EN 410
Energy Management

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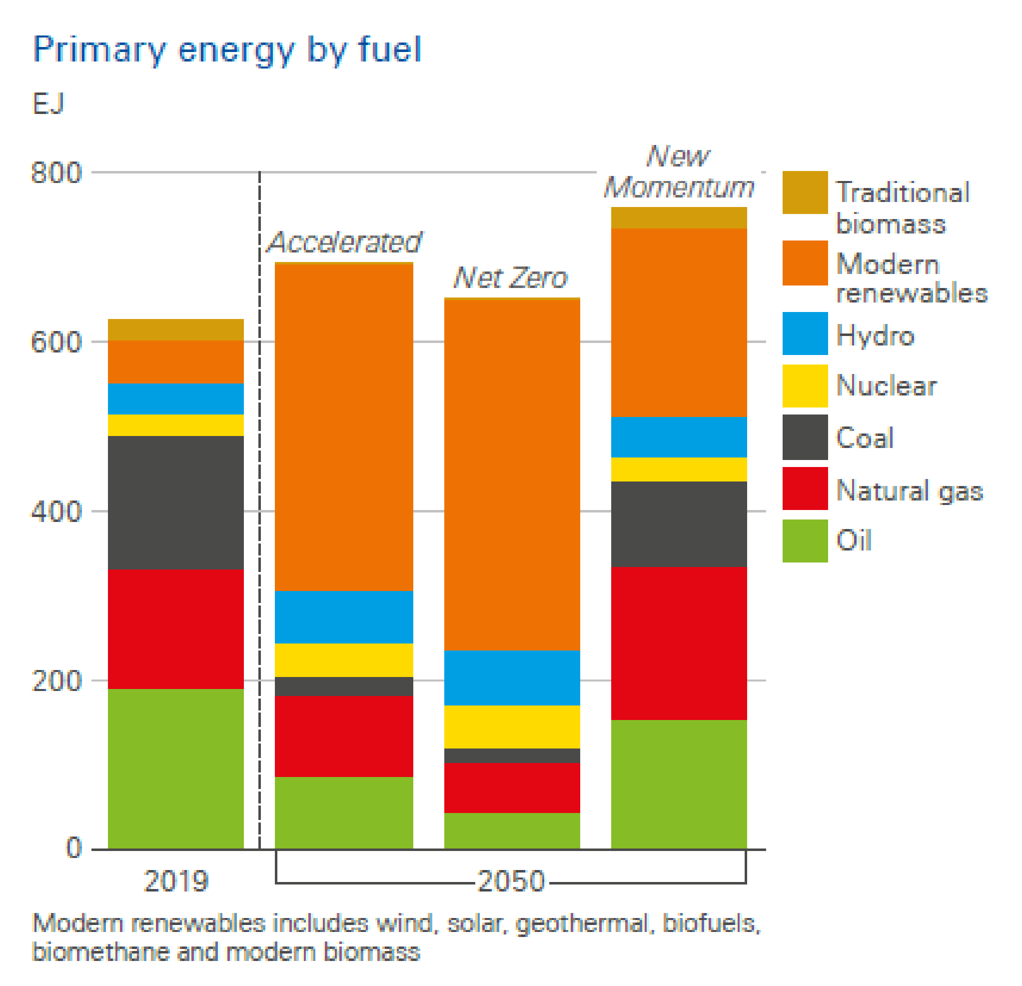
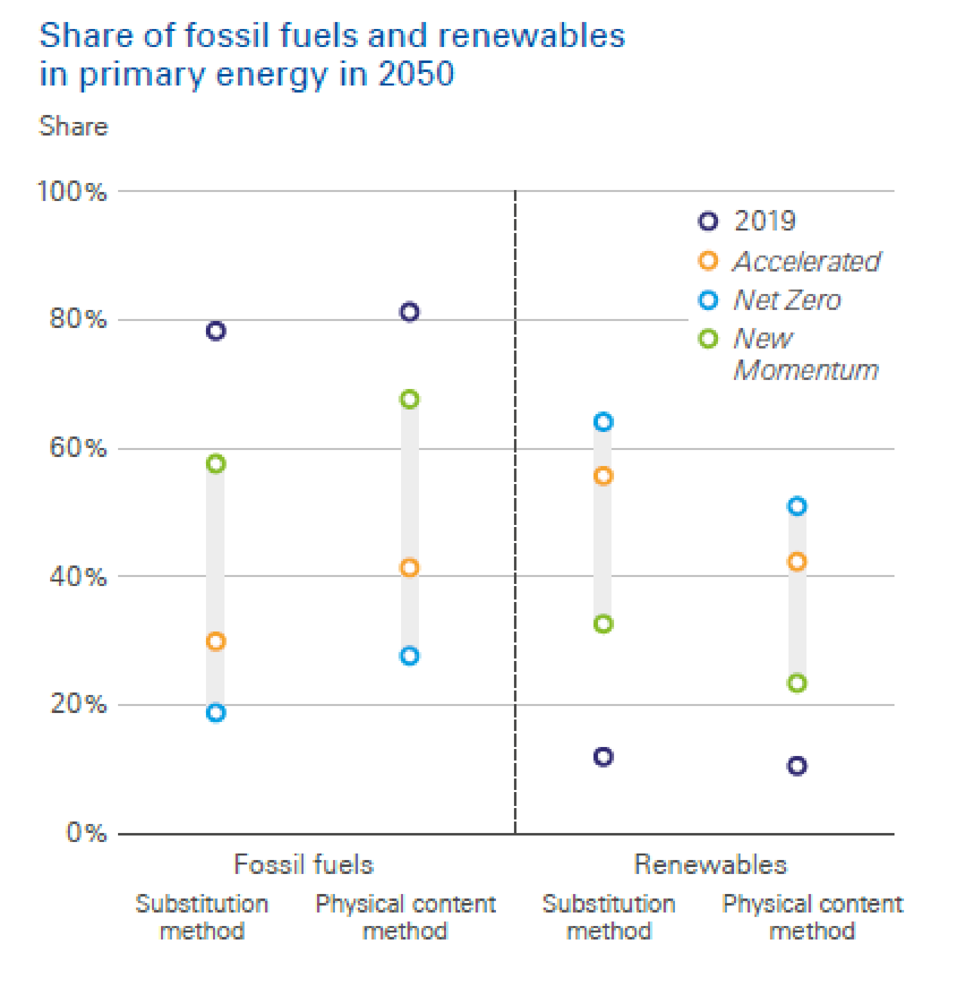
World energy need by fuel type





