



## Chapter 19 Air Pollution



“It’s A Small World After All”

### Outline

#### Structure and science of the atmosphere

- A. The atmosphere consists of several layers with different temperatures, pressures, and composition
  - 1. The atmosphere is a thin layer of gases divided into several spherical sublayers.
  - 2. Density and atmospheric pressure vary throughout the atmosphere due to gravitational forces that pull the gas molecules toward the earth’s surface. Air at sea level has a higher density than air at the top of a mountain.
  - 3. Atmospheric pressure is a measure of the mass per unit of air. It decreases with altitude.
- B. About 75-80% of the earth’s air mass is found in the troposphere, the atmospheric layer closest to the earth’s surface.
  - 1. This layer extends about 11 miles above sea level at the equator and about 5 mile above the poles.
  - 2. About 99% of the volume of air is made up of nitrogen (78%) and oxygen (21%) with the rest consisting of water vapor, argon, carbon dioxide and traces of several other gases.
  - 3. This layer is also responsible for short-term weather and long-term climate.
- C. The stratosphere is the second layer of the atmosphere and extends from 11-30 miles above the earth’s surface.
  - 1. The concentration of ozone in this layer is much higher than in the troposphere.
  - 2. Ozone is produced when oxygen molecules interact with ultraviolet radiation ( $3 \text{ O}_2 + \text{UV} \rightarrow 2 \text{ O}_3$ ). This “global sunscreen” keeps about 95% of the sun’s harmful UV radiation from reaching the earth’s surface.
  - 3. This ozone layer protects us from sunburn, cataracts, cancer of skin and eye and damage to our immune system.
  - 4. There is evidence of a decrease in “good” ozone in the stratosphere and increase in “bad” ozone in the troposphere.

#### Air Pollution

- A. Air pollutants come mostly from natural sources and from burning fossil fuels.
- B. Primary pollutants are pollutants emitted into the air. They can react with one another and/or with air to form secondary pollutants.
- C. Major air pollutants include carbon oxides, nitrogen oxides, particulates, volatile organic compounds, ozone, and radon.

#### Urban Outdoor Air Pollution

- A. Outdoor air pollution comes mostly from natural sources and burning fossil fuels in vehicles and power and industrial plants.
  - 1. Chemicals in the atmosphere in concentrations high enough to affect climate, materials, and health are what constitute air pollution.
  - 2. Natural sources of air pollution such as dust particles, organic chemicals released by plant decay; forest fires, etc. rarely reach harmful levels.
  - 3. Increased use of fossil fuels has greatly increased the amount of air pollution, especially in urban areas where people, cars and industry are concentrated.
  - 4. Outdoor air pollutants are classified into two categories: primary pollutants that enter directly into the troposphere (soot, carbon monoxide, nitric oxides), and secondary pollutants that may form when primary pollutants interact with one another or with the air to form new pollutants (nitric acid).
  - 5. Cities generally have higher pollution levels than rural areas. Winds can carry these pollutants away from their source to other areas.
  - 6. Indoor air pollutants come from infiltration of outside air, chemicals used or produced inside buildings.
  - 7. Air pollution is classified as a high-risk human health problem.
  - 8. Most people exposed to poor air live in developing countries.
  - 9. Six conventional air pollutants have maximum standards of allowable concentrations set by

