Air Pollution, Climate Disruption, and Ozone Depletion

Chapter 15
Three big ideas

• All countries need to step up efforts to control air pollution.

• Reducing the projected harmful effects of rapid climate disruption during this century requires emergency action to increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

• We need to continue phasing out the use of chemicals that have reduced ozone levels.
WHAT IS THE NATURE OF THE ATMOSPHERE?
The earth’s atmosphere is a dynamic system that includes 4 layers.
Section 15-2

WHAT ARE THE MAJOR AIR POLLUTION PROBLEMS?
This first link is to a news clip that highlights some of the potential hazards of fine particulate matter.

http://www.youtube.com/watch?v=JaAd8OuwwPk

The second link is an entertaining clip reinforcing these ideas… just for fun 😊

http://www.youtube.com/watch?NR=1&v=po3jPq5LT0g&feature=fvwp
Air pollution comes from natural and human sources

- Air pollution is the presence of chemicals in the atmosphere in concentrations high enough to **harm** organisms, ecosystems, or human made materials, or to **alter** climate.
  
  - **Natural sources** include dust blown by wind, pollutants from wildfires and volcanic eruptions, and volatile organic chemicals released by some plants.
  
  - Most **human inputs** of outdoor air pollutants come from the burning of fossil fuels in power plants and industrial facilities (stationary sources) and in motor vehicles (mobile sources).
Air pollution comes from natural and human sources

• Scientists classify outdoor air pollutants into two categories.
  – **Primary pollutants** are harmful chemicals emitted directly into the air from natural processes and human activities.
  – **Secondary pollutants** react with one another and with other normal components of air to form new harmful chemicals, called secondary pollutants (ex. O$_3$).

• Outdoor air pollution is a **global problem**, largely due to the sheer volume of pollutants produced by human activities.
Various pollutants

**Primary Pollutants**
- CO
- CO₂
- SO₂
- NO
- NO₂
- CH₄ and most other hydrocarbons
- Most suspended particles

**Secondary Pollutants**
- SO₃
- HNO₃
- H₂SO₄
- H₂O₂
- O₃
- PANs
- Most NO₃⁻ and SO₄²⁻ salts
What are the major outdoor air pollutants?

• Carbon oxides.

  - **Carbon monoxide** (CO) is a colorless, odorless, and highly toxic gas that forms from motor vehicle exhaust, burning of forests and grasslands, tobacco smoke, and open fires and inefficient stoves used for cooking.

    • CO reacts with hemoglobin in red blood cells and reduces the ability of blood to transport oxygen to body cells and tissues.
    
    • Long-term exposure can trigger heart attacks and aggravate lung diseases such as asthma and emphysema.
    
    • At high levels, CO can cause headache, nausea, drowsiness, mental impairment, collapse, coma, and death.
What are the major outdoor air pollutants?

- **Carbon dioxide** (CO\textsubscript{2}) is a colorless, odorless gas.
  - About 93% of the CO\textsubscript{2} in the atmosphere is the result of the natural carbon cycle.
  - The rest comes from human activities, primarily the burning of fossil fuels and the clearing of CO\textsubscript{2}-absorbing forests and grasslands.
  - Until recently CO\textsubscript{2} has not been classified as an air pollutant.
  - Growing scientific evidence that increasing levels are contributing to atmospheric warming and projected climate change, which can contribute to human health problems.
What are the major outdoor air pollutants?

- **Nitrogen oxides** and nitric acid.
  
  • Nitric oxide (NO) is a colorless gas that forms when nitrogen and oxygen gas in air react at the high-combustion temperatures in automobile engines and coal-burning power and industrial plants.
  
  • Lightning and certain bacteria in soil and water also produce NO as part of the nitrogen cycle.
  
  • In the air, NO reacts with oxygen to form nitrogen dioxide (NO$_2$), a reddish-brown gas.
  
  • Collectively, NO and NO$_2$ are called nitrogen oxides (NO$_X$).
What are the major outdoor air pollutants?

- Some of the NO₂ reacts with water vapor in the air to form nitric acid (HNO₃) and nitrate salts (NO₃⁻)—components of harmful acid deposition.
- NO₂ plays a role in the formation of photochemical smog—a mixture of chemicals formed under the influence of sunlight in cities with heavy traffic.
- Nitrous oxide (N₂O) is a greenhouse gas.
- Nitrogen oxides can irritate the eyes, nose, and throat; aggravate lung ailments such as asthma and bronchitis; and suppress plant growth and reduce visibility when they are converted to nitric acid and nitrate salts.
What are the major outdoor air pollutants?

– Sulfur dioxide and sulfuric acid.

  • Sulfur dioxide (SO$_2$) is a colorless gas with an irritating odor.
  • About one third of the SO$_2$ in the atmosphere comes from natural sources as part of the sulfur cycle.
  • Human sources include combustion of sulfur-containing coal in electric power and industrial plants and oil refining and smelting of sulfide ores.
  • In the atmosphere, SO$_2$ can be converted to aerosols, which consist of microscopic suspended droplets of sulfuric acid (H$_2$SO$_4$) and suspended particles of sulfate (SO$_4$ 2$^-$) salts that return to the earth as a component of acid deposition.
  • Sulfur dioxide, sulfuric acid droplets, and sulfate particles reduce visibility and aggravate breathing problems.
  • Damage crops, trees, soils, and aquatic life in lakes, and corrode metals and damage materials on buildings and statues.
What are the major outdoor air pollutants?

- **Particulates.**
  
  - Suspended particulate matter (SPM) consists of a variety of solid particles and liquid droplets small and light enough to remain suspended in the air for long periods.
  
  - EPA classifies particles as fine, or PM-10 (with diameters less than 10 micrometers), and ultrafine, or PM-2.5 (with diameters less than 2.5 micrometers).
  
  - 38% comes from human sources such as coal-burning power and industrial plants, motor vehicles, road construction, and tobacco smoke.
  
  - Irritate the nose and throat, damage the lungs, aggravate asthma and bronchitis, and shorten life.
  
