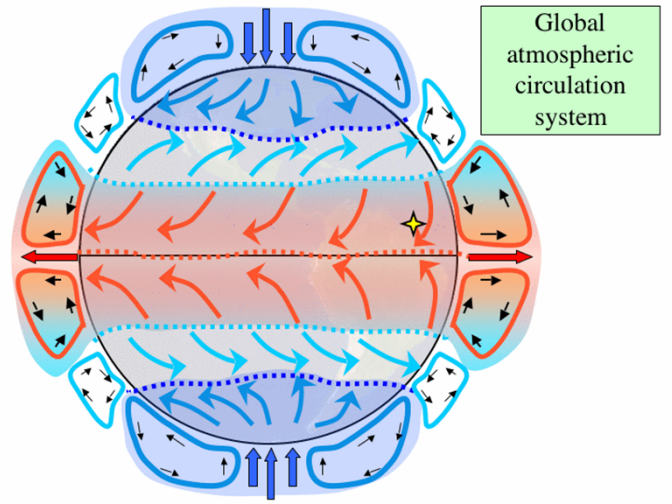
Chapter 1. Introduction

Long-Range Transport: Planetary Transport

- Transport of air (pollutants) hundreds/thousands of miles; resulting in air quality problems far away from the source



Pure dry air at sea level

78.08% nitrogen, 20.95% oxygen

Gas Name	Symbol	Percent by Volume
Nitrogen	**N_2**	**78.084 %**
Oxygen	**O_2**	**20.9476 %**
Argon	Ar	0.934 %
Carbon Dioxide	CO_2	0.0314 %
Neon	Ne	0.001818 %
Methane	CH_4	0.0002 %
Helium	He	0.000524 %
Krypton	Kr	0.000114 %
Hydrogen	H_2	0.00005 %
Xenon	Xe	0.0000087 %

Air Emissions

- **Air pollution emissions**
  - Commonly referred to as air pollutants
  - Species in the air that cause acute or chronic human health problems
  - and negative environmental impact.
- **Greenhouse gas (GHG) emissions.**
  - Not toxic unless at extremely high concentrations
  - May have resulted in global warming and climate change

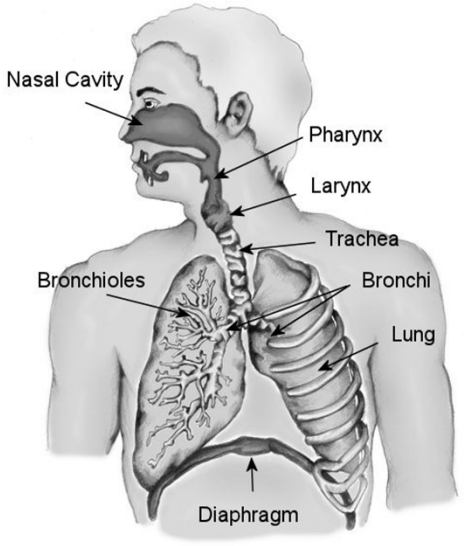
Air Pollution

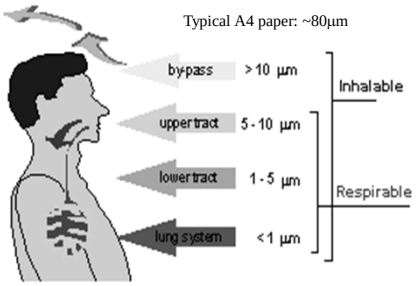
- Air pollution occurs when there is an addition of unwanted substances
- Especially when it is large enough to adversely affect the population's health as and the environment
- Only when an airborne compound that is against the interest of humans can be classified as an "*air pollutant*"

Effects of Air Pollution

On a daily basis an average adult consumes

- 1 kg of food, 2 kg of water, 20 kg of air.





- Respiratory problems:
  Lung dysfunctions, asthma, fever, cough, bronchial constriction, inflammation
- Irritation:
  dry eyes, headache, sneezing, nausea, allergy…
- Mortality: premature death
  - Example: 1.2 million premature death in China, each year. (WHO 2013)
- Entering brain and circulation system, resulting heart diseases and cancers.