## Chapter 19 Air Pollution

### “It’s A Small World After All”

- governments of developed countries.
- B. Photochemical smog is formed by the reaction of nitrogen oxides and volatile hydrocarbons under the influence of sunlight.
1. A photochemical reaction is any chemical reaction activated by light.
  2. Photochemical smog contains more than 100 primary and secondary pollutants.
  3. Nitrogen dioxide found in photochemical smog is a yellow-brown gas with a noxious odor and causes a brownish haze to form.
  4. Some NO<sub>2</sub> reacts with hydrocarbons to produce a mixture of ozone, nitric acid, aldehydes, peroxyacyl nitrates (PANs) and other pollutants.
  5. These substances are photochemical oxidants and can irritate the respiratory tract, damage crops and trees.
  6. Photochemical smog is more common in cities in warm, dry, sunny areas.
- C. Industrial smog is a mixture of sulfur dioxide, droplets of sulfuric acid, and a variety of suspended solid particles emitted by burning coal and oil.
1. When coal is burned it is converted to carbon dioxide and carbon monoxide and unburned carbon particles (soot).
  2. Coal and oil also contain sulfur that is then converted to sulfur dioxide.
  3. Reactions with water vapor changes sulfur dioxide to sulfuric acid in several steps. These droplets can then react with ammonia in the atmosphere to form ammonium sulfate. These various components give the air a gray color.
  4. Most countries have adopted pollution controls, but several countries with industrialized urban areas have serious smog problems.
- D. Outdoor air pollution can be reduced by precipitation, sea spray, and winds and increased by urban buildings, mountains, and high temperatures.
1. Five factors help reduce outdoor air pollution: heavy particles settle out of atmosphere due to gravity; rain and snow; salty sea spray; winds; and chemical reactions of pollutants. Each of these factors helps remove pollutants, but they are then deposited elsewhere.
  2. Six factors can increase outdoor air pollution: urban buildings; hills and mountains; higher temperatures; VOC emissions from certain trees and plants; the grasshopper effect where volatile compounds are carried from tropical or temperate areas to the poles; and temperature inversions.
- E. A layer of warm air sitting on top of a layer of cool air near the ground can prevent outdoor pollutants from rising and dispersing.
1. Turbulence, caused by the mixing of warm and cold air disperses air pollutants.
  2. A temperature inversion, where a layer of warm air sits over a layer of cold air prevents the mixing and dense, colder air becomes stagnant and accumulates more pollutants.
  3. Two areas are particularly susceptible to inversions:
    - a. a city located in a valley surrounded by mountains that experiences cloudy, cold weather part of the year
    - b. a sunny climate, light winds, mountains on three sides and several million people and vehicles (Los Angeles basin).
- F. Much of Southeastern Asia has a huge brown cloud of industrial smog from coal burning.
1. The rapid industrialization of China and India is repeating what had existed in Europe and the U.S. as part of the industrial revolution during the 19<sup>th</sup> and early 20<sup>th</sup> century.
  2. Solar energy reaching the earth is reduced 2-15% in some areas.
  3. Rice crops may be reduced 3-10% by this in India’s winter harvests.
  4. Crops, trees and life in lakes are being damaged.
  5. This may also be an important contributor to premature deaths from respiratory diseases.
  6. This huge brown cloud also seems to be causing changes in regional climate, warming some areas and cooling others. There are also shifting rainfall patterns.
  7. The good news is that this problem can be greatly reduced by setting standards for coal-burning industries, changing to cleaner burning gas, using catalytic converters on cars. China has begun to do this, as has Delhi, India.

#### Acid Deposition

- A. Sulfur dioxide, nitrogen oxides, and particulates react in the atmosphere to produce acidic