  - Can cause mutations, reproductive problems, and cancer.
  
  - Particulates reduce visibility, corrode metals, and discolor clothes and paints.
What are the major outdoor air pollutants?

– Ozone.

- Ozone (O₃), a colorless and highly reactive gas, is a major ingredient of photochemical smog.
- Causes coughing and breathing problems, aggravates lung and heart diseases, reduces resistance to colds and pneumonia, and irritates the eyes, nose, and throat.
- Damages plants, rubber in tires, fabrics, and paints.
- Ozone in the troposphere near ground level is often referred to as “bad” ozone, while ozone in the stratosphere as “good” ozone.
What are the major outdoor air pollutants?

– Volatile organic compounds (VOCs).

• Organic compounds that exist as gases in the atmosphere or that evaporate into the atmosphere are called volatile organic compounds (VOCs).

• Global methane emissions come from natural sources, mostly plants, wetlands, and termites, while human sources include primarily rice paddies, landfills, oil and natural gas wells, and cows.

• Benzene and other liquids used as industrial solvents, dry-cleaning fluids, and components of gasoline, plastics, and other products.
Sunlight plus cars equals photochemical smog

- A photochemical reaction is any chemical reaction activated by light.
- Photochemical smog is a mixture of primary and secondary pollutants formed under the influence of UV radiation from the sun.
- The formation of photochemical smog begins when exhaust from morning commuter traffic releases large amounts of NO and VOCs into the air over a city.
- The NO is converted to reddish-brown NO$_2$, which leads to the name brown-air smog.
Sunlight plus cars equals photochemical smog

• When exposed to ultraviolet radiation from the sun, some of the NO$_2$ reacts in complex ways with VOCs released by certain trees, motor vehicles, and businesses.

• The resulting mixture of pollutants, dominated by ground-level ozone, usually builds up to peak levels by late morning, irritating people’s eyes and respiratory tracts.

• Some of its pollutants, known as photochemical oxidants, can damage lung tissue.

• All modern cities have some photochemical smog, but it is much more common in cities with sunny, warm, and dry climates, and a great number of motor vehicles.
Several factors can decrease or increase outdoor air pollution

• Five natural factors help reduce outdoor air pollution.
  – Particles heavier than air settle out as a result of gravitational attraction to the earth.
  – Rain and snow help cleanse the air of pollutants.
  – Salty sea spray from the oceans washes out many pollutants from air that flows from land over the oceans.
  – Winds sweep pollutants away and mixes them with cleaner air.
  – Some pollutants are removed by chemical reactions.
Several factors can decrease or increase outdoor air pollution

- Six other factors can increase outdoor air pollution.
  - Urban buildings slow wind speed and reduce dilution and removal of pollutants.
  - Hills and mountains reduce the flow of air in valleys below them and allow pollutant levels to build up at ground level.
  - High temperatures promote the chemical reactions leading to formation of photochemical smog.
Several factors can decrease or increase outdoor air pollution

- VOCs emissions from certain trees and plants in heavily wooded urban areas can play a large role in the formation of photochemical smog.
- Grasshopper effect—occurs when air pollutants are transported by evaporation and winds from tropical and temperate areas through the atmosphere to the earth’s polar areas, where they are deposited.
- Temperature inversions occurs when a layer of warm air can temporarily lie atop a layer of cooler air nearer the ground.
Acid deposition is a serious regional air pollution problem

- Most coal-burning power plants, ore smelters, and other industrial facilities in more-developed countries use tall smokestacks, which reduce local air pollution, but can increase regional air pollution downwind.

- Prevailing winds may transport the primary pollutants $\text{SO}_2$ and $\text{NO}_x$ as far as 1,000 kilometers (600 miles), forming secondary pollutants such as droplets of sulfuric acid, nitric acid vapor, and particles of acid-forming sulfate and nitrate salts.
Acid deposition is a serious regional air pollution problem

- Descend to the earth’s surface in two forms:
  - Wet deposition consisting of acidic rain, snow, fog, and cloud vapor, and dry deposition resulting in a mixture called acid deposition, or acid rain.
  - Dry acid deposition (sulfur dioxide gas and particles of sulfate and nitrate salts).
- Mixture of wet and dry is called acid deposition—sometimes called acid rain.
Acid deposition, which consists of rain, snow, dust, or gas with a pH lower than 5.6, is commonly called acid rain.
Current and potential regions where acid deposition is a problem
Acid deposition has a number of harmful effects

- Damages statues and buildings, contributes to human respiratory diseases, and can leach toxic metals (such as lead and mercury) from soils and rocks into lakes used as sources of drinking water.
- Toxic metals can accumulate in the tissues of fish which are eaten by people and other animals.
- 45 U.S. states have issued warnings telling people to avoid eating fish caught from waters that are contaminated with toxic mercury.
Acid deposition has a number of harmful effects

• Harms aquatic ecosystems, and can leave lakes with few if any fish.
• Indirectly kills trees by leaching essential plant nutrients such as calcium and magnesium from soils and releasing ions of aluminum, lead, cadmium, and mercury, which are toxic to the trees, leaving them vulnerable to stresses.
We know how to reduce acid deposition

• The best solutions are prevention approaches that reduce or eliminate emissions of sulfur dioxide, nitrogen oxides, and particulates.

• Implementing these solutions is politically difficult.
There are several ways to reduce acid deposition and its damage.

**Solutions**

**Acid Deposition**

**Prevention**
- Reduce coal use
- Burn low-sulfur coal
- Increase use of natural gas and renewable energy resources
- Remove SO\(_2\) particulates and NO\(_X\) from smokestack gases and remove NO\(_X\) from motor vehicular exhaust
- Tax emissions of SO\(_2\)

**Cleanup**
- Add lime to neutralize acidified lakes
- Add phosphate fertilizer to neutralize acidified lakes
Indoor air pollution is a serious problem

- In less-developed countries, the indoor burning of wood, charcoal, dung, crop residues, coal, and other cooking and heating fuels in open fires or in unvented or poorly vented stoves exposes people to dangerous levels of particulate air pollution.