Children and the elderly are more vulnerable

- Children are more sensitive to the effects of air pollution as breathe more rapidly and inhale more pollution per body weight than adults do.
- Fine particles can permanently harm lung development, and cause early childhood asthma.
- Aging changes immune system

USA/Canada

- In the US where air is relative much cleaner than the rest of the world, lung dysfunction, which is a direct result of exposure to air pollutants, ranks among the top 10 most important occupational diseases and injuries.

China

- **440,000 dies from Air Pollution related heart diseases and cancer**
  - 300,000 by indoor air pollution
  - 110,000 by outdoor air pollution
  - In 2020 the number can reach550,000
- **Higher numbers reported by World Bank**

Environmental Impact

Acid rain

- Acid rain was first discovered in 1852 and extensively studied since the late 1960s

  $NO_2 + H_2O \rightarrow H_2NO_3$

  $SO_2 + H_2O + O_2 \rightarrow H_2SO_4$

Low visibility

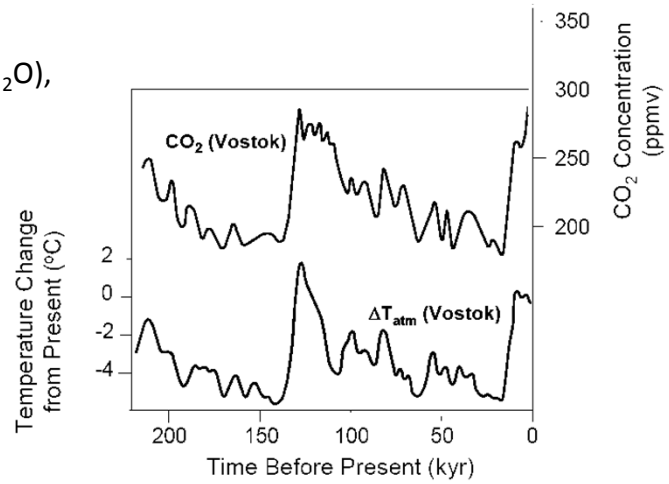
- Low visibility is a direct and practical perception of poor air quality
- Smog (Smoke + Fog)


Beijing


Los Angles

Greenhouse Gases and Climate change

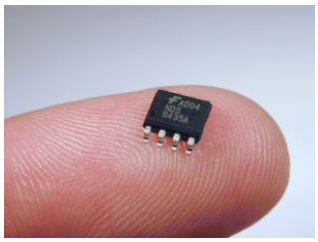
- CO_2
- Methane (CH_4)
- Nitrous oxide (N_2O),
- Water vapor!!!