## Chapter 19 Air Pollution

### “It’s A Small World After All”

- chemicals that travel long distances before coming back to earth.
1. Tall smokestacks reduce local pollution, but can increase regional pollution.
  2. Acidic particles remain in the atmosphere for 2-14 days, depending on the prevailing winds, precipitation, and other weather patterns.
  3. The acidic substances return to earth in one of two forms:
    - a. wet deposition as acidic rain, snow, fog, and could vapor with a pH less than 5.6.
    - b. dry deposition as acidic particles
  4. Acid deposition is a problem in areas downwind from coal-burning facilities and urban areas.
  5. Some areas have basic compounds in the soil that act to buffer or neutralize some acidic deposits.
  6. Many acid-producing chemicals generated in one country end up in other countries due to prevailing winds.
- B. Acid deposition can cause or worsen respiratory disease, attack metallic and stone objects, decrease atmospheric visibility, and kill fish.
1. Large amount of money are spent each year to clean and repair monuments and statues damages by acid deposition.
  2. Acid deposition also decreases atmospheric visibility.
  3. Acidified lakes have fish kill and aluminum ions are released into the water by the lower pH (4.5 or less).
  4. Many lakes in northern Europe and the eastern U.S. have few, if any, fish due to decreased pH.
- C. Acid deposition can deplete some soil nutrients, release toxic ions into soil, and weaken plants that become susceptible to other stresses.
1. Effect of acid deposition on plants is caused partly by chemical interaction in the soils.
  2. There may be an initial growth stimulus from added nitrogen and sulfur, but continued deposition leaches essential magnesium and calcium salts from the soil and lowers plant productivity.
  3. Herbivores that eat these plants can also develop calcium deficiencies.
  4. Synergistic effects may occur when the plants are exposed to several pollutants simultaneously.
  5. Acid can also dissolve aluminum, cadmium, and mercury ions from the soil. These ions are toxic to plants and animals.
  6. Acid loving mosses may be stimulated to grow and harm trees by holding quantities of water and killing mycorrhizal fungi needed by the trees.
  7. Weakened trees are more susceptible to diseases.
  8. The mountaintop trees are those that are most harmed by acidic rain because they are also growing in thin soils.
- D. Progress has been made in reducing acid deposition in the U.S., but there is a long way to go.
1. The 1990 amendments to the Clean Air Act have lead to significant reductions in SO<sub>2</sub> and NO<sub>x</sub> emissions from coal-fired power and industrial plants.
  2. Acid deposition has accelerated leaching of ions such as calcium and magnesium from soils in some areas, which could lead to a decrease in tree growth.
  3. Acid deposition has also increased concentrations of toxic forms of aluminum in some soil and in lakes and streams.
  4. It is predicted that an additional 80% reduction in SO<sub>2</sub> emissions would be needed to allow northeastern streams and lakes to recover from the effects of acid deposition.
- E. A number of prevention and control methods can reduce acid deposition, but they are politically difficult to implement.
1. The best approaches are those that reduce or eliminate emissions of SO<sub>2</sub>, NO<sub>x</sub> and particulates.
  2. Use of low sulfur coal is both good and bad, it lowers the amount of SO<sub>2</sub> released but because more must be burned to generate the same amount of electricity, it emits more mercury, CO<sub>2</sub>, and radioactive particles.
  3. Controlling acid deposition is a politically controversial issue.
  4. Inclusion of environmental and health costs to the current cost of coal would give a more realistic picture.
  5. Approaches to neutralize acid lakes include adding limestone or lime to the water or soil or adding a small amount of phosphate fertilizer, this approach is being evaluated.

## Chapter 19 Air Pollution

### “It’s A Small World After All”

#### Indoor Air Pollution

- A. Indoor air pollution is usually a much greater threat to human health than outdoor air pollution.
  - 1. EPA studies have shown that:
    - a. Levels of 11 common pollutants are 2-5 times greater inside homes and commercial buildings than outside.
    - b. Inside cars in traffic-clogged areas the pollution may be 18 times higher than outside.
    - c. Health risks are magnified because people usually spend 70-98% of their time indoors or in vehicles.
  - 2. Pesticide residues brought in on shoes can collect in carpets and many paints and sprays contain potentially harmful organic solvents.
  - 3. Living organisms’ excrement, from organisms like dust mites and cockroaches, play a role in the almost threefold increase in asthma cases between 1972 and 2002.
  - 4. Toxic airborne spores of molds and mildew that grow under houses and on inside walls can cause headaches, allergic reactions, and aggravate asthma and other respiratory diseases.
  - 5. Sick-building syndrome has been linked to various air pollutants, and new buildings are apt to be more prone to this than old building due to less air exchange.
  - 6. The EPA lists the four most dangerous indoor air pollutants in developed countries as cigarette smoke, formaldehyde, radioactive radon-222 gas, and very small fine and ultra fine particles.
  - 7. In developing countries as many as 2.8 million people die prematurely each year from breathing elevated levels of indoor smoke and particulates.
- B. Formaldehyde is the chemical that causes most people in developed countries difficulty. It is used to manufacture common household materials.
- C. Radon-222 gas is found in some soils and rocks and can seep into some homes and increase the risk of lung cancer.
  - 1. Radon is produced by the radioactive decay of uranium-238.
  - 2. Radon gas tends to be pulled into homes because of the slightly lower atmospheric pressure inside most homes.
  - 3. Radon is thought to be the second leading cause of lung cancer deaths each year in the U.S.
  - 4. The EPA and the Surgeon General’s Office recommended that everyone living in a detached home, a townhouse or the first 3 levels of an apartment building test for radon.
  - 5. Remedies include sealing cracks in foundation and walls, increase ventilation and use a fan for cross ventilation.