- Indoor air pollution is a serious problem in developed areas of all countries, mostly because of chemicals used in building materials and products.
Indoor air pollution is a serious problem

- EPA studies have revealed some alarming facts about indoor air pollution.
  - Levels of 11 common pollutants generally are two to five times higher inside U.S. homes and commercial buildings than they are outdoors.
  - Pollution levels inside cars in traffic-clogged urban areas can be up to 18 times higher than outside levels.
  - The health risks from exposure to such chemicals are magnified because most people in developed urban areas spend 70–98% of their time indoors or inside vehicles.
Indoor air pollution is a serious problem

• The four most dangerous indoor air pollutants in more-developed countries are:
  – tobacco smoke
  – formaldehyde emitted from many building materials and various household products
  – radioactive radon-222 gas, which can seep into houses from underground rock deposits
  – very small (ultrafine) particles of various substances in emissions from motor vehicles, coal-burning facilities, wood burning, and forest and grass fires
Numerous indoor air pollutants are found in most modern homes.
Air pollution is a big killer

- Your respiratory system helps protect you from air pollution.
  - Hairs in your nose filter out large particles.
  - Sticky mucus in the lining of your upper respiratory tract captures smaller (but not the smallest) particles and dissolves some gaseous pollutants.
  - Sneezing and coughing expel contaminated air.
  - Hundreds of thousands of tiny mucus-coated hairlike structures, called cilia, line your upper respiratory tract to trap pollutants.
Air pollution is a big killer

- Prolonged or acute exposure to air pollutants, can overload or break down these natural defenses.
- Fine and ultrafine particulates get lodged deep in the lungs, contributing to lung cancer, asthma, heart attack, and stroke.
- Years of inhaling smoke polluted air can lead to other lung ailments such as chronic bronchitis and emphysema, leading to acute shortness of breath.
- At least 2.4 million people worldwide die prematurely each year from the effects of air pollution.
Air pollution is a big killer

- The annual number of deaths related to indoor and outdoor air pollution ranges from 150,000 to 350,000 people in the U.S.
- Millions more suffer from asthma attacks and other respiratory disorders.
- Every year, 125,000+ Americans get cancer from breathing sooty diesel fumes emitted by buses, trucks, tractors, construction equipment, and train engines.
- Many cargo ships burn low-grade oil called bunker fuel in which the concentration of polluting sulfur is 30 times higher than that of diesel fuel sold at the pumps of U.S. gas stations.
The major components of the human respiratory system can help to protect you from air pollution, but these defenses can be overwhelmed or breached.
The distribution of premature deaths from air pollution in the United States
HOW SHOULD WE DEAL WITH AIR POLLUTION?
Laws and regulations can reduce outdoor air pollution

• The United States provides an excellent example of how a regulatory approach can reduce air pollution.

  – The federal government established air pollution regulations for key pollutants that are enforced by states and major cities.
Laws and regulations can reduce outdoor air pollution

- Six major outdoor pollutants regulated:
  - Carbon monoxide
  - Nitrogen dioxide
  - Sulfur dioxide
  - Suspended particulate matter
  - Ozone
  - Lead
Laws and regulations can reduce outdoor air pollution

• The combined emissions of the six major pollutants decreased by ~54% between 1980 and 2008, even with significant increases during the same period in gross domestic product, vehicle miles traveled, energy consumption, and population.

• The reduction of outdoor air pollution in the U.S. since 1970 has been a remarkable success story, mostly because of two factors.
  – Citizens insisted that laws be passed and enforced to improve air quality.
  – The country was affluent enough to afford such controls and improvements.
Laws and regulations can reduce outdoor air pollution

- U.S. air pollution laws could be strengthened by:
  - Putting significant emphasis on preventing air pollution.
  - Sharply reducing emissions from older coal-burning power and industrial plants, cement plants, oil refineries, and waste incinerators.
  - Improving fuel efficiency standards for motor vehicles to match or exceed those of Europe, Japan, and China.
  - Regulating emissions from motorcycles and two-cycle gasoline engines more strictly.
  - Setting much stricter air pollution regulations for airports and oceangoing ships in U.S. waters.
  - Sharply reducing indoor air pollution.
We can use the marketplace to reduce outdoor air pollution

- Allow producers of air pollutants to buy and sell government air pollution shares in the marketplace.
- The Clean Air Act of 1990 authorized an emissions trading, or cap-and-trade, program, enabled coal-burning power plants to buy and sell SO$_2$ pollution rights.
  - Each plant is annually given a number of pollution credits, which allow it to emit a certain amount of SO$_2$.
  - A utility that emits less than its allotted amount has a surplus of pollution credits which it can use to offset SO$_2$ emissions at its other plants, keep for future plant expansions, or sell to other utilities or private parties.
We can use the marketplace to reduce outdoor air pollution

– Cheaper and more efficient than government regulation of air pollution.
– Allows utilities with older, dirtier power plants to buy their way out of their environmental responsibilities and to continue polluting.
– Cheating possible because cap-and-trade is based largely on self-reporting of emissions.

• Emissions trading is also being used for NO\textsubscript{x}. 
There are many ways to reduce outdoor air pollution

**Stationary Source Air Pollution**

**Prevention**
- Burn low-sulfur coal or remove sulfur from coal
- Convert coal to a liquid or gaseous fuel
- Phase out coal use

**Reduction or Disposal**
- Disperse emissions (which can increase downwind pollution) with tall smokestacks
- Remove pollutants from smokestack gases
- Tax each unit of pollution produced

**Motor Vehicle Air Pollution**

**Prevention**
- Walk, bike, or use mass transit

**Reduction**
- Require emission control devices
- Inspect car exhaust systems twice a year
- Set strict emission standards
- Get older, polluting cars off the road
Reducing indoor air pollution should be a priority.

