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Lecture:

Fossil Energies and Pollution

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Foreword

Fossil energies, including coal, oil, and natural gas, remain the world's primary sources of power. While they have supported industrial growth and economic development for decades, their environmental impact is significant. The combustion of fossil fuels releases large amounts of carbon dioxide (CO_2), the main greenhouse gas responsible for global warming. In addition, pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulate matter contribute to air pollution, acid rain, and respiratory diseases. The extraction and transportation of fossil fuels can also cause soil and water contamination.

This handout is the result of a module taught of Fossils Energies and Pollution course, for years in the department of science and technology, specialty process engineering at the university Ahmed Ben Yahia El Wancharissi - Tissemsilt. This course handout is intended for LMD students in their third year of a Bachelor's degree in process engineering department, petrochemical industries specialization.

This course handout aims to introduce students to the concepts of fossil energies, environment and pollution. All the concepts covered in this handout are strictly in accordance with the approved curriculum, in order to maintain a purely educational character. The purpose of this work is to provide students with an introduction to different energy sources, give the characteristics of a fossil energy source, knowing the pollution released by fossil fuels that will be necessary for them to pursue their studies and professional careers in fossil energies.

This handout is divided into six (06) chapters; the content of each chapter is devoted to the presentation of fundamental acquisitions. The first and second chapters present a detailed study on fossil energies and environment. The third and fourth chapters are devoted to the presentation of carbon monoxide « CO » and nitrogen oxides « NO », respectively. In the fifth chapter, we exposed the Polycyclic Aromatic Hydrocarbons (PAHs), followed by the actions for a healthy planet as the sixth chapter.

Finally, we hope that this manual will be appreciated by our fellow teachers, and we would be happy to receive their feedback and advice. We appreciate your reviews in order to enrich this handout of courses which, in our opinion, will be a useful resource for our dear students. I have made this document available to internet users interested in this field, and they can send me their comments or suggestions by sending an email to the following address:

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General Introduction

General Introduction

Fossil energies such as coal, oil, and natural gas have played a fundamental role in shaping modern civilization. Since the Industrial Revolution, these energy sources have fueled economic growth, technological development, and global mobility. They provide around 80% of the world's total energy demand and remain the backbone of industries, transportation, and electricity generation. However, the extraction, processing, and combustion of fossil fuels come at a significant environmental cost.

The use of fossil fuels releases large amounts of greenhouse gases (GHGs), primarily carbon dioxide (CO₂) and methane (CH₄), into the atmosphere. These emissions are the main drivers of global warming and climate change, leading to rising sea levels, extreme weather events, and disruptions to ecosystems. Additionally, fossil fuel exploitation contributes to air and water pollution, soil degradation, and biodiversity loss. Oil spills, mining operations, and gas flaring are among the most visible examples of the damage caused to natural habitats and human health.

In recent decades, increasing awareness of these environmental challenges has prompted international efforts to transition toward cleaner, renewable energy sources. Agreements such as the Paris Climate Accord emphasize the need to reduce carbon emissions and invest in sustainable alternatives like solar, wind, and hydroelectric power. Nevertheless, the global dependence on fossil fuels remains high, posing both a technical and political challenge in achieving a low carbon future.

Understanding the relationship between fossil energies and the environment is therefore essential. It allows policymakers, scientists, and societies to make informed decisions that balance energy security, economic growth, and environmental protection. The future of energy depends on how effectively humanity can manage this transition and mitigate the ecological footprint of fossil fuel use.

Chapter I: Fossils Energies

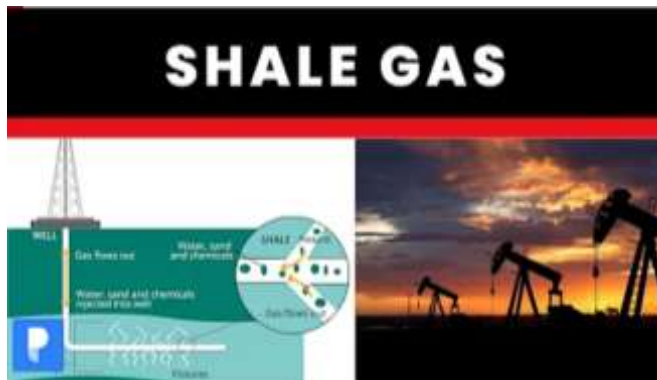
Chapter I: Fossil Energies

I. 1: Petroleum

I. 2: Natural Gas

I. 3: Coal Heat

I. 4: Shale Gas



Chapter I: Fossils Energies

I.1: Introduction

Fossil fuels are all carbon-rich fuels, mostly hydrocarbons, from the mechanization of dead living things that have been buried in the ground for millions of years, sometimes up to 650 million years. These sources of energy are not renewable because they take millions of years to build up and because they are used much faster than the time needed to recreate reserves.

A fossil energy is a hydrocarbon-containing material such as coal, oil, and natural gas, formed naturally in the earth's crust from the remains of dead plants and animals that is extracted and burned as a fuel.

Fossil fuels may be burned to provide heat for use directly (such as for cooking or heating), to power engines (such as internal combustion engines in motor vehicles), or to generate electricity. However, fossil fuels are non-renewable, meaning they take millions of years to form but are consumed much faster than they can be replaced. Fossil fuels contribute to environmental issues like climate change and air pollution. Their combustion releases **greenhouse gases** like carbon dioxide (CO₂), which contribute to **global warming** and **climate change**. Additionally, fossil fuel extraction and use can cause **air pollution**, **oil spills**, and **habitat destruction**. Due to these environmental concerns, many countries are investing in **renewable energy sources** like solar, wind, and hydroelectric power to reduce reliance on fossil fuels and promote sustainability. As a result, many countries are shifting toward renewable energy to reduce dependence on fossil fuels.

Origin

The origin of fossil energy is rooted in the decomposition of ancient organic matter over millions of years. The idea that fossil fuels, such as coal, oil, and natural gas, formed from the remains of dead plants and microorganisms under heat and pressure in earth's crust was first introduced by **Andreas Libavius** in his 1597 work *Alchemia*. Later, **Mikhail Lomonosov**, a Russian scientist, expanded on this concept in 1757 and formally described it in 1763. His studies laid the foundation for modern understanding of petroleum geology and the natural processes that create fossil fuels.

Chapter I: Fossils Energies

Historical theories on fossil fuel formation

The idea that fossil fuels come from the remains of ancient life forms has evolved over centuries:

1. Andreas Libavius (1597):

- One of the first recorded mentions of fossil fuel origins appears in *Alchemia*, written by **Andreas Libavius**, a German alchemist and physician. He speculated about the transformation of organic materials into coal and other combustible substances.

2. Mikhail Lomonosov (1757–1763):

- The Russian scientist **Mikhail Lomonosov** is considered one of the pioneers of modern petroleum geology.
- In 1757, he proposed that oil and coal originated from the decomposition of organic materials under heat and pressure.
- By 1763, he had further developed his theory, arguing that fossil fuels formed naturally over geological timescales and were not simply mineral substances. His work laid the foundation for later studies on petroleum and coal formation.

