molecule; the chlorine atom steals an oxygen atom from an ozone molecule].

WRAP UP AND ACTION

Spend some class time letting students share their projects with classmates.



ASSESSMENT

HAVE STUDENTS:

- Explain in writing or orally the difference between ground-level ozone and stratospheric ozone; how ground-level ozone is formed; and how CFCs damage the ozone layer.
- Discuss in class or answer individually the question: Is ozone an air pollutant? Why or why not?

EXTENSIONS

For students who want to use animation software, here are some sources:
www.toondoo.com
http://goanimate.com

RESOURCES

For good information on ground-level ozone, check out these websites:

- From EPA: http://www.epa.gov/groundlevelozone/ or http://www.epa.gov/glo/
- From the University Corporation for Atmospheric Research: http://www.ucar.edu/learn/1_7_1.htm
- From "Air Pollution: What's the Solution?": http://ciese.org/curriculum/airproj/

For good information on stratospheric ozone, check out these websites:

- From the EPA: http://www.epa.gov/ozone/strathome.html
- From The Ozone Hole, Incorporated: http://www.theozonehole.com
- From the University Corporation for Atmospheric Research: http://www.ucar.edu/learn/1_6_1.htm

For more information on a project at Duke and other universities about the benefits of learning through drawing, see this website:
http://www.picturingtolearn.org/

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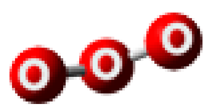
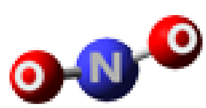
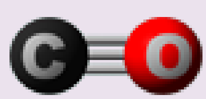
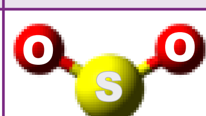
Student Page #1

CRITERIA POLLUTANTS REFERENCE SHEET

NAME	SYMBOL	MOLECULE	SOURCES	PROBLEMS CAUSED
Ozone	O_3		Combustion, VOC's + NO2 + sunlight + heat, vehicles, power plants, lightning	Breathing problems for people with lung diseases such as asthma, children, older adults, and people who are active outdoors. Premature death from heart or lung disease.
Particle Pollution or Particulate Matter	PM10 PM2.5	NA	**COARSE PARTICLES**: <10 micrometers – dust storms, mining. **FINE PARTICLES**: <2.5 micrometers – chemical processes, combustion, factories, power plants, vehicles	When inhaled can cause serious health problems and premature death. In air can cause visual haze.
Nitrogen Dioxide	NO_2 (NOX)		Combustion, vehicles, power plants	Makes asthma worse and increases respiratory illnesses. Contributes to ground-level ozone, acid rain, nutrient over-loading in streams and lakes.
Carbon Monoxide	CO		Vehicles, industrial processes, residential wood burning, forest fires	At low levels-harmful to people with heart conditions. At high levels-poisionous, can kill you.
Sulfur Dioxide	SO_2		Burning coal or oil that contains sulfur	Breathing problems. Contributes to acid rain and particle pollution.
Lead	Pb	NA	Historically – vehicles Currently – lead smelters	Inhaling lead is harmful to brain function in children and cardiovascular disease in adults.

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Student Page #2

PRODUCTION OF **GROUND-LEVEL OZONE**

Work in groups of two or three to make cartoon booklets explaining the production of ground-level ozone.

Cover the following topics in the cartoon booklets, not necessarily in this order:

- What is ozone?
- What are the necessary ingredients for ground-level ozone?
- Where do these ingredients come from?
- What are some of the problems caused by ground-level ozone?

To find the answers to these questions, use your textbook, your notes from class, and these websites:
From EPA: http://www.epa.gov/groundlevelozone/ or http://www.epa.gov/glo/

From the University Corporation for Atmospheric Research: http://www.ucar.edu/learn/1_7_1.htm

From “Air Pollution: What’s the Solution?”: http://ciese.org/curriculum/airproj/

Have fun with this project and be creative! Use color and let your atoms and molecules walk and talk. If possible, watch the short videos on this website about global warming for fun ideas about how to turn molecules and atoms into funny human-like characters: http://www.npr.org/news/specials/climate/video/

DESTRUCTION OF **OZONE IN THE STRATOSPHERE**

Work in groups of two or three to make cartoon booklets explaining the destruction of ozone in the stratosphere.

Cover the following topics in your cartoon booklets, not necessarily in this order:

- What is ozone?
- How does the ozone layer in the stratosphere protect us?
- What are CFCs and where do they come from?
- How do CFCs destroy ozone in the stratosphere?

To find the answers to these questions, use your textbook, your notes from class, and information these websites:
From the EPA: http://www.epa.gov/ozone/strathome.html

From The Ozone Hole, Incorporated: http://www.theozonehole.com

From the University Corporation for Atmospheric Research: http://www.ucar.edu/learn/1_6_1.htm

Have fun with this project and be creative! Use color and let your atoms and molecules walk and talk. If possible, watch the short videos on this website about global warming for fun ideas about how to turn molecules and atoms into funny human-like characters: http://www.npr.org/news/specials/climate/video/