**Solutions**

**Indoor Air Pollution**

**Prevention**
- Ban indoor smoking
- Set stricter formaldehyde emissions standards for carpet, furniture, and building materials
- Prevent radon infiltration

**Cleanup or Dilution**
- Use adjustable fresh air vents for work spaces
- Circulate air more frequently
- Circulate a building’s air through rooftop greenhouses
- Use efficient venting systems for wood-burning stoves

**Use less polluting cleaning agents, paints, and other products**
Replacing tradition wood-burning stoves with energy-efficient ones can reduce indoor pollution.

**Solutions**

**Indoor Air Pollution**

**Prevention**
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**Cleanup or Dilution**
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We can emphasize pollution prevention

• Greater emphasis on preventing air pollution.
• Will not take place unless individual citizens and groups put political pressure on elected officials to enact and enforce appropriate regulations.
• Citizens can, through their purchases, put economic pressure on companies to get them to manufacture and sell products and services that do not add to pollution problems.
Ways to prevent your exposure to indoor air pollution

What Can You Do?

Indoor Air Pollution

- Test for radon and formaldehyde inside your home and take corrective measures as needed
- Do not buy furniture and other products containing formaldehyde
- Remove your shoes before entering your house to reduce inputs of dust, lead, and pesticides
- Switch to phthalate-free detergents
- Use baked lemons as natural fragrance
- Test your house or workplace for asbestos fiber levels, and check for any crumbling asbestos materials if it was built before 1980

- Do not store gasoline, solvents, or other volatile hazardous chemicals inside a home or attached garage
- If you smoke, do it outside or in a closed room vented to the outside
- Make sure that wood-burning stoves, fireplaces, and kerosene and gas-burning heaters are properly installed, vented, and maintained
- Install carbon monoxide detectors in all sleeping areas
How might the earth’s climate change in the future?
Weather and climate are not the same

- Weather consists of short-term changes in atmospheric variables, such as the temperature and precipitation in a given area over a period of hours or days.
- Climate is determined by the average weather conditions of the earth or of a particular area, especially temperature and precipitation, over periods of at least three decades to thousands of years.
- One or two warmer or colder years or decades can result simply from changes in the weather; don’t necessarily tell us that the earth’s climate is warming or cooling.
- Climate scientists look at data on normally changing weather conditions to see if there has been a general rise or fall in any measurements such as average temperature or precipitation over a period of at least 30 years.
Climate change is not new

- Over the past 3.5 billion years, the planet’s climate has been altered by volcanic emissions, changes in solar input, continents moving slowly atop shifting tectonic plates, and other factors.
- Over the past 900,000 years, the atmosphere has experienced prolonged periods of global cooling and warming, known as glacial and interglacial periods.
- For roughly 10,000 years, we have lived in an interglacial period characterized by a fairly stable climate and a fairly steady average global surface temperature.
Climate change is not new

- For the past 1000 years, the average temperature of the atmosphere has remained fairly stable but began rising during the last century when people began clearing more forests and burning more fossil fuels.
- Past temperature changes are estimated through analysis of radioisotopes in rocks and fossils; plankton and radioisotopes in ocean sediments; tiny bubbles, layers of soot, and other materials trapped in different layers of ancient air found in ice cores from glaciers; pollen from the bottoms of lakes and bogs; tree rings; and temperature measurements taken regularly since 1861.
Estimated global average temperatures and average temperature change.

**Average Temperature (over past 900,000 years)**

- Temperature range from 9°C to 17°C.
- Peaks and troughs indicating variability over thousands of years.
- Present temperature around 15°C.

**Average Temperature (over past 130 years)**

- Temperature range from 13.6°C to 15.0°C.
- Steady increase from 1880 to 2020.

**Temperature Change (over past 22,000 years)**

- Agriculture established around 10,000 years ago.
- End of last ice age around 20,000 years ago.
- Average temperature over past 10,000 years = 15°C (59°F).

**Temperature Change (over past 1,000 years)**

- Temperature change ranging from -1°C to 2°C.
- Steady increase from 1,000 to 2,100 years.

Human activities emit large quantities of greenhouse gases

• A natural process called the greenhouse effect occurs when some of the solar energy absorbed by the earth radiates into the atmosphere as infrared radiation (heat).

• Four greenhouse gases absorb the heat which warms the lower atmosphere and the earth’s surface, helping to create a livable climate.
  – Water vapor (H₂O).
  – Carbon dioxide (CO₂).
  – Methane (CH₄).
  – Nitrous oxide (N₂O).
Human activities emit large quantities of greenhouse gases

- Since the beginning of the Industrial Revolution in the mid-1700s, human actions—mainly the burning of fossil fuels—have led to significant increases in the levels of greenhouse gases in the lower atmosphere.
- The average atmospheric concentration of CO₂ rose dramatically during that time, along with the average temperature of the atmosphere.
- The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 to document past climate changes and project future changes; its network includes more than 2,500 climate scientists and scientists in disciplines related to climate studies from more than 130 countries.
Human activities emit large quantities of greenhouse gases

- In 2007, the IPCC issued a report based on more than 29,000 sets of data, finding that:
  - The earth’s lower atmosphere has warmed, especially since 1980, due mostly to increased levels of CO\textsubscript{2} and other greenhouse gases.
  - Most of these increases are due to human activities, especially the burning of fossil fuels and deforestation.
  - These human-induced changes are beginning to change the earth’s climate.
  - If greenhouse gas concentrations continue to rise, the earth is likely to experience rapid atmospheric warming and climate disruption during this century.
Comparing atmospheric concentrations of carbon dioxide (CO2) and the atmosphere’s average temperature, 1880–2009
Human activities emit large quantities of greenhouse gases

- Evidence that the IPCC and other climate scientists used to support the major conclusions of the 2007 IPCC report:
  - Between 1906 and 2005, the average global surface temperature has risen by about 0.74 °C (1.3 °F). Primarily since 1980.
  - Average levels of CO₂ in the atmosphere rose sharply between 1960 and 2010.
  - The first decade in this century (2000–2009) was the warmest decade since, and 2010 was the warmest year on record.
  - In some parts of the world, glaciers are melting and floating sea ice is shrinking.
Human activities emit large quantities of greenhouse gases

- In 2010, NASA scientists reported on a survey of the world’s major lakes, which showed that these lakes have warmed since 1985 at rates of 0.81–1.8 °F per decade.