Scientific Advancements

Later, in the 19th and 20th centuries, geologists and chemists confirmed that fossil fuels are the result of biological processes and long-term geological transformations. The development of organic chemistry and petroleum geology further refined these ideas, explaining how different types of fossil fuels form based on temperature, pressure, and the type of organic material involved.

Today, scientists recognize that fossil fuels are non-renewable because they take millions of years to form but are being consumed rapidly. This has led to growing interest in renewable energy sources to reduce dependence on fossil fuels and combat climate change.

Importance

Fossil fuels have been important to human development because they can be readily burned in the open atmosphere to produce heat. Coal was burned in some early furnaces for the smelting of metal ore, while semi-solid hydrocarbons from oil seeps were also burned in ancient times; they were mostly used for waterproofing and embalming. The 19th century was the era when commercial exploitation of petroleum began. Natural gas, once flared-off as an unneeded byproduct of petroleum production, is now considered a very valuable resource. Natural gas deposits are also the main source of helium.

Chapter I: Fossils Energies

I. 2: Petroleum

What is Petroleum?

Petroleum is referred to as ***“Black Gold”***. This name itself is an indication of its importance to humans. Crude oil is considered to be the ***“mother of all commodities”*** as it is used to manufacture various products such as pharmaceuticals, plastics, gasoline, synthetic fabrics, etc. Petroleum or oil has also been the world’s leading source of energy since the 1950s.

Petroleum is a liquid which occurs naturally in rock formations. It is composed mainly of hydrocarbons, along with small amounts of sulfur, nitrogen, and oxygen. Petroleum is formed from the remains of ancient marine organisms such as plankton and algae that were buried under layers of sediment millions of years ago. Over time, heat and pressure transformed this organic material into oil, plus other organic compounds. Some petroleum-produced chemical compounds are also obtained from other fossil fuels.

Petrochemicals are produced mainly at a few manufacturing sites around the world. Petroleum is also the raw material for many industrial products, including pharmaceuticals, solvents, fertilizers, pesticides, synthetic fragrances, and plastics.



Figure.I.1: Oil petroleum

Chapter I: Fossils Energies

Petroleum Meaning

The word petroleum translates to “**rock oil**”. It is derived from the Greek word **Petra** and the Latin word **oleum**. When it is drilled from the ground in the liquid form, it is called crude oil. Humans have known about its existence for 4000 years. However, the first time crude oil was pumped from the ground was 2500 years ago in China and the world’s first crude oil well was drilled in Pennsylvania, USA only in the year 1859.

Petroleum or mineral oil is India’s next biggest source of energy after coal. It supplies heat and lighting power, machinery lubricants, and raw materials for a variety of manufacturing industries. Petroleum refineries for synthetic textiles, fertilizers and numerous chemical industries act as a **nodal industry**. Most of India’s petroleum occurrences are associated with anticlines and fault traps in tertiary-age rock formations. It occurs in folding regions, anticlines, or domes, where oil is trapped in the unfolded crest.

Is Petroleum Renewable?

No, petroleum is a non-renewable resource. That means it cannot be replaced quickly once it is used. It takes millions of years to form. Because of this, people are also looking for alternative energy sources, like solar, wind, and electric power.

Chapter I: Fossils Energies

How is Petroleum Formed?

- Petroleum is formed from the remains of dead plants and animals.
- When plants and animals die, they sink and settle on the seabed.
- Millions of years ago, these dead wildlife and vegetation decomposed and got mixed with sand and silt.
- Certain bacteria helped in the decomposition of this organic matter and caused some chemical changes
- Matter consisting largely of carbon and hydrogen was left behind. However, as there is no sufficient oxygen at the bottom of the sea, the matter could not decompose completely.
- The partially decomposed matter remained on the seabed and eventually was covered with multiple layers of sand and silt.
- This burying took millions of years, and finally, due to high temperature and pressure, the organic matter decomposed completely and formed oil.

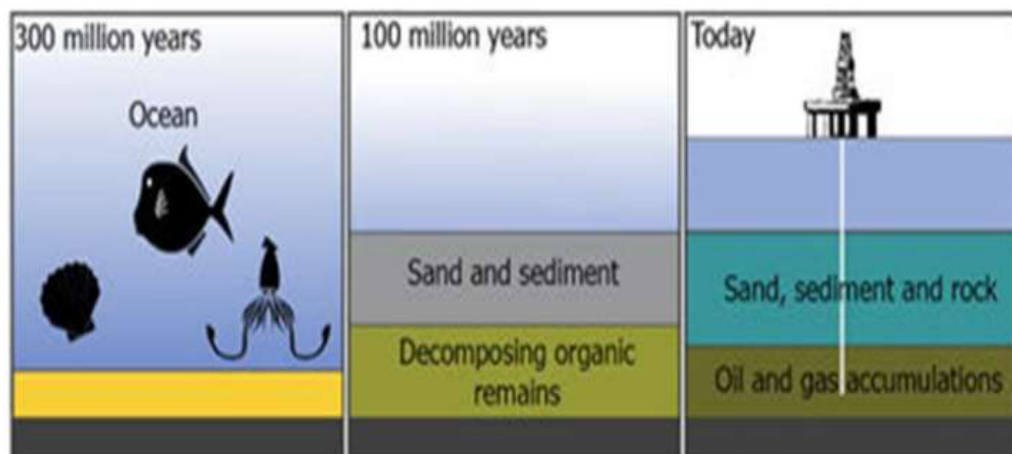


Figure.I.2: Oil petroleum formation through time

How is Petroleum Collected?

- Petroleum is collected through a process called drilling:
 - Companies use machines to drill deep into the Earth.
 - When oil is found, it is pumped to the surface.
 - The oil is sent to refineries for processing.

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Type of Petroleum

The crude oil produced from the atmospheric separator has a composition different from the reservoir fluid from a producing well. Two important things that determine the quality and the price of crude oil are the API gravity and the sulfur content in crude oil.

Generally, a crude oil with the API gravity:

- Less than 20-22 is called heavy crude oil.
- Greater than 33-40 is called light crude.
- If sulfur content of crude is less than 0.5 wt % is called Sweet oil.

Sulfur is the most important heteroatom in petroleum and it can be found in cyclic as well as noncyclic compounds such as mercaptans (R-S-H) and sulfides (R-S-R). Where R and R are alkyl groups. Sulfur in natural gas is usually found in the form of hydrogen sulfide (H₂S). Some natural gas contains H₂S as high as 30% by volume. The amount of sulfur in crude may vary from 0.05 to 6% by weight.

Petroleum-Refining

Oil refineries essentially serve as the second stage in the production process following the actual extraction of crude oil by rigs. The first step in the refining process is distillation, where crude oil is heated at extreme temperatures to separate the different hydrocarbons. Oil refineries serve an important role in the production of transportation and other fuels. The crude oil components, once separated, can be sold to different industries for a broad range of purposes. Lubricants can be sold to industrial plants immediately after distillation, but other products require more refining before reaching the final user. Major refineries have the capacity to process hundreds of thousand barrels of crude oil daily. In the industry, the refining process is commonly called the downstream sector, while raw crude oil production is known as the upstream sector.