Fuel

- A fuel is a combustible substance which on proper burning gives large amount of heat
- The main elements are carbon and hydrogen

$$Fuel + O_2 \rightarrow CO_2 + H_2O + Heat$$

- According to physical state - Solid or liquid or gas
- According to the procurement – Natural or manufactured

Natural Fuels	Manufactured Fuels
Solid Fuels	
Wood Coal Oil shale	Tanbark, Bagasse, Straw Charcoal Coke Briquettes
Liquid Fuels	
Petroleum	Oils from distillation of petroleum Coal tar Shale-oil Alcohols, etc.
Gaseous Fuels	
Natural gas	Coal gas Producer gas Water gas Hydrogen Acetylene Blast furnace gas Oil gas

Properties of fuel

- The calorific value of a fuel is the quantity of heat produced by its combustion – at standard conditions for the given quantity
  - **Higher Calorific Value** - the water of combustion is entirely condensed and the heat contained in the water vapor is recovered
  - **Lower Calorific Value** - the products of combustion contains the water vapor and the heat in the water vapor is not recovered
- **Ash content** – related to inorganic material, excessive may lead to erosive effect on burner tips
- **Sulphur** – depend of source, risk of corrosion by sulphuric acid formation during and after combustion, condensing in cooled parts
- **Carbon residue -** tendency to deposit carbonaceous solid residue on a hot surface
- **Water Content -** present in free or emulsified form

Advantages

- They posses higher calorific value per unit mass than solid fuels
- They burn without dust, ash, clinkers, etc.
- They are easy to transport through pipes
- They can be stored indefinitely without any loss
- Their firing is easier and also fire can be extinguished easily by stopping liquid fuel supply
- They are clean in use and economic to handle
- Loss of heat in chimney is very low due to greater cleanliness
- They require less excess air for complete combustion
- They require less furnace space for combustion

Disadvantages

- The cost of liquid fuel is relatively much higher as compared to solid fuel
- There is a greater risk of fire hazards, particularly, in case of highly inflammable and volatile liquid fuels
- Costly special storage tanks are required for storing liquid fuels
- For efficient burning of liquid fuels, specially constructed burners and spraying apparatus are required

Solid Fuels

Advantages

- They are convenient to store without any risk of spontaneous explosion
- Their cost of production is low
- They are easy to transport
- They posses moderate ignition temperature

Disadvantages

- Their ash content is high
- Their cost of handling is high
- Their large proportion of heat is wasted
- They burn with clinker formation
- Their combustion operation cannot be controlled easily

Gaseous Fuels

Advantages

- They are clean in use
- They burn without any shoot, or smoke and ashes
- They are free from impurities found in solid and liquid fuels
- They do not require any special burner
- They can be conveyed easily through pipelines to the actual place of need, thereby eliminating manual labour in transportation.
- They can be lighted at ease.
- They have high heat contents and hence help us in having highertemperatures.
- They can be pre-heated by the heat of hot waste gases, thereby affecting economy in heat.
- Their combustion can readily by controlled for change in demand like oxidizing or reducing atmosphere, length flame, temperature, etc.