- During the 20th century, the world’s average sea level rose by 19 centimeters (7 inches), mostly because of runoff from melting land-based ice and the expansion of ocean water as its temperature increased. By comparison, sea levels rose about 2 centimeters (3/4 of an inch) in the 18th century and 6 centimeters (2 inches) in the 19th century.
Satellite data shows a 39% drop in the average cover of summer arctic sea ice between 1979 and 2010.
**CO₂ emissions play an important role**

- Data from the National Oceanic and Atmospheric Administration (NOAA) show that the atmospheric concentration of carbon dioxide rose from a level of 285 parts per million (ppm) around 1850 at the start of the Industrial Revolution, to 390 ppm in 2010, a 37% increase.
- Major climate models indicate a need to prevent CO₂ levels from exceeding 450 ppm—an estimated threshold, or irreversible tipping point, that could set into motion large-scale climate changes for hundreds to thousands of years.
How CO2 emissions from the burning of fossil fuels in selected countries increased between 1965 and 2009.
What role does the sun play?

• The energy output of the sun plays the key role in the earth’s temperature and this output has varied over millions of years, but separate studies concluded that most of the rise in global average atmospheric temperatures since 1980 could not be the result of increased solar output.

• The atmosphere is now heating from the bottom up, which indicates that inputs at the earth’s surface play an important role.

• Since the mid-1970s, the sun’s output has remained about the same and thus cannot account for the rise in temperature since 1975.
What role do oceans play in projected climate disruption?

- The world’s oceans help to moderate the earth’s average surface temperature, and thus its climate, by removing about 25–30% of the CO$_2$ pumped into the lower atmosphere by human activities.
- The oceans absorb heat from the lower atmosphere and currents slowly transfer some CO$_2$ to the deep ocean.
- The ability of the oceans to absorb CO$_2$ decreases as water temperatures increase, so as the oceans warm up, some of their dissolved CO$_2$ is released into the lower atmosphere.
What role do oceans play in projected climate disruption?

• The upper portion of the oceans warmed by an average of 0.32–0.67°C (0.6–1.2°F) during the last century—an astounding increase considering the huge volume of water involved—most likely due to increasing atmospheric temperatures.

• Increasing levels of CO₂ in the ocean have increased the acidity of its surface. This threatens corals and other organisms with shells made of calcium carbonate, which dissolves when acidity reaches a certain level.
There is uncertainty about the effects of cloud cover on projected atmospheric warming

- Warmer temperatures increase evaporation of surface water and create more clouds, which can either warm or cool the atmosphere.
- An increase in thick and continuous cumulus clouds at low altitudes could decrease surface warming by reflecting more sunlight back into space.
- An increase in thin, wispy cirrus clouds at high altitudes could increase the warming of the lower atmosphere by preventing more heat from escaping into space.
WHAT ARE SOME POSSIBLE EFFECTS OF A WARMER ATMOSPHERE?
Enhanced atmospheric warming could have severe consequences

• During this century, we face a rapid increase in the average temperature of the lower atmosphere.
• This is very likely to cause climate disruption, a rapid change in the fairly mild climate that we have had for the past 10,000 years.
• Such changes will determine where we can grow food and how much of it we can grow; which areas will suffer from increased drought and which will experience increased flooding; and in what areas people and many forms of wildlife can live.
Enhanced atmospheric warming could have severe consequences

- A 2003 U.S. National Academy of Sciences report laid out a nightmarish worst-case scenario in which human activities trigger new and abrupt climate and ecological changes that could last for thousands of years.
  - Ecosystems collapsing.
  - Floods in low-lying coastal cities.
  - Forests consumed in vast wildfires.
  - Grasslands, dried out from prolonged drought, turning into dust bowls.
  - Rivers and supplies of drinking and irrigation water could dry up.
Enhanced atmospheric warming could have severe consequences

– Premature extinction of up to half of the world’s species.
– Prolonged droughts.
– More intense and longer-lasting heat waves.
– More destructive storms and flooding.
– Much colder weather in some parts of the world.
– Rapid spread of some infectious tropical diseases.
Severe drought is likely to increase

• Severe and prolonged drought affects at least 30% of the earth’s land (excluding Antarctica).

• By 2059 up to 45% of the world’s land area could experience extreme drought.

• Effects of increased drought could include:
  – The growth of trees and other plants declines.
  – Wildfires increase in frequency.
  – Declining stream flows and less available surface water.
  – Falling water tables with more evaporation, worsened by farmers irrigating more to make up for drier conditions.
  – Shrinking lakes, reservoirs, and inland seas.
  – Dwindling rivers.
  – Water shortages for 1–3 billion people.
  – Declining biodiversity.
More ice and snow are likely to melt

- Climate models predict that climate change will be the most severe in the world’s polar regions.
- Light-colored ice and snow in these regions help to cool the earth by reflecting incoming solar energy.
- The melting of such ice and snow exposes much darker land and sea areas, which absorb more solar energy.
- Arctic atmospheric temperatures have risen almost twice as fast as average temperatures in the rest of the world during the past 50 years.
- Soot generated by North American, European, and Asian industries is darkening arctic ice and lessening its ability to reflect sunlight.
More ice and snow are likely to melt

• The overall projected long-term trend is for the average summer ice coverage to decrease.

• During the past 25 years, many of the world’s mountain glaciers have been melting and shrinking at accelerating rates.
  – Mountain glaciers are sources of water for drinking, irrigation, and hydropower.
  – Water, food, and power shortages could threaten billions of people in Asia and South America as these glaciers slowly melt over the next century or two.
Sea levels are rising

• A 2008 U.S. Geological Survey report concluded that the world’s average sea level will most likely rise 0.8–2 meters (3–6.5 feet) by the end of this century and probably keep rising for centuries.