An oil refinery or petroleum refining is an industrial manufacturing facility where crude oil is extracted and converted into more valuable goods, such as petroleum naphtha, gasoline, and jet fuel, asphalt foundation, heating oil, petroleum kerosene, and liquefied gas. Oil

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refineries are usually huge, vast industrial facilities with extensive pipelines running throughout, holding fluid streams in between.

- Petroleum is a mixture of many substances such as gas, petrol, diesel, kerosene, lubricating oil, paraffin wax, etc.
- As these constituents serve different purposes, it is important to separate them, or in other words, refine the crude oil. This process of separation of various constituents of petroleum is called petroleum refining.
- This is done in oil refineries. It is a three-step process.
- The first step is separation where the crude oil is separated into various components through the distillation process. The heavier constituents remain settled at the bottom whereas lighter constituents rise up as vapor, or remain liquid.
- Next, these constituents, who are still quite heavy, are converted into gas, gasoline, and diesel. Thus, the next step is conversion.
- These have certain impurities, so the last step is treating, where they are treated to obtain pure forms of various products.

Oil refining plays an important role in our lives. Most transportation vehicles are powered by refined products such as gasoline, diesel, aviation turbine kerosene and fuel oil. An oil refinery is an industrial process plant crude oil converted to petroleum products. Where crude oil is processed and refined into more useful products. The petroleum products are natural gas, LPG, jet fuel, gasoline, kerosene, diesel fuel, lube oils, petrolatum. That is shown in **Fig.I.3**.

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- 1 barrel is equal to 42 gallons of crude oil.
- 83% becomes fuel.
- 17% other (solvents, fertilizers, pesticides, and plastics)

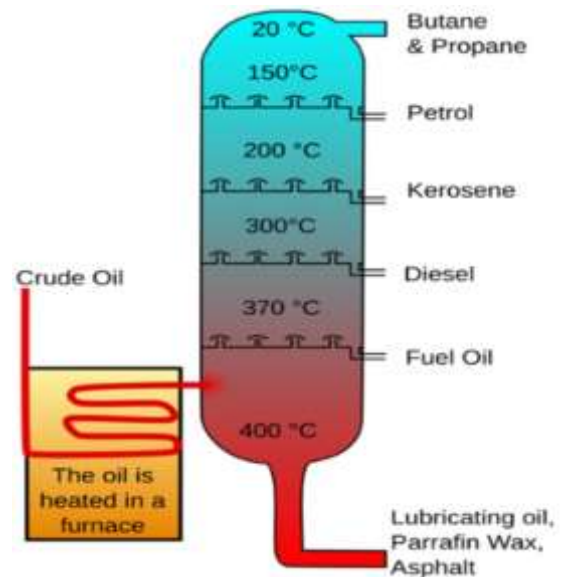


Figure.I.3: Fractional distillation of crude oil

Petroleum products are all the substances made from petroleum. Petrochemicals feed stock like ethylene and propylene can also be produced directly by cracking crude oil without the need of using refined products of crude oil such as naphtha. Oil refineries use much of the technology of, and can be thought of, as types of chemical plants. The crude oil feed stock has typically been processed by an oil production plant. There is usually an oil depot (tank farm) at or near an oil refinery for the storage of incoming crude oil feedstock as well as bulk liquid products. The world's first systematic petroleum refinery was built in Ploiesti, Romania in 1856 using the abundant oil available in Romania. In North America, the first oil well was drilled in 1858 by James Miller Williams in Oil Springs, Ontario, Canada.

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Theory and method

The oldest and most common way of separating things into different components (called fractions) is to do it using the boiling temperature differences. That process is known as fractional distillation. You essentially heat up crude oil, let it spray, and then condense the vapor.

New methods, in a method called conversion; use chemical processing on certain fractions to produce others. For example, chemical processing may split lengthier chains into shorter chains. This allows a refinery to convert diesel fuel into gasoline, depending on the gasoline demand. In industry, the refining process is generally called the “downstream” sector, while the “upstream” sector is known as the raw crude oil output. The word downstream is synonymous with the idea of sending oil down the supply chain of a commodity to an oil refinery to be refined into petrol. The downstream phase also includes the actual sale of petroleum products to other companies, governments or private individuals. Here are some of the chemical processes found and use in oil refinery the units and their works in the oil refinery.

- Desalted unit: washes out salt from the crude oil before it enters the atmospheric distillation unit.
- Crude Oil Distillation: unit distills the incoming crude oil into various fractions for further processing in other units.
- Vacuum distillation: further distills the residue oil from the bottom of the crude oil distillation unit. The vacuum distillation is performed at a pressure well below atmospheric pressure.
- Naphtha hydrotreater unit: uses hydrogen to desulfurize naphtha from atmospheric distillation. Naphtha must be desulfurized before sending it to a catalytic reformer unit.

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Uses of Petroleum

Refined into many fractions that serve different purposes in daily life, industry, and energy. Here are the main uses of petroleum and its products:

1. Fuel Uses:

- a) Petrol (Gasoline): Used in cars, motorcycles, and small engines.
- b) Diesel: Used in trucks, buses, trains, ships, and some cars.
- c) Kerosene: Used as jet fuel (aviation turbine fuel), in heating, and sometimes in lamps.
- d) Liquefied Petroleum Gas (LPG) – Butane & Propane: Used for cooking, heating, and as fuel in some vehicles.
- e) Fuel Oil: Powers ships, factories, and power stations.

2. Industrial Uses

- a) Lubricating Oils: Reduce friction in machinery and engines.
- b) Asphalt & Bitumen: Road construction, roofing, waterproofing.
- c) Paraffin Wax: Used in candles, polishes, cosmetics, and packaging.

3. Chemical Industry (Petrochemicals): Petroleum is the raw material for the petrochemical industry, producing:

- a) Plastics (polyethylene, polypropylene, PVC).
- b) Synthetic fibers (nylon, polyester, acrylic).
- c) Synthetic rubber (used in tires).
- d) Detergents, solvents, and dyes.
- e) Fertilizers and pesticides.

4. Energy Production

- a) Used in power plants to generate electricity.
- b) Backup fuel for industries and homes in some countries.

5. Other Uses

- a) Medical products: Vaseline, ointments, anesthetics, pharmaceutical ingredients.
- b) Cosmetics: Creams, lotions, shampoos.
- c) Household goods: Paints, adhesives, cleaning agents.

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Appendix

Q1: How is petroleum refined?

Petroleum refining or oil refining is an automated procedure that removes crude oil from the earth and converts it into usable items such as liquefied petroleum gas (LPG), kerosene, asphalt foundation, jet fuel, diesel, heating oil, cooking oils, etc.

Q2: What does a petroleum refinery do?