Air emission is an evolving challenge





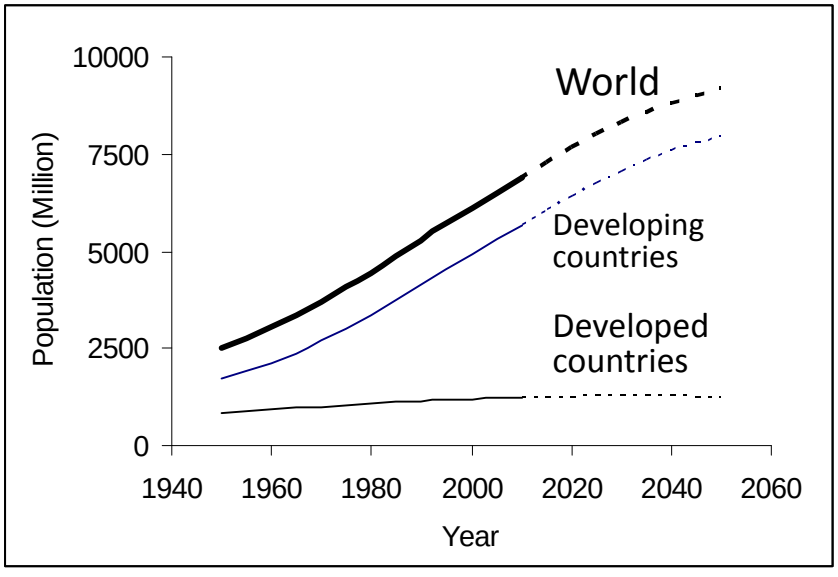


Sources of Air Pollution

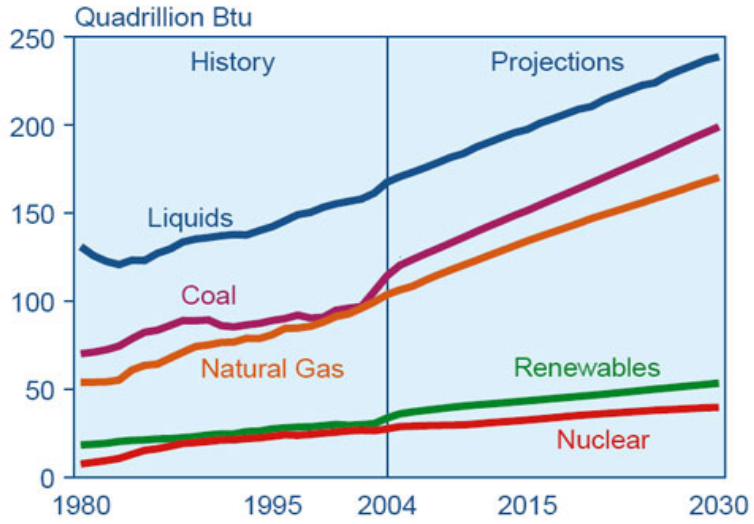
Anthropogenic

Energy and Environment

Global Population

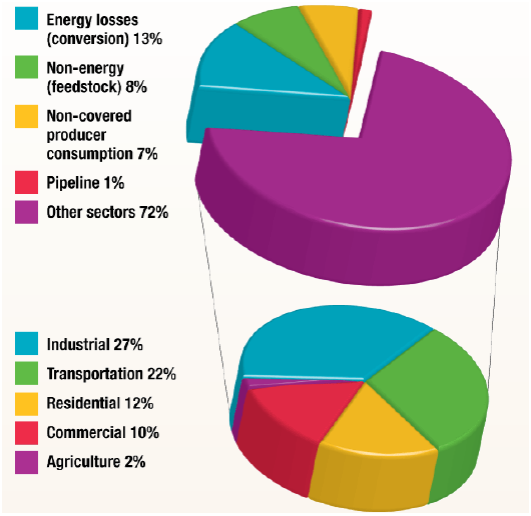


Global Energy Consumption



Canadian Energy Report

In 2009, Canadians spent about $152 billion on energy to heat and cool their homes and offices and to operate their appliances, cars and industrial processes.