• Rising sea levels are due to the expansion of seawater as it warms, and to the melting of land-based ice.
Sea levels are rising

- A 1-meter (3.3-foot) rise in the world’s average sea level by 2100 could:
  - degrade or destroy at least one-third of the world’s coastal estuaries, wetlands, and coral reefs
  - disrupt many of the world’s coastal fisheries
  - cause flooding and erosion of low-lying barrier islands and gently sloping coastlines, especially in U.S. coastal states
If the average sea level rises by 1 meter (3.3 feet), the areas shown in red in Florida will be flooded.
Sea levels are rising

• The projected rise in sea levels would also:
  – flood agricultural lowlands and deltas in coastal areas where much of the world’s rice is grown.
  – cause saltwater contamination of freshwater coastal aquifers and decreased supplies of groundwater needed for irrigation and drinking water supplies.
  – submerge low-lying islands around the world, flooding out a total population greater than that of the U.S.
  – displace at least 150 million people from flooded coastal cities
  – threaten trillions of dollars worth of buildings, roads, and other forms of infrastructure
Extreme weather is likely to increase in some areas

- Atmospheric warming will increase the incidence and intensity of extreme weather events.
  - Kill large numbers of people.
  - Reduce crop production
  - Expand deserts
- A warmer atmosphere can hold more moisture, so other areas will experience increased flooding from heavy and prolonged precipitation.
Extreme weather is likely to increase in some areas

- In some areas, global atmospheric warming will likely lead to colder winter weather.
- The consensus view of the effect of atmospheric warming on tropical storms and hurricanes is that projected atmospheric warming is likely to lead to fewer but stronger hurricanes that could cause more damage.
Climate disruption is a threat change will threaten biodiversity

- Projected climate disruption is likely to upset ecosystems and decrease biodiversity in areas of every continent.
- Approximately 30% of the land-based plant and animal species assessed so far could disappear if the average global temperature change exceeds 1.5–2.5°C (2.7–4.5°F).
- The hardest hit will be:
  - Plant and animal species in colder climates
  - Species at higher elevations
  - Plant and animal species with limited ranges
  - Those with limited tolerance for temperature change.
Climate disruption is a threat change will threaten biodiversity

- The populations of plant and animal species that thrive in warmer climates could grow.

- The ecosystems most likely to suffer disruption and species loss from climate change are:
  - Coral reefs.
  - Polar seas.
  - Coastal wetlands.
  - High-elevation mountaintops.
  - Alpine and arctic tundra.
Climate disruption is a threat change will threaten biodiversity

- The warmer climate would increase populations of insects and fungi that damage trees.
- Shifts in regional climate would also threaten many existing state and national parks, wildlife reserves, wilderness areas, and wetlands, along with much of the biodiversity they contain.
Agriculture could face an overall decline

- Crop productivity is projected to increase slightly at middle to high latitudes with moderate atmospheric warming, but decrease if warming goes too far (2007 IPCC report).
- Climate change models predict a decline in agricultural productivity in tropical and subtropical regions.
- Flooding of river deltas due to rising sea levels could reduce crop production in these areas and fish production in nearby coastal aquaculture ponds.
Agriculture could face an overall decline

- Food production could also decrease in farm regions that are dependent on rivers fed by snow and glacial melt, and in any arid and semiarid areas where droughts become more prolonged.
  - These disruptions could be largely unpredictable because of the projected increase in extreme weather as a result of a warmer atmosphere.
- By 2050, some 200–600 million of the world’s poorest and most vulnerable people could face starvation and malnutrition due to the effects of projected climate disruption.
A warmer world is likely to threaten the health of many people

- More frequent and prolonged heat waves in some areas will increase numbers of deaths and illnesses, especially among older people, people in poor health, and the urban poor who cannot afford air conditioning.
- Hunger and malnutrition will increase in areas where agricultural production drops.
- A warmer, CO$_2$-rich world will favor rapidly multiplying insects, microbes, toxic molds, and fungi that make us sick, and plants that produce pollens that cause allergies and asthma attacks.
A warmer world is likely to threaten the health of many people

- Microbes that cause infectious tropical diseases such as dengue fever and yellow fever are likely to expand their ranges and numbers if mosquitoes that carry them spread to warmer temperate and higher elevation areas as they have begun to do.
- A 2009 study estimated that climate disruption already contributes to the premature deaths of more than 300,000 people, and that 325 million people are now seriously affected by accelerating climate change through natural disasters and environmental degradation.
The orange-colored trees are those that are dead or dying—killed by mountain pine beetles.
Areas in blue show counties in 28 U.S. states where one or both species of mosquitoes that transmit dengue fever have been found as of 2005.
WHAT CAN WE DO TO SLOW PROJECTED CLIMATE CHANGE?
What are our options?

- Calling for urgent action at the national and international levels to curb greenhouse gas emissions by regulating and taxing such emissions will not work.
  - Psychological research indicates that using fear and guilt, and promoting sacrifice to change behavior rarely works.
  - People are primarily interested in the short-term, not long-term, benefits of changing their behavior.
  - For elected officials whose future depends on running every few years, spending their efforts on long-term problems is most often not in their best short-term.
What are our options?

- Important short-term benefits for individuals, corporations, schools, and universities of working locally to reduce greenhouse gas emissions include:
  - Money saved from cutting energy use and waste; better health because of cleaner air; more jobs in the less polluting and more cost-competitive domestic wind and solar industries
  - Improved national and economic security due to reduced dependence on imported oil.
What are our options?

• Most climate scientists argue that our most urgent priority is to do all we can to avoid any and all climate change tipping points—thresholds beyond which natural systems can change irreversibly.

• There are two basic approaches to dealing with the projected harmful effects of global climate disruption.
  – Mitigation is to act to slow it and avoid tipping points.
  – Adaptation is to recognize that some climate change is unavoidable and to try to reduce some of its harmful effects.