Petroleum refineries convert crude oil into petroleum products for use as fuel for shipping, cooking, paving roads and electricity production and as feedstocks for chemical manufacturing. The refining cycle breaks down crude oil into its different components and is then gradually reconfigured into new products.

Q3: What are petroleum and its uses?

Petroleum products include aviation fuels, heating and electricity-generating fuel oils, asphalt and road tar, and feedstocks for producing the additives, plastics, and industrial materials that are in almost everything we use.

Q4: What is the chemical formula of petrol?

For petrol the basic chemical formula is C_nH_{2n+2} . This formula applies to alkanes, and because it contains different chemicals, the chemical formula for petrol can be changed.

Q5: How is coal and petroleum formed?

Coal and petroleum are produced as a result of the destruction of the old plant life that existed millions of years ago. This dead plant matter started building up and finally developed a material called peat. Over time these materials were transformed into coal by heat and pressure from geological processes.

Q6: How is petroleum refined?

Petroleum refining or oil refining is an industrial process that extracts crude oil from the earth and converts it into useful items such as liquefied petroleum gas (LPG), kerosene, asphalt base, jet fuel, diesel, heating oil, fuel oils, etc.

Q7: What is the main purpose of petroleum refining?

Petroleum refining is mainly aimed at transforming crude oil into useful goods such as LPG, gasoline, jet fuel, diesel oil, jet fuel and fuel oils.

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Q8: Where is petroleum found?

Today petroleum is found in vast underground reservoirs where there were ancient seas. Petroleum reserves can be located beneath the land, or under the ocean. They extract their crude oil using giant drilling machines.

Q10: How is petroleum used?

Petroleum products include transportation fuels, heating and electricity-generating fuel oils, asphalt and road oil, and feedstocks for producing the chemicals, plastics, and synthetic materials that are in almost everything we use.

Q9: What are examples of petroleum products?

Petroleum products which are covered by the Oil Spill Law are commonly used for home heating and power engine energy. Types of petroleum products include kerosene, gasoline, home heating oil, and jet fuel.

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I. 3: Natural Gas

Natural gas is a fossil fuel that forms deep underground from the remains of plants and animals that lived millions of years ago. It is primarily composed of methane (CH₄), but can also contain small amounts of other hydrocarbons such as ethane, propane, and butane, as well as impurities like carbon dioxide, nitrogen, and hydrogen sulfide. Natural gas can be found in deep underground rock formations and in coal beds. It is found as methane clathrate or in combination with other hydrocarbon reservoirs.

Here are some key points about natural gas:

- **Formation:** Created over millions of years by heat and pressure acting on organic material buried under layers of sediment and rock.
- **Extraction:** Obtained through drilling wells in underground reservoirs or from shale formations using hydraulic fracturing (“fracking”).

I.3.1: Natural Gas Processes: Natural Gas must be processed to eliminate impurities such as water. This is done to make it marketable before it may be used as fuel. By products of processing include ethane, propane, butane, pentane, hydrogen sulphide, carbon dioxide, water vapor, helium, and nitrogen.

1. Extraction:

- a) Natural gas is found in underground rock formations (conventional reservoirs) or trapped in shale rock (unconventional sources).
- b) It's extracted through drilling wells. In shale gas, hydraulic fracturing (“fracking”) is often used to release gas trapped in rock.

2. Processing: Raw natural gas that comes out of the ground is not pure methane. It contains: (i) Hydrocarbons (ethane, propane, butane, and condensates), (ii) Impurities (water vapor, carbon dioxide, hydrogen sulfide, nitrogen, etc.) So, it must be cleaned and processed:

- a) Separation: water and heavier hydrocarbons are removed.
- b) Gas sweetening: hydrogen sulfide and carbon dioxide are removed.
- c) Dehydration: water vapor is removed to prevent pipeline corrosion and freezing.
- d) Fractionation: natural gas liquids (NGLs) like ethane, propane, and butane are separated for sale.

After this, the gas is mainly methane, ready for transport.

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3. Transportation

- a) Pipelines: The main way natural gas is moved. High-pressure transmission pipelines move gas long distances across countries and regions.
- b) Liquefied Natural Gas (LNG): For overseas transport, natural gas is cooled to -162°C , turning it into a liquid that takes up about 1/600th of the volume. Then it's shipped in special LNG tankers.
- c) Compressed Natural Gas (CNG): Stored at high pressure in cylinders for vehicles and small-scale transport.

4. Distribution

- a) Once it reaches a city or town, gas goes into local distribution pipelines.
- b) Pressure is reduced at distribution stations, making it safe for delivery.
- c) Gas companies add an odorant (mercaptan), since natural gas is odorless; this “rotten egg” smell helps detect leaks.

I.3.2: Uses

Natural gas finally reaches homes, businesses, power plants, and industries where it's used for:

- 1- Heating homes and buildings
- 2- Cooking and water heating
- 3- Generating electricity in power plants
- 4- Industrial processes (fertilizer, steel, glass, etc.)
- 5- As a transportation fuel (Compressed Natural Gas, CNG, or Liquefied Natural Gas, LNG)

Natural Gas Usage Limitations

- Natural gas is a finite, non-renewable resource. It is found extremely deep within the earth.
- It is impossible to collect all in-place gas from a producible deposit due to a lack of technology

Chapter I: Fossils Energies

I.3.3: Advantages, Disadvantages, and Natural Gas Benefits

1- Advantages: Burns cleaner than coal and oil, producing fewer air pollutants and about half the carbon dioxide emissions of coal per unit of energy.

2- Disadvantages: Still a fossil fuel that emits greenhouse gases; methane leaks during extraction and transport are a major concern because methane is a very potent greenhouse gas.

3- Natural Gas Benefits: Here are the various benefits of Natural Gas described below:

- a)** It is used for heating, cooking, and power generation.
- b)** It's also used as car fuel and a chemical feedstock for making plastics.
- c)** It burns completely. Hence, it is cleaner as compared to other energy sources.
- d)** It emits 70% less carbon dioxide when compared to other fossil fuels. It does not create ashes after releasing energy.
- e)** Natural gas was predominantly employed in the nineteenth and twentieth centuries for lighting residential and commercial areas.
- f)** It now has a far larger range of industrial and home applications.
- g)** Turbines are turned by it to produce wind and sun energy.
- h)** It is a domestic fuel as well. It operates heaters, ovens, boilers, and other appliances while heating our homes.
- i)** For cooking and heating, some families utilize compressed natural gas (CNG), which is gas that has been held under high pressure.
- j)** For low-load cars that demand excellent fuel economy, CNG is also a reasonably priced and environmentally beneficial transportation fuel.
- k)** Off-road trucks and trains are powered by LNG or liquefied natural gas.