#### Health Effects of Air Pollution

- A. The respiratory system has several ways to help protect you from air pollution.
  - 1. Hairs in the nose filter out large particles. Sticky mucus lines the respiratory trap to capture smaller particles and some dissolved gases.
  - 2. Sneezing and coughing expel contaminated air and mucus.
  - 3. Prolonged or acute expose to air pollutants can overload or break down the natural defenses.
  - 4. Several respiratory diseases can develop such as asthma, lung cancer, chronic bronchitis and emphysema.
  - 5. People with respiratory diseases, older adults, infants, pregnant women, and people with heart disease are especially vulnerable to air pollution
- B. Each year, air pollution kills about 3 million people, mostly from indoor air pollution in developing countries.
  - 1. Air pollution deaths in the U.S. range from 150,000 to 350,000 people per year.
  - 2. A large diesel-powered bulldozer produces as much air pollution as 26 cars.
  - 3. The EPA proposed emission standards for diesel-powered vehicles that go into effect in 2007 with full compliance by 2012. It is thought that this will reduce diesel-fuel emissions by 90%.
  - 4. There is a connection between international trade and air pollution in which diesel engines from cargo ships and idling trucks emit large amounts of pollution.

#### Preventing and Reducing Air Pollution

- A. Clean Air Acts in the United States have greatly reduced outdoor air pollution from six major

## Chapter 19 Air Pollution

### “It’s A Small World After All”

pollutants.

1. The U.S. Congress passed Clean Air Acts in 1970, 1977, and 1990.
  2. National air quality standards (NAAQS) were established for six outdoor criteria pollutants.
  3. Two limits were established: a primary standard is set to protect human health and a secondary standard is set to prevent environmental and property damage.
  4. EPA has established national emission standards for 188 hazardous air pollutants (HAPs) that may cause serious health and ecological effects. These include neurotoxins, carcinogens, mutagens, teratogens, and others.
  5. In 2005, the EPA proposed requiring industries to report their HAP emissions every other year and raising threshold for reporting these chemical tenfold.
  6. Great news:
    - a. According to a 2005 EPA report, combined emissions of the six criteria air pollutants decreased by 54% between 1970 and 2004; energy consumption, miles traveled and population increase.
    - b. Between 1970 and 2004, emissions from the six major air pollutants decreased: 98% for lead, 56% for carbon monoxide, 55% for volatile organic compounds, 79% for suspended particulate matter, 52% for sulfur dioxide, and 30% for NO<sub>x</sub>.
  7. Bad news:
    - a. After dropping in the 1980s, photochemical smog levels did not decline between 1993 and 2004 due to a failure to reduce ground-level ozone concentrations
    - b. In 2003, more than 170 million people or 59% of the population lived in areas where air is unhealthy to breathe for part of the year due primarily to ozone and particulates.
    - c. Despite more than two decades of reducing carcinogenic emissions from cars and factories, in 2006, the EPA reported that residents of some urban areas of New York and California are exposed to twice the cancer risk from outdoor air pollution as the national average.
- B. Outdoor air pollution in the U.S. has been reduced since 1970.
1. U.S. citizens insisted that laws be passed and enforced to improve air quality, and the country was affluent enough to afford the controls and improvements.
  2. Scientists point out several deficiencies in the Clean Air Act; they include:
    - a. The U.S. continues to mostly rely on cleanup rather than prevention.
    - b. The U.S. Congress has failed to increase fuel-efficiency standard for cars, SUVs, and light trucks.
    - c. Regulation of emissions from motorcycles and two-cycle gasoline engines remains inadequate.
    - d. There is little or no regulation of air pollution from oceangoing ship in American ports.
    - e. Airports are exempt from any air pollution regulations.
    - f. The Act does not regulate emissions of carbon dioxide.
    - g. Urban ozone levels are still too high in many areas.
    - h. The Act has failed to deal seriously with indoor air pollution.
    - i. There is a need for better enforcement of the Clean Air Act.
- C. Allowing producers of air pollutants to buy and sell government air pollution allotments in the marketplace can help reduce emissions.
1. The Clean Air Act of 1990 allows an emissions trading policy that permits companies to buy and sell SO<sub>2</sub> pollution rights.
  2. This cap-and-trade approach may be an improvement over command-and-control as long as it reduces SO<sub>2</sub> emissions. The cap would gradually be lowered.
  3. These pollution credits may be purchased by anyone and then not used if they so desire.
  4. This method allows “hot spots” to continue to exist. Spot monitoring to check for emissions should be done.
  5. Between 1990 and 2002 this scheme reduced SO<sub>2</sub> emissions by 35% in the U.S.
  6. Emissions trading has been expanded to include NO<sub>x</sub>, particulate emissions, and volatile organic compounds, and for the combined emissions of SO<sub>2</sub>, NO<sub>x</sub>, and mercury from coal-burning power plants.
- D. There are a number of ways to prevent and control air pollution from coal-burning facilities and motor vehicles.
1. Figure 19-17 summarizes ways to reduce emissions of sulfur oxides, nitrogen oxides, and