• Some say that climate change will provide economic opportunity and that making a shift to a low-carbon economy will lead us into a new era of economic growth and prosperity.
Scientists have come up with this list of possible climate change tipping points:

- Atmospheric carbon level of 450 ppm
- Melting of all Arctic summer sea ice
- Collapse and melting of the Greenland ice sheet
- Severe ocean acidification, collapse of phytoplankton populations, and a sharp drop in the ability of the oceans to absorb CO₂
- Massive release of methane from thawing Arctic permafrost
- Collapse and melting of most of the western Antarctic ice sheet
- Severe shrinkage or collapse of the Amazon rain forest
Preventing and reducing greenhouse gas emissions

• Four major prevention strategies.
  – Improve energy efficiency to reduce fossil fuel use, especially the use of coal.
  – Shift from nonrenewable carbon-based fossil fuels to a mix of low-carbon renewable energy resources based on local and regional availability.
  – Stop cutting down tropical forests and plant trees to help remove more CO₂ from the atmosphere.
  – Shift to more sustainable and climate-friendly agriculture.
Ways to slow atmospheric warming and projected climate disruption during this century

**Solutions**

**Slowing Climate Disruption**

**Prevention**
- Cut fossil fuel use (especially coal)
- Shift from coal to natural gas
- Improve energy efficiency
- Shift to renewable energy resources
- Transfer energy efficiency and renewable energy technologies to developing countries
- Reduce deforestation
- Use more sustainable agriculture and forestry
- Put a price on greenhouse gas emissions
- Reduce poverty
- Slow population growth

**Cleanup**
- Remove CO₂ from smokestack and vehicle emissions
- Store (sequester) CO₂ by planting trees
- Sequester CO₂ in soil by using no-till cultivation and taking cropland out of production
- Sequester CO₂ deep underground (with no leaks allowed)
- Sequester CO₂ in the deep ocean (with no leaks allowed)
- Repair leaky natural gas pipelines and facilities
- Use animal feeds that reduce CH₄ emissions from cows (belching)
Preventing and reducing greenhouse gas emissions

• Output, or cleanup, strategies focus on dealing with CO$_2$ after it has been produced.
  – Carbon capture and storage, or CCS, involves removing CO$_2$ from the smokestacks of coal-burning power and industrial plants and storing it deep underground in abandoned coal beds and oil and gas fields or under the sea floor.
  • Stored CO$_2$ would have to remain sealed from the atmosphere forever because leaks could dramatically increase atmospheric warming in a very short time.
Preventing and reducing greenhouse gas emissions

• Focus on reducing and preventing greenhouse gas emissions, as soon as possible.

• Some scientists urge us to increase efforts to reduce emissions of other greenhouse gases.
  – Methane (CH$_4$) is 25 times more effective in warming the atmosphere than CO$_2$.
  – Soot is accumulating on glaciers and ice fields and contributing to the melting of this ice and to atmospheric warming.
Preventing and reducing greenhouse gas emissions

• Geo-engineering or trying to manipulate natural conditions to counter an enhanced greenhouse effect.
  – Injecting sulfate particles into the stratosphere to reflect some of the incoming sunlight into space and cool the troposphere.
  – Placing a series of giant mirrors in orbit above the earth for the same purpose.

• One major problem with most of these fixes is that they require huge investments of energy and materials, and there is no guarantee that they will work.
Preventing and reducing greenhouse gas emissions

• If we rely on these systems and continue emitting greenhouse gases, and if the systems then fail, atmospheric temperatures will likely soar at a rapid rate, greatly speeding up the processes of climate disruption.
Governments can help to reduce the threat of climate disruption

• Governments can use six major methods to promote the solutions.
  – Strictly regulate carbon dioxide (CO₂) and methane (CH₄).
  – Phase out the most inefficient polluting coal-burning power plants and replace them with more efficient, cleaner natural gas and renewable energy such as wind power.
  – Tax each unit of CO₂ or CH₄ emitted or burned by fossil fuel use, and offsetting these tax increases by reducing taxes on income, wages, and profits.
  – Use a cap-and-trade system.
Governments can help to reduce the threat of climate disruption

– Replace government subsidies and tax breaks for the fossil fuels industry and industrialized food production with energy efficiency technologies, low-carbon renewable energy sources, and more sustainable agriculture.

– Focus research and development efforts on innovations that lower the cost of clean energy alternatives, so that they can compete more favorably with fossil fuels.

– Finance and monitor efforts to reduce deforestation—which accounts for 12% to 17% of global greenhouse gas emissions—and to promote global tree-planting efforts.

– Encourage more-developed countries to help fund the transfer of the latest energy-efficiency and cleaner energy technologies to less-developed countries so that they can bypass older, energy wasting and polluting technologies.
Governments can help to reduce the threat of climate disruption

- Many say that the most critical goal for governments is to find ways to put a price on carbon emissions.
- The resulting higher costs for fossil fuels may spur innovation in finding ways to reduce carbon emissions, improve energy efficiency, and phase in a mix of cleaner, low-carbon renewable energy alternatives.
- Establishing laws and regulations that raise the price of fossil fuels is politically difficult because of the immense political and economic power of the fossil fuel industries.
Governments can help to reduce the threat of climate disruption

• In December 1997, delegates from 161 nations met in Kyoto, Japan, to negotiate a treaty to slow global warming and its projected climate disruption.
  – The Kyoto Protocol went into effect in 2005 with 187 of the world’s 194 countries (not including the U.S.) ratifying the agreement by late 2009.
  – Requires the 36 participating more-developed countries to cut their emissions of CO₂, CH₄, and N₂O to certain levels by 2012, when the treaty expires.
  – Less-developed countries were excluded from this requirement, because such reductions would curb their economic growth.
  – Negotiations have failed to extend the original agreement after 2012.
Government interventions have advantages and disadvantages

**Trade-Offs**

**Carbon and Energy Taxes**

**Advantages**
- Simple to administer
- Clear price on carbon
- Covers all emitters
- Predictable revenues

**Disadvantages**
- Tax laws can get complex
- Vulnerable to loopholes
- Doesn’t guarantee lower emissions
- Politically unpopular

**Trade-Offs**

**Cap and Trade Policies**

**Advantages**
- Clear legal limit on emissions
- Rewards cuts in emissions
- Record of success
- Low expense for consumers