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I.3.4. Natural Gas Importance

- Natural gas is one of the most important energy sources in the world for both economic development and environmental reasons. Here's a clear breakdown of its importance:

Aspect	Importance
Energy	Power generation, heating, and transport fuel
Security	Reliable and flexible energy source
Economy	Employment, exports, and stable prices
Environment	Lower emissions and cleaner energy
Industry	Raw material for chemicals and fertilizers

Table.I.1: Key Aspects of the Energy Sector and Their Importance

- Currently, the manufacture of fertilisers consumes the majority of natural gas or roughly 40%.
- 10% is used for LPG, while about 30% is used to generate electricity. Production of natural gas has increased in tandem with each of these areas. Natural gas production has significantly increased, particularly since 1971.
- Nearly 10% of India's electricity came from gas-powered power plants.
- Existing facilities are using expensive imported liquefied natural gas at less than full capacity (LNG).
- About 25% of the world's energy is provided by natural gas.

I.3.5. Global distribution of natural gas

The global distribution of natural gas refers to where natural gas reserves, production, and consumption are located around the world. Here's a breakdown based on the most recent global data (as of 2024 estimates from the **International Energy Agency** (IEA) and BP Statistical Review of World Energy):

Chapter I: Fossils Energies

1. Proven Natural Gas Reserves (by Region)

These are the confirmed quantities that can be extracted economically with today's technology.

Region	Share of Global Proven Reserves	Key Countries
Middle East	40 %	Iran, Qatar, Saudi Arabia, UAE
Europe & Eurasia	30 %	Russia, Turkmenistan, Azerbaijan
North America	7 %	United States, Canada, Mexico
Asia-Pacific	9 %	China, Australia, Indonesia
Africa	7 %	Nigeria, Algeria, Egypt, Mozambique
South & Central America	6 %	Venezuela, Argentina, Bolivia

Table. I.2: Global Distribution of Proven Natural Gas Reserves by Region

Top 5 countries by reserves:

- Russia (~20% of world total)
- Iran (~17%)
- Qatar (~13%)
- Turkmenistan (~9%)
- United States (~6%)

2. Natural Gas Production (2024 estimates)

Region	Share of Global Production	Key Countries
North America	30 %	United States, Canada
Middle East	20 %	Iran, Qatar, Saudi Arabia
Europe & Eurasia	25 %	Russia, Norway
Asia-Pacific	15 %	China, Australia
Africa	5 %	Nigeria, Algeria, Egypt
South & Central America	5 %	Venezuela, Argentina, Bolivia

Table. I.3: Regional Shares of Global Natural Gas Production and Key Producing Countries

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Top producers (2024):

- United States (~24% of world output)
- Russia (~17%)
- Iran (~6%)
- China (~5%)
- Qatar (~5%)

3. Natural Gas Consumption

Region	Share of Global Consumption
North America	25 %
Europe & Eurasia	25 %
Asia-Pacific	30 %
Middle East	15 %
Africa & Latin America	5 %

Table. I.4: Regional Shares of Global Natural Gas Consumption

Top consumers:

- United States
- China
- Russia
- Iran
- Japan

4. Trade & Distribution

- Pipeline exports: Dominated by Russia, Norway, and U.S. to neighboring regions.
- LNG (Liquefied Natural Gas) trade is growing fast led by Qatar, Australia, and the U.S. as top exporters.
- Top LNG importers: Japan, China, South Korea, India, and Europe (collectively).

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I.3.6. Algeria natural gas

Here's a detailed overview of Algeria's natural gas sector its current status, strengths, challenges, and strategic importance.

Algeria's natural gas refers to the large reserves and production of natural gas resources that the country possesses; it's one of the pillars of Algeria's economy and energy exports.

Reserves and Ranking

- Algeria holds some of the largest natural gas reserves in Africa and is among the top 10 globally.
- Proven reserves: roughly 159 Trillion Cubic Feet (TCF) (about 4.5 trillion cubic meters).
- Major reserves are located in the Sahara Desert, especially in the Hassi R'Mel field, one of the largest gas fields in the world.

Production

- Algeria is one of the top 3 natural gas producers in Africa, alongside Nigeria and Egypt.
- Production is mainly managed by Sonatrach, the state-owned oil and Gas Company.
- Annual output is around 90–100 Billion Cubic Meters (BCM), though this fluctuates with domestic demand and export contracts.

Exports

Algeria exports natural gas through:

Pipelines to Europe:

- 1- Trans Med pipeline → Italy via Tunisia
 - 2- Medgaz pipeline → Spain directly under the Mediterranean
 - 3- Liquefied Natural Gas (LNG) shipped globally from ports like Skikda and Arzew.
- Europe is the main market Algeria is a key alternative supplier to Russian gas.

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Domestic Use

- Natural gas provides more than 90% of Algeria's electricity.
- The government is working to expand LNG capacity and develop petrochemical industries using natural gas feedstock.

Future & Challenges

Algeria aims to:

- Boost production through new exploration in shale gas and offshore fields.
- Attract foreign investment under reformed energy laws.
- Balance exports with growing domestic consumption.

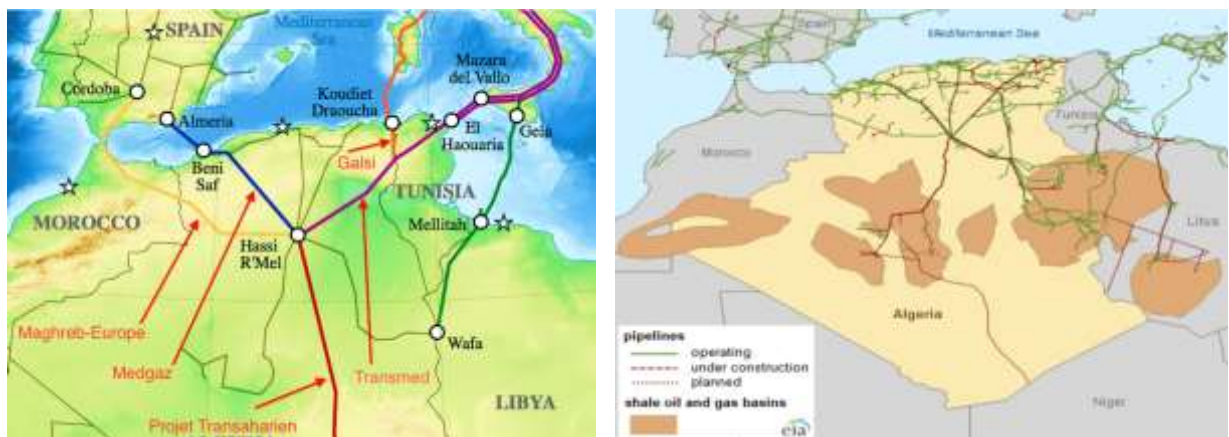


Figure.I.4: Algeria's natural gas fields, pipeline network, and export routes

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Appendix

Q1: What is in a natural gas?

- Methane makes up the majority of the odorless, gaseous combination of hydrocarbons known as natural gas (CH₄).

Q2: What are the 4 main natural gases?

- They combine to form natural gas when the proper ratios are used. Methane, ethane, butane, and propane are the first four alkanes and collectively known as the "four natural gases".