Source: NRC, 12/2011, Energy Efficiency Trends in Canada 1990 to 2009

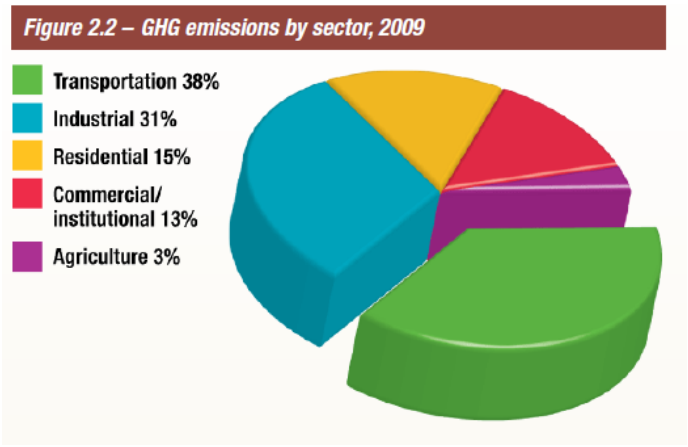
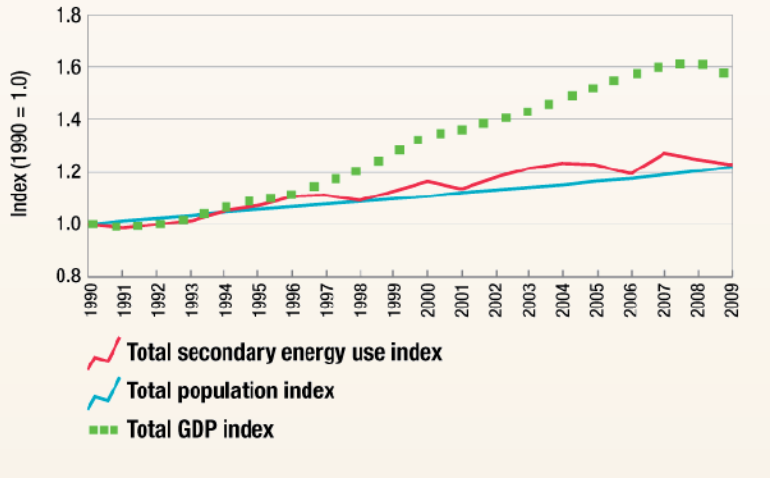
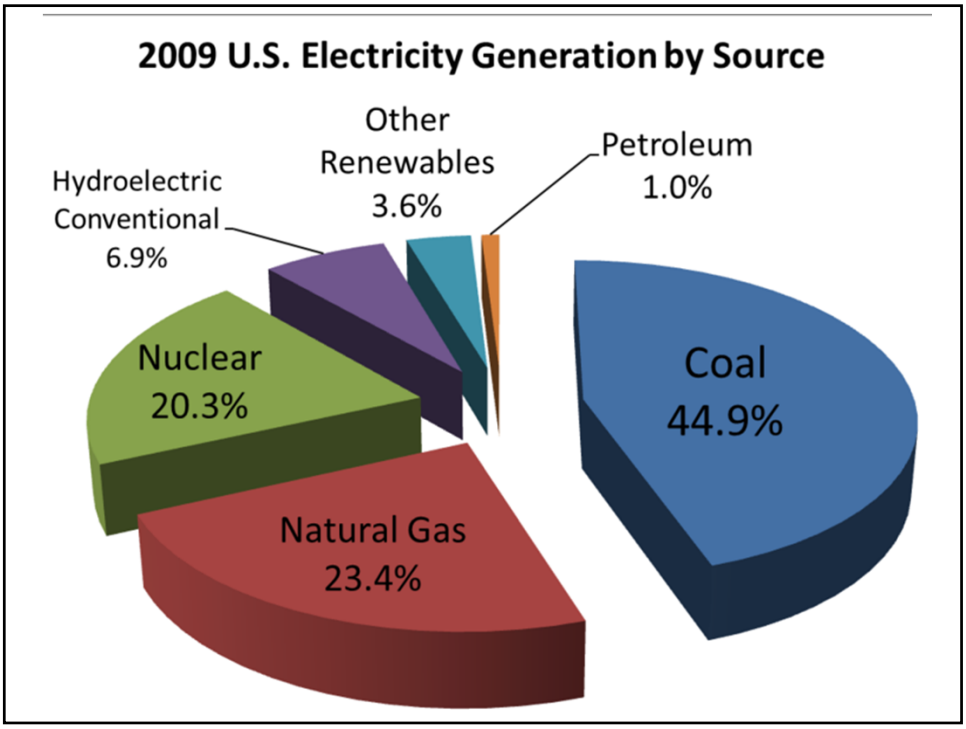
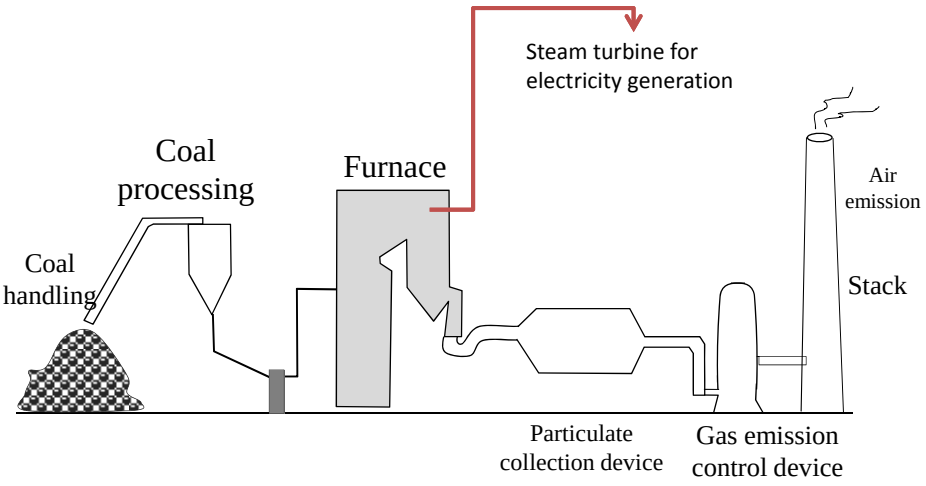