Disadvantages

- Very large storage tanks are needed.
- They are highly inflammable, so chances of fire hazards in their use is high.

Combustion

- A chemical reaction during which a fuel is oxidised which is accompanied with a large quantity of heat
- Oxidizer – pure oxygen $\Rightarrow$ Air – free and readily available

$$C + O_2 \rightarrow CO_2 + 8084 \text{ kcal/kg of carbon burnt}$$

$$H_2 + 1/2\ O_2 \rightarrow H_2O + 28922 \text{ kcal/kg of } H_2$$

$$S + O_2 \rightarrow SO_2 + 2224 \text{ kcal/kg of S}$$

- $C + 1/2\ O_2 \rightarrow CO$ + 2430 kcal/kg of carbon burnt
- Each kg of CO formed means a loss of 5654 kcal of heat

Combustion

- Air: 20.9% oxygen, 79% nitrogen and other **(vol. basis)**

Effect of Nitrogen

- Nitrogen acts as inert gas, no reaction except forming of small amount forms NOx at high temperatures
- Nitrogen reduces the combustion efficiency by absorbing the combustion heat

Effect of water vapor

✓ Only water vapour needs consideration in other gases

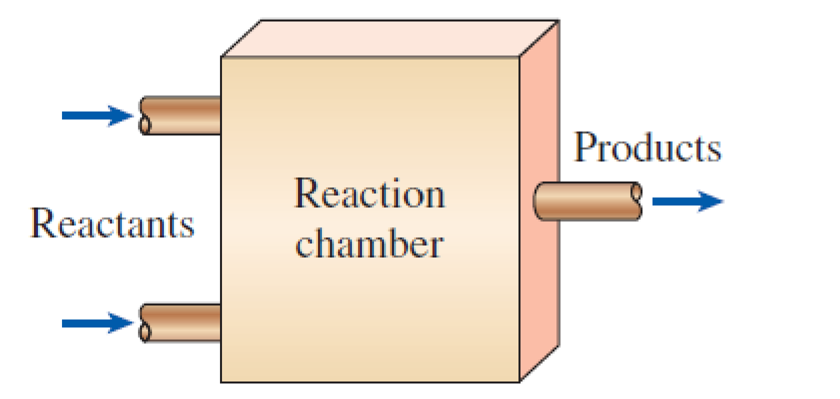
✓ Moisture $\Rightarrow$ H_2O which is inert during combustion and reduces the combustion efficiency

✓ Rarely, H_2O $\Rightarrow$ H_2, O_2 , H, O, OH

✓ When cooled below dew point temperature, condensate water reacts with SO_2 to form sulphuric acid which is corrosive

3 Ts to optimize combustion

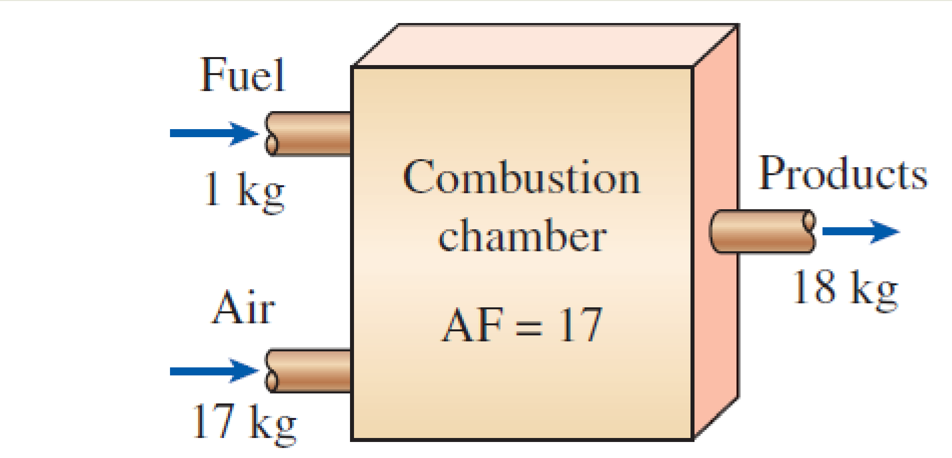
- Temperature high enough to ignite and maintain the ignition of fuel
- Turbulence mixing of fuel and oxygen
- Time sufficient for complete combustion



Air-Fuel

Air-fuel ratio (AF): The ratio of the mass of air to the mass of fuel for a combustion process

$$AF = \frac{m_{air}}{m_{fuel}}$$



Stoichiometric or **theoretical air:** The minimum amount of air needed for the complete combustion of a fuel. Also referred to as the *chemically correct amount of air*, or *100% theoretical air.*

Stoichiometric or **theoretical combustion:** The ideal combustion process during which a fuel is burned completely with theoretical air.