Q3: What is natural gas called?

- Natural gas is a colorless, extremely flammable gaseous hydrocarbon that is mostly composed of methane and ethane. It is also known as methane gas or natural methane gas. This particular type of petroleum commonly coexists with crude oil.

Q4: How is natural gas made?

- Drilling is used to extract natural gas from underground rock formations. Large amounts of shale-derived natural gas are now accessible because of developments in hydraulic fracturing technology.

Q5: Is LPG a natural gas?

- LPG is propane, but natural gas is methane, therefore they are not the same thing. Processing of natural gas and refining of crude oil result in the production of LPG. LPG is processed and then kept in gas cans or tanks under pressure as a liquid.

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I. 4. Coal Heat

Introduction:

Around the world, there are more than 1.06 trillion tons of coal reserves and they can be found in abundance in the Eastern United States, Russia, China, Australia and India. Coal was considered to be a type of plant; however, millions of years of geological pressure transformed this organic matter into brownish-black sedimentary rock that is now deposited all around the world.

Coal has been used for thousands of years as one of the primary sources of fuel because of its high carbon content, which offers significant energy. However, all coal is not created equal. Some burn cleaner and hotter, while others have high moisture content that can pollute the air.



Coal reserves are beds of coal still in the ground waiting to be mined. The United States has the world's largest known coal reserves, about 263.8 billion tons. This is enough coal to last approximately 225 years at today's level of use.

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I.3.1. Definition

Coal is a sedimentary rock composed primarily of carbon, along with varying amounts of hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). It forms from the diagenesis and metamorphism of accumulated plant material under anaerobic (oxygen-poor) conditions over millions of years.

I.3.2: Formation Process (Coalification)

Coal originates from peat, a partially decayed accumulation of plant debris in swamp environments. Over geologic time, increasing temperature and pressure due to sediment burial drive off water and volatile compounds, concentrating carbon and transforming the material through these stages:

Stage	Description	Carbon Content	Energy Content
Pea	Unconsolidated organic matter	55 %	Very Low
Lignite (Brown coal)	Lowest grade of true coal; soft and earthy	60-70 %	Low
Sub-bituminous coal	Intermediate stage	70-76 %	Moderate
Bituminous coal	Dense, black coal; widely used for power and steel	77-87 %	High
Anthracite	Hard, lustrous coal; highly metamorphosed	88-98 %	Very High

Table. I.5: Coal Formation Stages and Their Carbon and Energy Content

This transformation is termed coalification, driven by biochemical degradation, compaction, and thermal maturation.

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I.3.3: Chemical and Physical Properties

Elemental composition (approximate):

- Carbon: 60–95%
- Hydrogen: 3–6%
- Oxygen: 1–30%
- Nitrogen: 0.5–3%
- Sulfur: 0.5–5%

Physical characteristics:

- Black to brownish-black in color
- Brittle, with varying luster (from dull to shiny)
- Combustible, producing high heat energy when oxidized

I.3.4: How Coal Was Formed?

Coal is a combustible black or brownish-black sedimentary rock composed mostly of carbon and hydrocarbons. It is the most abundant fossil fuel produced in the United States.

Coal is a nonrenewable energy source because it takes millions of years to create. The energy in coal comes from the energy stored by plants that lived hundreds of millions of years ago, when the earth was partly covered with swampy forests. For millions of years, a layer of dead plants at the bottom of the swamps was covered by layers of water and dirt, trapping the energy of the dead plants. The heat and pressure from the top layers helped the plant remains turn into what we today call coal.

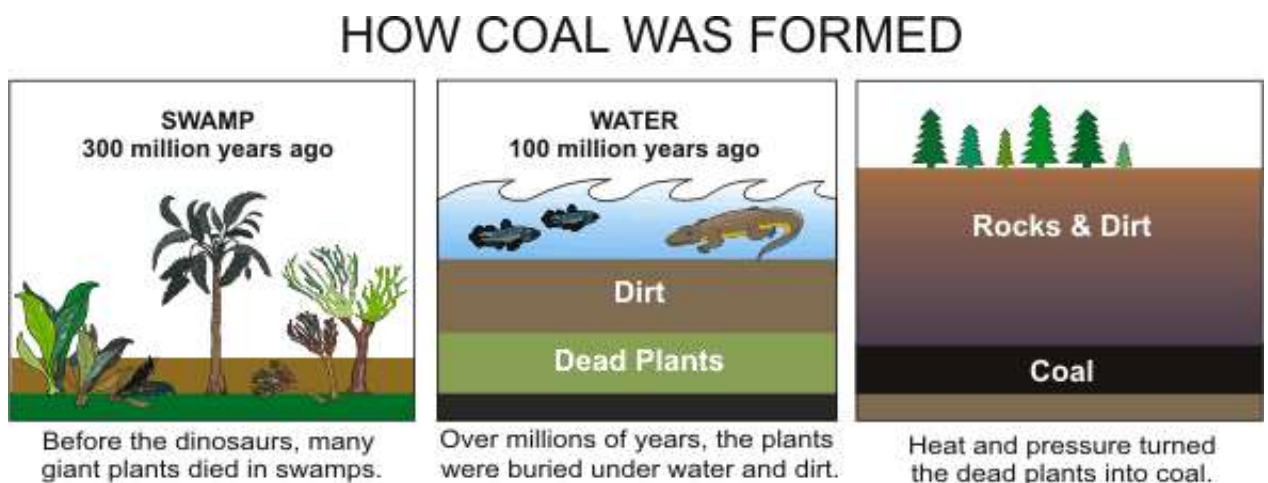


Figure.I.5: Geological process of coal formation through plant burial and metamorphism

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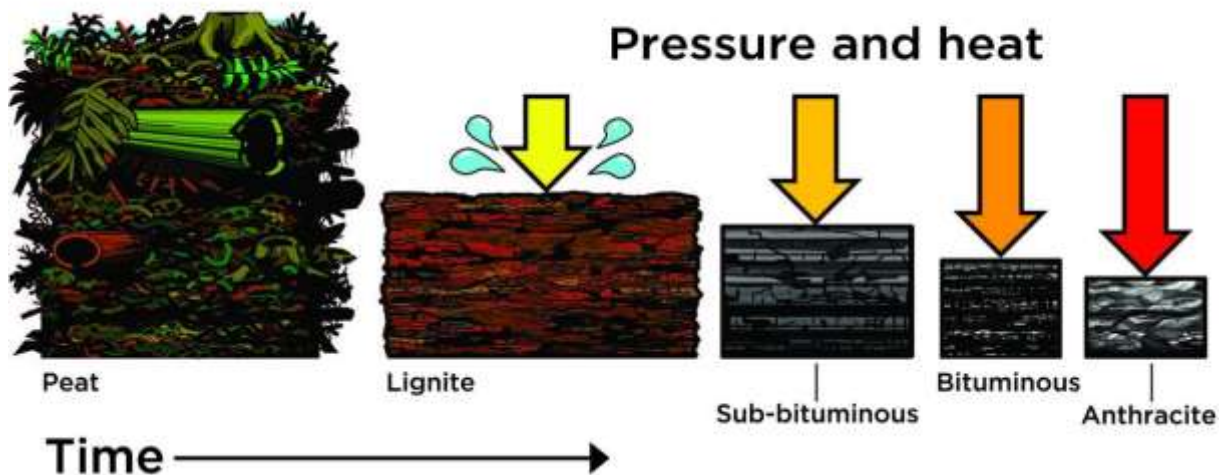


Figure.I.6: Formation of coal deposits through burial, compression, and thermal maturation.