Figure 2.4 – Total secondary energy use, Canadian population and GDP, 1990–2009

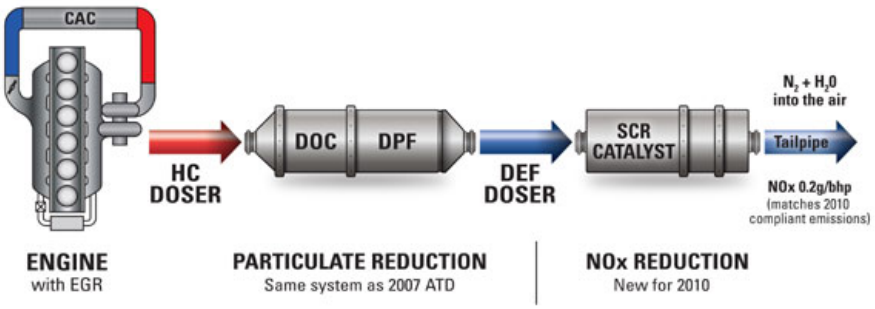




Schematic of a Power Plant



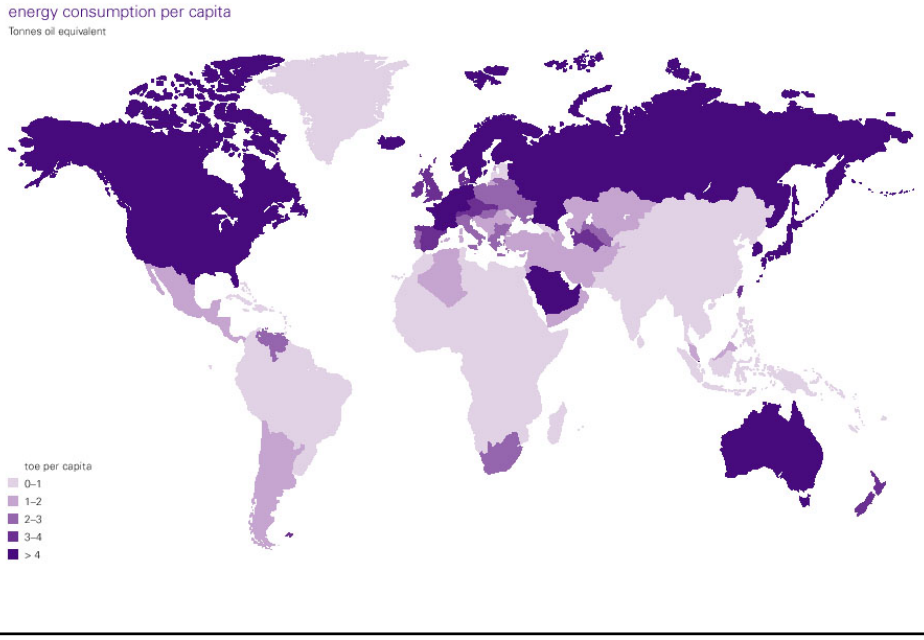
Schematic Diagram of an Engine Exhaust



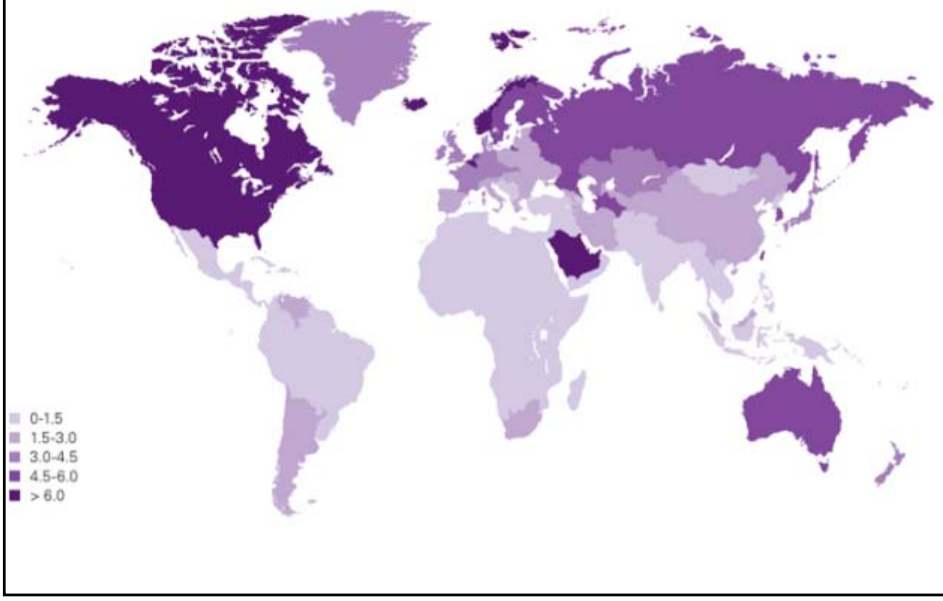
Diesel Particulate Filter (DPF)