Excess Air

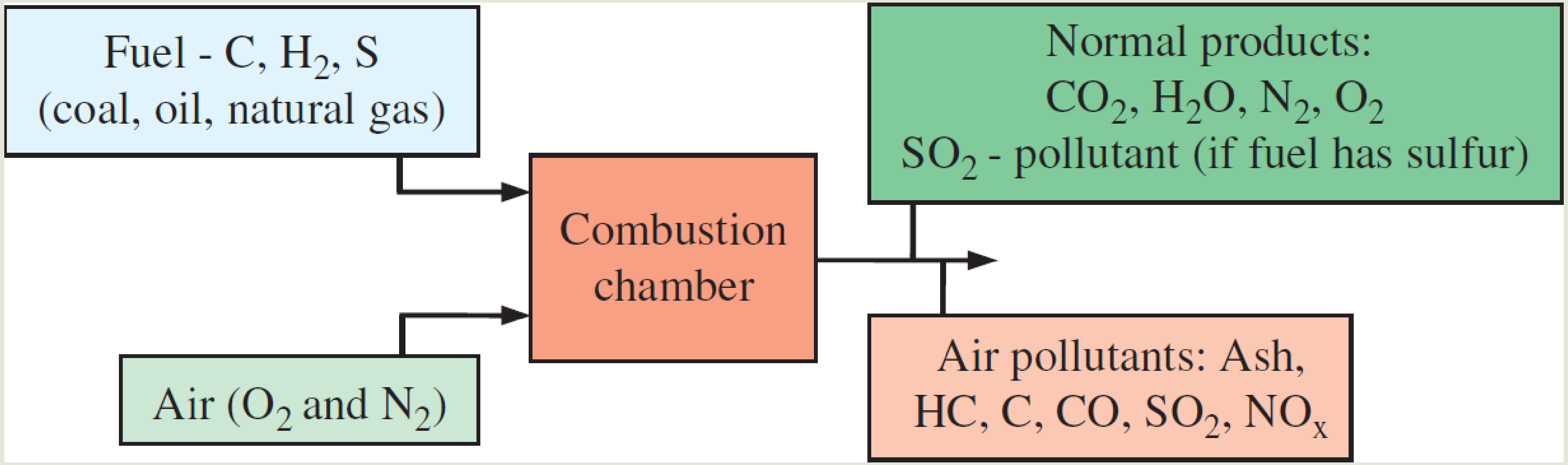
- Certain amount of excess air is needed to complete combustion and ensure that release of the entire heat contained in fuel
- Less air would lead to the incomplete combustion and smoke
- More excess air: additional heat would be lost in heating the surplus air to the chimney temperature → increased stack loss
- Optimally controlled by monitoring the flue gases – 14-15% of CO_2 and 2-3% for O_2

Theoretical and Actual Combustion Processes

- **Complete combustion:** If all the carbon in the fuel burns to CO_2, all the hydrogen burns to H_2O, and all the sulfur (if any) burns to SO_2.
- **Incomplete combustion:** If the combustion products contain any unburned fuel or components such as C, H_2, CO, or OH.
- **Reasons for incomplete combustion:**
  - *Insufficient oxygen*
  - *Insufficient mixing* in the combustion chamber during the limited time that the fuel and the oxygen are in contact
  - *Dissociation* (at high temperatures)
- Oxygen has a much greater tendency to combine with hydrogen than it does with carbon. Therefore, the hydrogen in the fuel normally burns to completion, forming H_2O

Pollutants

- Main air pollutants resulting from the combustion of fossil fuels are
    - Particulate matter (PM)
    - Sulfur dioxide (SO_2)
    - Nitrogen oxides (NO_x)
    - Hydrocarbons (HC) including carbon soot particles (C)
    - Carbon monoxide (CO)



Source of pollutants

- Particulate matter is commonly called ash and it is produced mostly when coal or oil is burned.
- SO_2 is inevitably produced when the fuel contains sulfur.
- NO_x generation is due to high temperature reactions between atomic nitrogen and oxygen.
- HC, C, and CO emissions are mainly produced due to incomplete combustion which may be due to insufficient oxygen, insufficient mixing of fuel and air, etc.