I.3.5: How we Get Coal

I.3.5.1: Mining the Coal

Coal miners use giant machines to remove coal from the ground. They use two methods: surface or underground mining.

A- Surface mining:

It is used to produce most minerals, because it is less expensive than underground mining. Surface mining can be used when the coal is buried less than 200 feet underground. In surface mining, giant machines remove the top-soil and layers of rock to expose large beds of coal. Once the mining is finished, the dirt and rock are returned to the pit, the topsoil is replaced, and the area is replanted. The land can then be used for croplands, wildlife habitats, recreation, or offices or stores.

Surface mining



Figure.I.7: Mining the coal, surface mining.

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B- Underground mining:

Sometimes called deep mining, is used when the coal is buried several hundred feet below the surface. Some underground mines are 1,000 feet deep. To remove coal in these underground mines, miners ride elevators down deep mine shafts where they run machines that dig out the coal.



Figure.I.8: Mining the coal, underground mining

I.3.5.2: Cleaning and Preparation

After coal comes out of the ground, it typically goes on a conveyor belt to a preparation plant that is located at the mining site. The plant cleans and processes coal to remove dirt, rock, ash, sulfur, and other unwanted materials, increasing the heating value of the coal.

The preparation process includes:

1. *Crushing and Screening:*

Coal is crushed to a uniform size.

Screening separates large lumps from fine particles.

2. *Washing (Coal Beneficiation):* The coal is washed in water or chemical baths to remove impurities like soil and rock. Denser materials sink; lighter clean coal floats.

3. *Dewatering:* Excess water is removed using centrifuges or filters.

4. *Drying:* Coal may be air-dried or thermally dried to reduce moisture content.

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I.3.7: Main Types of Coal and Uses

Coal is classified into four main types or ranks (Peat, lignite, bituminous, and anthracite), depending on the amounts and types of carbon it contains and on the amount of heat energy it can produce. The rank of a deposit of coal depends on the pressure and heat acting on the plant debris as it sank deeper and deeper over millions of years. For the most part, the higher ranks of coal contain more heat-producing energy.

Main types

Type of Coal	Carbon Content	Moisture and Impurities	Heat Value	Appearance
Peat	Very low (around 50–60%)	Very high moisture	Very low	Soft, brown, partly decayed plant material
Lignite (Brown Coal)	60–70%	High moisture	Low to medium	Brownish-black, crumbly
Bituminous Coal	70–90%	Moderate	High	Black, dense, shiny
Anthracite	90–95%	Very low	Very High	Hard, shiny black, burns with little smoke

Uses

Type of Coal	Main Uses
Peat	Early stage of coal; sometimes used as fuel in rural areas
Lignite (Brown Coal)	Used in power plants near mining areas
Bituminous Coal	Used for electricity generation and to make coke for steel
Anthracite	Used for domestic heating and high-quality industrial fuel

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I.3.8: Transporting Coal

Transporting coal means moving the processed or mined coal from where it is extracted (the mine) to where it will be used or sold such as power plants, steel mills, or export terminals.

Most coal is transported by train, but coal can also be transported by barge, ship, truck, and even pipeline. About 68 percent of coal in the U.S. is transported, for at least part of its trip to market, by train. It is cheaper to transport coal on river barges, but barges cannot take coal everywhere that it needs to go. If the coal will be used near the coal mine, it can be moved by trucks and conveyors.

Coal can also be crushed, mixed with water, and sent through a "slurry" pipeline. Sometimes, coal-fired electric power plants are built near coal mines to lower transportation costs.

Here's a clear explanation of Transporting coal:

I.3.8.1: Modes of Coal Transportation

a. Railways: Most common method for long distances.

- Large quantities can be moved efficiently in railway wagons.
- Coal is loaded at the mine and unloaded at the power plant or port using conveyor belts or tipplers.
- Example: In countries like India, the USA, and China, most inland coal is moved by rail.

b. Roadways:

- Used for short distances (from mines to nearby plants or railway sidings).
- Coal is carried in trucks or dumpers.
- Cheaper to set up but more expensive for long-distance transport.

c. Waterways:

- Barges and ships are used to carry coal along rivers, canals, or across seas.
- Very cost-effective for large volumes and long distances.
- Common for export coal (e.g., from ports to other countries).

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C. Conveyors and Pipelines

- Conveyor belts are used to transport coal within mining areas or from mine to nearby power plants.
- Slurry pipelines (where coal is mixed with water and pumped) are used in some modern systems, though less common.

I.3.8.2: Factors Affecting Coal Transport

- Distance to destination
- Quantity of coal
- Type of terrain (mountains, rivers, etc.).
- Cost and time efficiency
- Environmental impact (fuel use, dust, spillage)

I.3.8.3: Environmental & Safety Measures

- Covered wagons or trucks to prevent coal dust pollution.
- Proper loading and unloading systems to reduce loss and spillage.
- Maintenance of transport infrastructure to ensure safe handling.

I.3.9: How Coal is used?

About 92 percent of the coal used for generating electricity (For example, in the United States). Except for a small amount of net exports, the rest of the coal is used, as a basic energy source in many industries, including, steel, cement and paper. The six major uses of coal are:

1. Electricity Generation

- In thermal power plants, coal is burned to produce heat, which turns water into steam.
- The steam spins turbines connected to generators, producing electricity.
- Example: Many countries still rely on coal-fired power stations for a large part of their energy supply.

2. Steel Production

- Coal is used to make coke, a high-carbon fuel made by heating coal in the absence of air.
- Coke is essential in blast furnaces to convert iron ore into iron.
- This process is crucial in making steel for buildings, vehicles, and machines.

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3. Cement Manufacturing

- Coal is burned as a fuel in cement kilns to heat raw materials (like limestone) to form clinker, which is ground into cement.

4. Chemical Industry

- Coal is used as a raw material to produce various chemical products, such as:
 - ✓ Coal tar → used to make dyes, plastics, and medicines.
 - ✓ Ammonia and methanol → for fertilizers and fuels.
 - ✓ Synthetic gas (syngas) → used to make synthetic fuels and chemicals.

5. Domestic and Industrial Heating

- In some areas, especially where coal is locally available, it is used for home heating and industrial boilers.
- Anthracite coal, being clean-burning, is preferred for domestic use.

6. By-products of Coal

- Coal produces useful by-products like:
 - ✓ Coal gas – used as a fuel.
 - ✓ Coal tar – used for making dyes, drugs, and paints.
 - ✓ Coke– used in metallurgy.