Selective Catalytic Reduction (SCR)

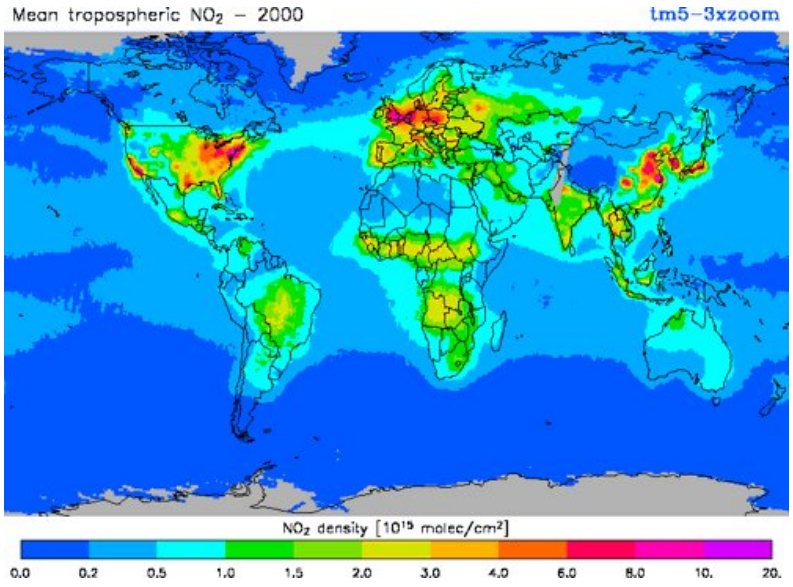
2002


energy consumption per capita
Tonnes oil equivalent
toe per capita
0–1
1–2
2–3
3–4
> 4

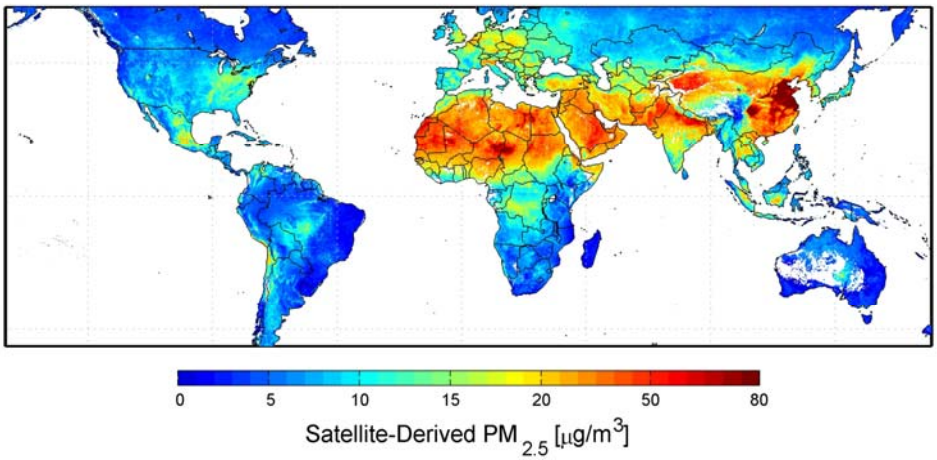
2009


Consumption per capita 2009
Tonnes oil equivalent
0-1.5
1.5-3.0
3.0-4.5
4.5-6.0
> 6.0

Global air pollution



Global satellite-derived map of PM2.5 averaged over 2001-2006.



Standard: USA: 35 μg/m3 (was 65); Europe: 25 μg/m3

- NASA website (2012) (Credit:, Aaron van Donkelaar)

China

- Chinese EPA, 2010 Report：
  - Air in 1/3 of the 113 cities under monitoring did not meet the Chinese standard.
- World Bank research results: only 1% of the population in the cities can inhale air meeting European standard.