Methods of minimizing harmful emissions:

- The first one is to design and optimize the combustion process such that minimum emissions are generated.
- The second method involves after treatment. In this method, the exhaust gases leaving the combustion chamber goes through some systems in which harmful components are treated or collected.

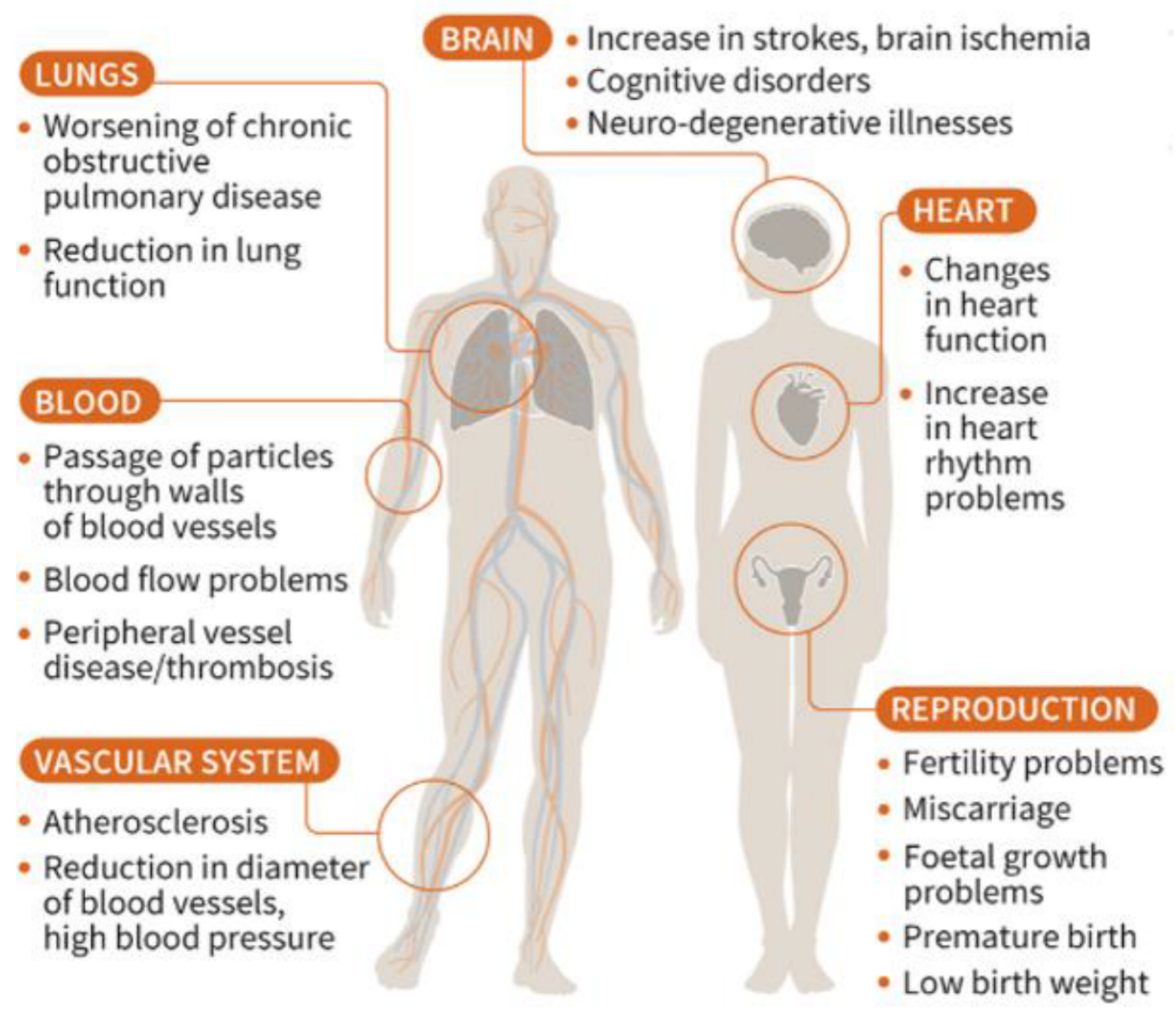
Particulate Matter

- Small solid and liquid particles suspended in air is generally referred to as particulate matter (PM).
- **Primary Content:** A primary group of PM is ash and soot particles generated from the combustion of coal and oil.
- **Secondary PM:** Nitrates and sulfates are formed as a result of SO_2 and NO_x emissions, and referred to as secondary PM.
- Many manufacturing and other industrial processes are responsible for the production of various PMs.
- Dust particles from roads and construction and agricultural activities as well as iron, silicon, soil, and materials of earth can also be considered as part of PM.
- **PM10:** When the particles are less than 10 micrometers and classified as coarse.
- **PM2.5:** It refers to particles less than 2.5 mm, and referred to as fine.