## **Chapter 19** **Air Pollution**

### **“It’s A Small World After All”**

- particular matter from stationary sources like power plants.
2. Output approaches like electrostatic precipitators, and wet scrubbers are used on coal plants.
  3. Input approaches include reduced sulfur coal, coal gasification and fluidized-bed combustion.
  4. Between 1980 and 2002, emissions of sulfur dioxides from U.S. electric power plant decreased by 40% and NO<sub>x</sub> by 30% and soot by 75%.
  5. Because of the Clean Air Act, a new car today in the United States emits 75% less pollution than did pre-1970 cars.
- E. Indoor air pollution is a greater threat to human health, but little effort has been spent on reducing it.
1. Figure 19-20 suggests several ways to reduce indoor air pollution.
  2. In developing countries indoor air pollution can be reduced by use of clay or metal stoves and venting to the outside, and by use of solar cookers in sunny areas. This would also reduce deforestation.
- F. There is a need to focus on preventing air pollution of all types.
1. At present there is an output approach to controlling pollution.
  2. We need to shift focus to preventing air pollution.
  3. Figure 19-221 shows ways to prevent air pollution over the next 30-40 years.
  4. Figure 19-21 lists ways to reduce your exposure to indoor air pollution.

### **Summary**

1. The layers of the atmosphere are the troposphere, stratosphere, mesosphere, and thermosphere.
2. Major classes of air pollutants include carbon, sulfur, and nitrogen oxides, volatile organic compounds, suspended particulate matter, photochemical oxidants, radioactive substances, and hazardous chemicals that can cause health problems. Primary sources of these pollutants include cars, industry, and natural phenomena such as volcanic eruptions.
3. The two types of smog are the photochemical and the industrial or gray-air smog.
4. Acid deposition includes wet deposition of acidic rain, snow, fog, and cloud vapor with pH less than 5.6, and dry deposition of acidic particles. The solution to this problem is prevention that reduces emissions of acidic nitrogen and sulfur oxides, and particulates.
5. Harmful effects of air pollution include various respiratory diseases, premature deaths, damage to plants, and materials such as buildings, cars, statues, etc.
6. We can reduce air pollution through prevention and cleanup, including low sulfur coal, shifting to less polluting fuels, removal of pollutants after combustion, use of mass transit or alternative transportation, improving fuel efficiency, and tax incentives.

### **Objectives**

1. Briefly describe the structure of the atmosphere being sure to include troposphere, stratosphere, mesosphere, and the boundaries between each set of layers.
2. Summarize ways in which humans disrupt Earth's major gaseous nutrient cycles.
3. Distinguish between primary pollutant and secondary pollutant; stationary source and mobile source; photochemical smog and industrial smog. List eight major classes of primary outdoor pollutants. Describe how smog is formed. Describe a thermal inversion and conditions under which it is most likely to occur.
4. Define *acid deposition*. Identify the level of risk that acid deposition creates for ecological systems and for human health. Give one example of the complexities of interactions which can be set in motion by acid deposition. List six strategies to prevent acid deposition.

## Chapter 19 Air Pollution

### “It’s A Small World After All”

5. Compare the risks of indoor and outdoor air pollution. List the four most dangerous indoor air pollutants, the potential health effects of each, and strategies for dealing with each.
6. Briefly describe how air pollution affects human health, plants, aquatic life, and materials.
7. Summarize the Clean Air Act. List six criticisms that environmentalists make about the Clean Air Act. Summarize the controversy over the stricter particle emission standards in the United States.
8. List four prevention strategies and three cleanup strategies to reduce emissions from stationary sources of air pollution. Define *emissions trading policy* and tell which pollutants are being regulated by this policy.
9. List eight prevention strategies and three cleanup strategies to reduce emission from motor vehicles. List six prevention strategies and six cleanup strategies to reduce indoor air pollution.
10. Visualize an integrated picture puzzle of a healthy sustaining atmosphere. Describe as many pieces of the puzzle as you can.