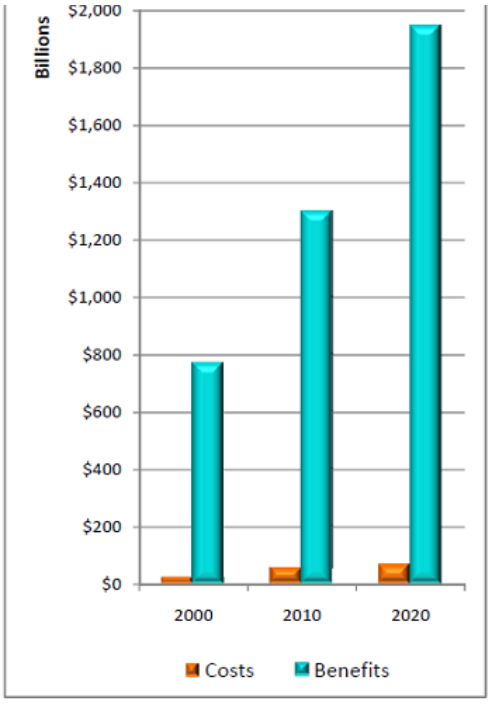
Benefits of air pollution control

- avoiding early death,
- preventing heart attacks and asthma attacks,
- reducing the number of sick days for employees

The US Clean Air Act After 40 Years

- In March 2011, the EPA released its report, "The Benefits and Costs of the Clean Air Act From 1990 to 2020."
- According to the report estimates
  - the benefits of reducing fine particle and ground level ozone pollution under the 1990 Clean Air Act amendments **Saved 160,000 lives in 2010 alone.**
- will reach approximately $2 trillion in 2020 while saving 230,000 people from early death in that year alone.

Estimates of costs and benefits of the 1990 Clean Air Act Amendments.
Source: US EPA



History of air pollution

- 1970s: energy crisis ➔tight building envelopes ➔Indoor air quality➔ asthma and allergies.
- Dust/Haze
- Global warming
- Nano-air pollution

Air quality regulations

- Quantify the allowable amounts of substances that can be contained within the air without causing harm.
- Based on proven scientific and medical research
- Vary with location, time, sector, and so on
- Examples,
  - US National Ambient Air Quality Standards (NAAQS) established by the United States Environmental Protection Agency (US EPA) only applies to outdoor air quality throughout the country, and is subjected to review and revision regularly.
  - American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) ventilation standards define the best acceptable indoor air.

US Clean Air Act

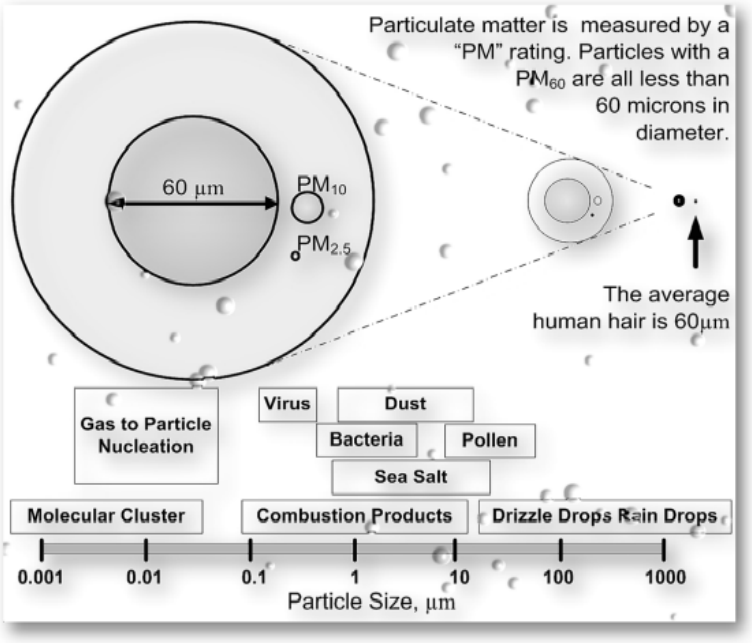
- Not all air pollutants are regulated by the government.
- The US Clean Air Act requires the EPA to set National Ambient Air Quality Standards for six criteria air pollutants:
  - Ground level ozone (O_3) ,
  - Particulate matter (PM),
  - Carbon monoxide (CO),
  - Sulfur dioxide (SO_2),
  - Nitrogen oxides (NO_x), and
  - Lead (Pb).
- These air pollutants are found all over the world.