"About 1 g of PM is released to the environment for each kWh of electricity produced from a coal-fired power plant"

Health impacts of PM2.5

- PM2.5 can penetrate deeply into the respiratory system, and therefore it is more dangerous to health than PM10



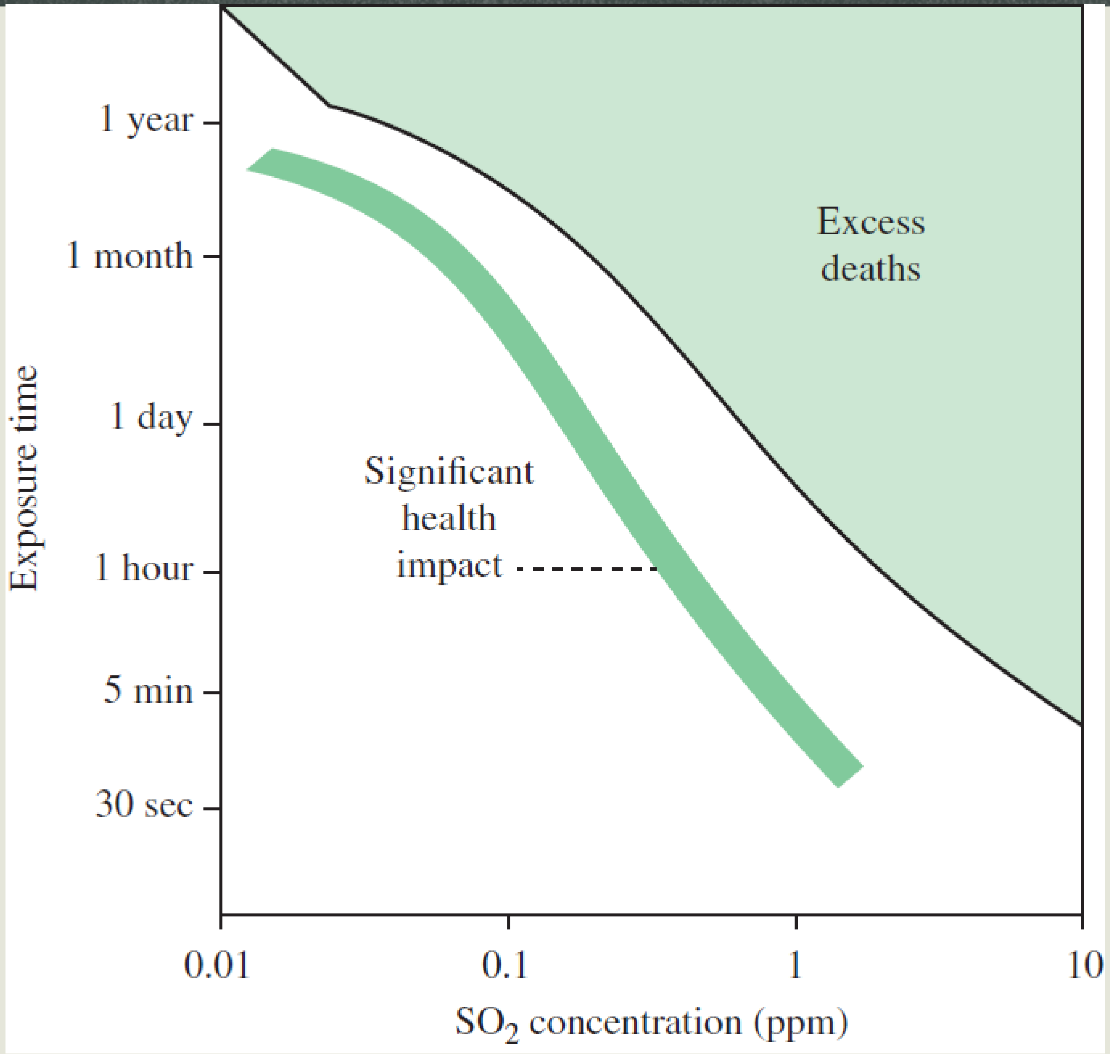
Sulfur Dioxide

- Fossil fuels are mixtures of various chemicals, including some amounts of sulfur.
- The sulfur in the fuel reacts with oxygen to form sulfur dioxide (SO_2)