**Disadvantages**
- Revenues not predictable
- Vulnerable to cheating
- Rich polluters can keep polluting
- Puts variable price on carbon
Some countries, states and localities are leading the way

- Costa Rica aims to be the first country to become carbon neutral by cutting its net carbon emissions to zero by 2030.
- China has one of the world’s most intensive energy efficiency programs.
- By 2010, at least 30 U.S. states had set goals for reducing greenhouse gas emissions.
- Since 1990, local governments in more than 650 cities around the world (including more than 450 U.S. cities) have established programs to reduce their greenhouse gas emissions.
Some companies are reducing their carbon footprints

• Leaders of some of the most prominent U.S. companies, including Alcoa, DuPont, Ford Motor Company, General Electric, Johnson & Johnson, PepsiCo, and Shell Oil, have joined with leading environmental organizations to form the U.S. Climate Action Partnership.
  – Called on the government to enact strong national climate change legislation.
  – Profit opportunity in developing or using energy-efficient and cleaner-energy technologies, such as fuel-efficient cars, wind turbines, and solar cells.
Individual choices make a difference

• Each of us plays a part in the projected acceleration of atmospheric warming and climate disruption during this century. Whenever we use energy generated by fossil fuels, for example, we add a certain amount of CO$_2$ to the atmosphere. Each use of energy adds to an individual’s carbon footprint, the amount of carbon dioxide generated by one’s lifestyle.
You can reduce your annual emissions of CO₂

What Can You Do?

Reducing CO₂ Emissions

- Calculate your carbon footprint (there are many helpful websites)
- Walk, bike, carpool, and use mass transit or drive fuel-efficient cars
- Reduce garbage by recycling and reusing more items
- Use energy-efficient appliances and compact fluorescent or LED lightbulbs
- Wash laundry in warm or cold water
- Dry clothes on a rack or line
- Use a low-flow showerhead
- Eat less meat or no meat
- Heavily insulate your house and seal all air leaks
- Use energy-efficient windows
- Insulate your hot water heater and set it at 49°C (120°F)
- Plant trees to shade your house during summer
- Buy from businesses working to reduce their emissions
We can prepare for climate change

- The world needs to make a 50–85% cut in emissions of greenhouse gases by 2050 to stabilize concentrations of these gases in the atmosphere which would help prevent the planet from heating up by more than 2ºC (3.6ºF) and to head off rapid changes in the world’s climate and the projected harmful effects that would result.

- Also should begin to prepare for the likely harmful effects of projected climate disruption.
A no-regrets strategy

• What if it turns out that the climate models are wrong and atmospheric warming is not a serious threat?
  – Should we abandon the search for preventive solutions?
    • No, we should begin implementing changes now as a no-regrets strategy.
    • Changes should be implemented because they will lead to very important environmental, health, and economic benefits.
Section 15-7

HOW HAVE WE DEPLETED OZONE IN THE STRATOSPHERE AND WHAT CAN WE DO ABOUT IT?
Our use of certain chemicals threatens the ozone layer

- A layer of ozone in the lower stratosphere keeps about 95% of the sun’s harmful ultraviolet (UV-A and UV-B) radiation from reaching the earth’s surface.
- Measurements show considerable seasonal depletion (thinning) of ozone concentrations in the stratosphere above Antarctica and the Arctic and a lower overall ozone thinning everywhere except over the tropics.
- Ozone depletion in the stratosphere poses a serious threat to humans, other animals, and some primary producers (mostly plants) that use sunlight to support the earth’s food webs.
A massive ozone thinning over Antarctica during several months in 2009
Our use of certain chemicals threatens the ozone layer

- Problem began with the discovery of the first chlorofluorocarbon (CFC) in 1930 and later Freon.
  - Popular non-toxic, inexpensive coolants in air conditioners and refrigerators, propellants in aerosol spray cans, cleaners for electronic parts such as computer chips, fumigants for granaries and ship cargo holds, and gases used to make insulation and packaging.
  - CFCs are persistent chemicals that destroy the ozone layer.
Why should we worry about ozone depletion?

• More biologically damaging UV-A and UV-B radiation will reach the earth’s surface.
• Causes problems with human health, crop yields, forest productivity, climate change, wildlife populations, air pollution, and degradation of outdoor materials.
Decreased levels of ozone in the stratosphere can have a number of harmful effects.
You can reduce your exposure to harmful UV radiation

**What Can You Do?**

**Reducing Exposure to UV Radiation**

- Stay out of the sun, especially between 10 A.M. and 3 P.M.
- Do not use tanning parlors or sunlamps.
- When in the sun, wear protective clothing and sunglasses that protect against UV-A and UV-B radiation.
- Be aware that overcast skies do not protect you.
- Do not expose yourself to the sun if you are taking antibiotics or birth control pills.
- When in the sun, use a sunscreen with a protection factor of at least 15.
- Examine your skin and scalp at least once a month for moles or warts that change in size, shape, or color and sores that do not heal. If you observe any of these signs, consult a doctor immediately.
We can reverse stratospheric ozone depletion

• The problem of ozone depletion has been tackled quite impressively.

• In 2008, the area of ozone thinning was still near its record high of 29 million square kilometers (11 million square miles), set in 2006.

• Models indicate that even with immediate and sustained action.
  – About 60 years for the earth’s ozone layer to recover the levels of ozone it had in 1980.
  – About 100 years for recovery to pre-1950 levels.
We can reverse stratospheric ozone depletion

• In 1987, representatives of 36 nations met in Montreal, Canada, and developed the Montreal Protocol to cut emissions of CFCs.

• In 1992, adopted the Copenhagen Protocol, an amendment that accelerated the phase-out of key ozone-depleting chemicals signed by 195 countries.

• The ozone protocols set an important precedent by using prevention to solve a serious environmental problem.
Three big ideas

• All countries need to step up efforts to control air pollution.

• Reducing the projected harmful effects of rapid climate disruption during this century requires emergency action to increase energy efficiency, sharply reduce greenhouse gas emissions, rely more on renewable energy resources, and slow population growth.

• We need to continue phasing out the use of chemicals that have reduced ozone levels.