Criteria air pollutants

- Of the six pollutants, particle pollution and ground-level ozone are the most widespread health threats.
- EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria for setting permissible levels.
- The set of limits based on human health are called primary standards.
- Similarly, secondary standards are intended to prevent environmental and property damage.

Particulate matter

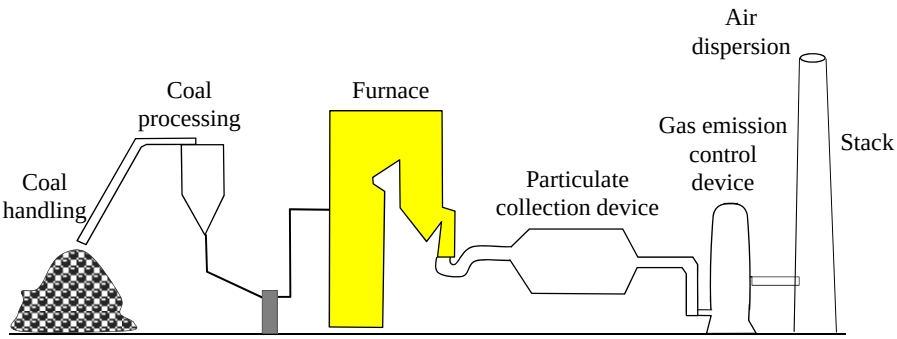
- PM is a mixture of solid particles and liquid droplets suspended in the air. In this book particulate matter is interchangeable with *aerosol*, a suspension of solid or liquid particles in a gas.
  - It is a two-phase system consisting of the particles and the gas in which they suspended.
- The airborne particles can be both primary pollutants and secondary pollutants,
  - Primary PM: sent directly into the atmosphere in the form of windblown dust and soil, sea salt spray, pollen and spores.
  - Secondary particles are formed through chemical reactions involving nitrogen oxides, sulfur dioxide, VOCs and ammonia.



Air Pollution Control Engineering Approaches

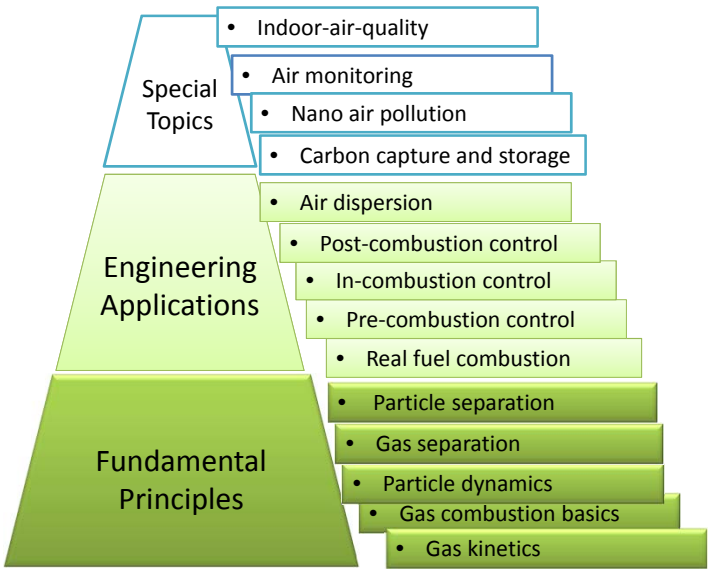
- Pre-combustion
  - Fuel refinery and cleaning
  - Renewable fuels
  - Energy conservation
- In-combustion
  - Combustion process modification
  - Injection of absorbents
- Post-combustion
  - Air cleaning
  - Air dispersion

Air Pollution Control Approaches



Pre-combustion	In-combustion	Post-combustion
• Fuel refinery and cleaning • Renewable fuels • Energy conservation	• Combustion process modification • Injection of absorbents	• Air cleaning • Air dispersion

Course Structure



Units

- SI units will be used in this book unless stated otherwise.
- The dimension of length (e.g. particle diameter) and mass may take different units and the conversions are as follows.
  - 1 mm = 1000 micrometer (μm)
  - 1 μm = 1000 nanometer (nm)
  - 1 gram (g) = 1000 milligram (mg) = 1,000,000 microgram (μg)
- Concentrations of air pollutants and GHGs can be presented in several dimensions including
  - mass per volume: kg/m^3 or mg/m^3 or $\mu g/m^3$
  - volume ratio: part per million (ppmv)
  - mass ratio: ppmm