$$S + O_2 \rightarrow SO_2$$

- **Sulfur in coal:** Coal contains the most amount of sulfur among fossil fuels.
  - Bituminous coal contains 0.5 to 4.0% sulfur by mass.
  - Subbituminous coal typically contains an average of 0.4% by mass.
  - Low-sulfur coal is more desirable and has high monetary value.
- **Sulfur in oil:** Mass percentage of sulfur in oil may range between 0.3 and 2.3%.
- **Sulfur in natural gas:** Natural gas also contains sulfur with varying amounts when extracted from the ground but it is removed in gas treatment plants

Health effects of SO_2



- Longer exposures at low concentrations and shorter exposures at high concentrations may result in the similar health effects.
- When SO_2 level in atmosphere is more than 1 ppm, it can lead to airway constriction.
- The health effects of SO_2 include respiratory, lung, and cardiovascular illnesses.
- Children and elderly with asthma and breathing problems are more sensitive to SO_2 exposure.
- It also negatively affects ecosystems of rivers, lakes, and forests.

Nitrogen Oxides

- Nitrogen oxides are produced at high combustion temperatures when a fuel is burned with oxygen in air
- Effect of combustion temperature: At higher combustion temperatures, more dissociation reactions cause greater amounts of NO_x production.
- Very little NO_x is formed at low temperatures.
- Nitrogen oxides react in the atmosphere to form ground-level ozone.
- It contributes to the photochemical smog and acidification of waters and soils.
- The emission of NO_x causes the formation of nitrates, which are considered as PM (mostly PM2.5).
- Nitrogen dioxide (NO_2) gas is toxic at high concentrations.
- Health effects: The primary health effects of NO_2 are related to respiratory illnesses such as asthma and bronchitis.

Hydrocarbons

- In a combustion reaction, some of the fuel cannot find oxygen to react with during the combustion period. As a result, some unburned or partially burned fuel particles leave the exhaust gases as HC components.
- **Deficiency of air:** This will certainly happen when there is deficiency of air (not enough air to burn all the fuel) during combustion.
- **Causes of HC emissions:** Insufficient mixing between fuel and air, nonhomogeneous mixture, and short time of reaction are some of the causes for incomplete combustion and resulting HC emission.
- **Consequences of HC emissions:** Hydrocarbon components and carbon soot particles in air act as irritants and odorants. Some of them are believed to be carcinogenic.
- Nitrogen oxides and HC are two main sources for the formation of ground level ozone and also for smog