**Key Terms (Terms are listed in the same font style as they appear in the text.)**

<p><i>acid deposition</i> (p. 444)  <b>acid deposition</b> (p. 447)  <i>acid rain</i> (p. 447)  <b>air pollution</b> (p. 441)  <i>airborne spores of mold</i> (p. 452)  <i>Asian Brown Cloud</i> (p. 445)  <i>atmosphere</i> (p. 440)  <b>atmospheric pressure</b> (p. 440)  <i>brown-air smog</i> (p. 445)  <i>buffer</i> (p. 447)  <i>cap-and-trade program</i> (p. 458)  <i>dust mites</i> (p. 452)  <i>electrostatic precipitator</i> (p. 459)  <i>emissions trading policy</i> (p. 458)  <i>emphysema</i> (p. 455)  <i>fine particles</i> (p. 444)  <i>fluidized bed combustion</i> (p. 459)  <i>formaldehyde</i> (p. 453)  <i>grasshopper effect</i> (p. 446)  <i>gray-air smog</i> (p. 445)  <i>hazardous air pollutants (HAPs)</i> (p. 456)  <i>hybrid-electric vehicles</i> (p. 460)  <b>industrial smog</b> (p. 444)  <i>lung cancer</i> (p. 455)  <i>mildew</i> (p. 452)  <i>mobile sources</i> (p. 441)  <i>national ambient air quality standards (NAAQS)</i>            (p. 456)  <i>nitric acid (HNO<sub>3</sub>)</i> (p. 443)  <i>nitrogen dioxide (NO<sub>2</sub>)</i> (p. 443)  <i>nitrogen oxide (NO)</i> (p. 443)  <i>nitrogen oxides</i> (p. 443)  <i>output approach</i> (p. 462)</p>	<p><i>carbon dioxide (CO<sub>2</sub>)</i> (p. 442)  <i>carbon monoxide (CO)</i> (p. 442)  <b>carbon oxides</b> (p. 442) (p. 442)  <i>chronic bronchitis</i> (p. 455)  <i>cilia</i> (p. 455)            Clean Air Acts (p. 457)  <i>climate</i> (p. 440)  <i>cockroach droppings</i> (p. 452)  <i>coal gasification</i> (p. 459)  <i>density</i> (p. 440)  <i>dry deposition</i> (p. 447)  <i>photochemical oxidants</i> (p. 445)  <i>photochemical reaction</i> (p. 445)  <b>photochemical smog</b> (p. 444)  <b>primary pollutants</b> (p. 441)  <i>primary standard</i> (p. 456)  <i>Radon-222</i> (p. 444)  <i>radon-222</i> (p. 454)  <b>secondary pollutants</b> (p. 441)  <i>secondary standard</i> (p. 456)  <i>sick-building syndrome</i> (p. 452)  <i>stationary sources</i> (p. 441)  <i>stratosphere</i> (p. 441)  <i>sulfur dioxide (SO<sub>2</sub>)</i> (p. 444)  <i>sulfuric acid (H<sub>2</sub>SO<sub>4</sub>)</i> (p. 444)  <i>suspended particulate matter</i> (p. 444)  <b>temperature inversion</b> (p. 446)  <i>tobacco smoke</i> (p. 453)  <i>Toxic Release Inventory (TRI)</i> (p. 456)  <i>troposphere</i> (p. 440)  <i>ultrafine particles</i> (p. 444)  <b>volatile organic compounds (VOCs)</b> (p. 444)  <i>weather</i> (p. 440)</p>
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**Chapter 19**  
**Air Pollution**

**“It’s A Small World After All”**

<i>ozone (O<sub>3</sub>)</i> (p. 444) <b>ozone layer</b> (p. 441) <i>partial zero-emission vehicles (PZEVs)</i> (p. 460)	<i>wet deposition</i> (p. 447) <i>wet scrubber</i> (p. 459)
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