Carbon Monoxide

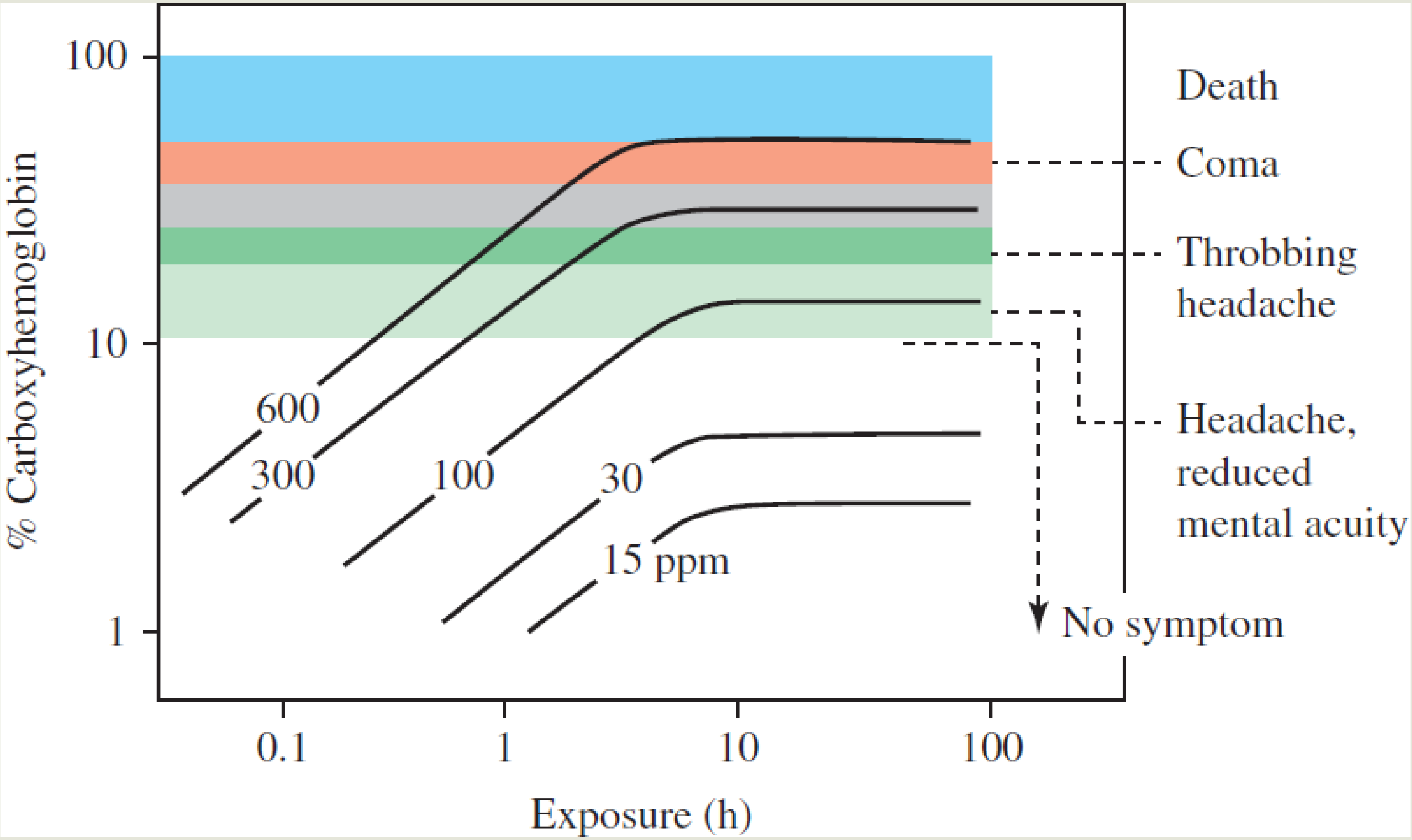
- Carbon monoxide (CO) is a colorless, odorless, poisonous gas.
- **How is it produced?** CO is produced during combustion when there is fuel-rich mixture (not enough air or oxygen in the air-fuel mixture).

$$C + \tfrac{1}{2}O_2 \rightarrow CO \qquad CO + \tfrac{1}{2}O_2 \rightarrow CO_2$$

- If CO cannot find oxygen after the first reaction due to deficiency of oxygen or insufficient mixing, some CO will be part of the exhaust.

Health effect of CO

- Hemoglobin is the protein molecule in red blood cells that carries oxygen from the lungs to the body's tissues and returns carbon dioxide from the tissues back to the lungs.
- Carbon monoxide absorbed in hemoglobin is called carboxyhemoglobin (COHb).
- Negative physiological effects on the body are observed when the levels of COHb is above 100 ppm or 0.01%. Serious effects including coma take place after 300 ppm, and long-term exposure above 600 ppm is fatal.



Negative Impacts of Renewables on the Environment

- Hydro – The Giant among Renewables Leading to Giant Floods
  - The dams constructed for harnessing hydropower tend to greatly influence the flow of rivers, which can alter ecosystems and negatively impact wildlife and people.
- Wind - It belongs to the Birds and Bats as Well
  - A recent review by the National Wind Coordinating Committee (NWCC) found that collisions with wind turbines and air pressure changes caused by spinning turbines resulted in several bird and bat deaths.
- Solar – What about the Soil Erosion?
  - The use of many acres of land can result in clearing and grading of land, which can cause soil compaction, erosion, and alteration of drainage channels. Disposal of solar panels and collectors after their useful life is a concern for solar systems.
- Biomass energy involves ecological impacts of harvesting, transportation, and processing of plants.
- Geothermal systems are known to contribute to hydrogen sulfide (H_2S) emissions.

Calculate the theoretical amount of air.

- GCV of fuel : 10880 kcal/kg
- Considering 100 kg of furnace oil, the chemical reactions are:

$$C + O_2 \rightarrow CO_2$$

$$H_2 + 1/2\ O_2 \rightarrow H_2O$$

$$S + O_2 \rightarrow SO_2$$

Constituents	% By weight
Carbon	85.9
Hydrogen	12
Oxygen	0.7
Nitrogen	0.5
Sulphur	0.5
H2O	0.35
Ash	0.05

- Consider molecular weight in kg/kg mole

Recap

- Fuel types
- Basics of Combustion
- 3 Ts to optimize combustion
- Air-Fuel ratio and Excess air
- Air pollutants, types, source, heath effects and elimination techniques

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