I.3.10: Environmental Considerations

Coal combustion releases:

- CO₂ (carbon dioxide): greenhouse gas causing climate change.
- SO₂ (sulfur dioxide) and NO_x (nitrogen oxides): contribute to acid rain and smog.
- Particulate matter and heavy metals (e.g., mercury, arsenic): harmful to human health.
- Fly ash and slag: solid residues requiring disposal or recycling.

Mitigation methods include:

- Flue-gas desulfurization (FGD)
- Electrostatic precipitators (ESPs)
- Carbon capture and storage (CCS)

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I.3.11. Algeria Coal

- Algeria consumes only very small amounts of coal on the order of ~24,000 short tons per year in recent years (2014-2023) according to the U.S. Energy Information Administration (EIA).
- Algeria does not produce significant coal (or at least has not been a major coal exporting or industrial coal producer historically); it imports nearly all the coal it uses.
- Despite the low consumption or production, Algeria does have coal resources and potential coal basins, especially in the Béchar region (west south of the country) in the “Kenadsa”, “Mezarif”, and “Abadla” sub-basins.
- For example, a reference notes: “The Béchar region has a reserve of 208 million tons of coal which is not yet exploitable” in one source.
- Coal reserves statistics vary: one data set shows Algeria has about 245.82 million short tons of coal reserves in 2023 (short ton measure) listed by The Global Economy.com.
- Some older data indicate recoverable reserves of ~65 million short tons (2015) in the Helgi library dataset.
- A recent mine “Menounet (Bechar region)” reportedly began extraction in April 2023, targeting 7,000–10,000 tons/month in its first phase.

In summary, Algeria coal refers to the coal resources and usage in Algeria. While there are coal deposits (especially in areas such as the Béchar / Kenadsa region), the country historically has very low consumption, essentially no large-scale domestic coal production, and relies largely on imports for the small quantity of coal it uses. Coal plays a very minor role in Algeria’s energy system, which is overwhelmingly focused on oil and natural gas.

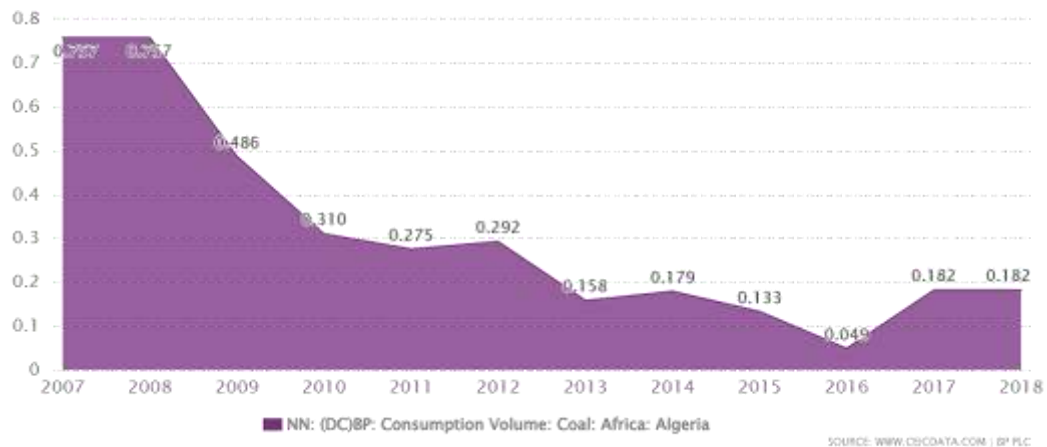


Figure.I.9: Algeria coal consumption, 1965-2024

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Appendix

Q1: Explain how coal is formed from dead plants.

- Coal forms from decaying plant material in swampy environments. Layers of plants are covered by water and soil, and over millions of years, heat and pressure increase carbon concentration, transforming it into coal.

Q2: List the four stages of coal formation by rank.

- Peat → Lignite → Bituminous → Anthracite

Q3: What is the difference between surface mining and underground mining?

- Surface mining: Used when coal is close to the surface (<200 feet). Soil and rock layers are removed to reach coal.
- Underground mining: Used for deep coal deposits. Miners use shafts and tunnels to extract coal.

Q4: Name three industrial uses of coal besides electricity generation.

- Steel production (coke), cement manufacturing, chemical industry (coal tar, ammonia, methanol).

Q5: Briefly describe the coal situation in Algeria.

- Algeria has coal reserves, especially in the Béchar region, but consumes very little (~24,000 tons/year). The country produces almost no coal and relies on imports. Coal plays a minor role in Algeria's energy system, which is mainly based on oil and natural gas.

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I. 5. Shale Gas

I.5.1: Introduction

What is shale gas?

Shale gas is a form of natural gas (mostly methane CH₄), found underground in shale rock. It is classified as ‘unconventional’ because it is found in shale, a less permeable rock formation than sandstone, siltstone or limestone in which ‘conventional’ gas is found, and it is generally distributed over a much larger area. Shale is a fine-grained sedimentary rock, with smaller spaces or pores containing gas, and these spaces are relatively unconnected to each other. Therefore natural gas does not flow easily through shale.

Shale gas has drawn increasing investments as an unconventional primary resource to renovate the global energy market. Over the last decade, factors linked to supply reliability and the recent developments in horizontal drilling and hydraulic fracturing or “fracking” technologies have boosted the natural gas production from tight shale formations. Nevertheless, shale gas operations remain a contentious issue due to their environmental and social implications. With regard to water-related impacts, shale gas production usually requires excessive freshwater amounts and produces large volumes of damaging high-salinity wastewater. Under this scenario, zero-liquid discharge (ZLD) membrane desalination emerges as an effective wastewater management option for maintaining sustainable progress of shale gas sector, while reducing risks associated with water resources depletion and brine disposals. It has become a major unconventional energy source in recent decades, especially in the United States, Canada, and China.

How much is there globally?

Estimates of the volume of shale gas can be expressed in different way. ‘Resource estimates’ refer to the amount of natural gas that is believed to exist in a particular location. In some cases, technically recoverable resources can be estimated. ‘Reserve estimates’ refer to the amount of gas that is both technically and economically viable to extract. Reserves typically represent a small percentage of resources and can only be reliably estimated when based on detailed exploration and evaluation, including drilling. Recovery rates for shale gas are much lower than for conventional gas.

In 2015, the total amount of ‘unproved technically recoverable resources’ of shale gas was estimated at 214.6 trillion cubic metres (tcm), across 46 countries.

The largest estimated resources are in China (31.6 tcm), followed by Argentina (22.7 tcm), Algeria (20 tcm), the United States (17.6 tcm) and Canada (16.2 tcm). In Europe the largest

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estimated resources lie in Poland (4.1 tcm) and France (3.9 tcm), with 0.7 tcm for the United Kingdom

Projections by the US Energy Information Administration in 2016 estimated that shale gas would account for 30 per cent of world natural gas production by 2040.

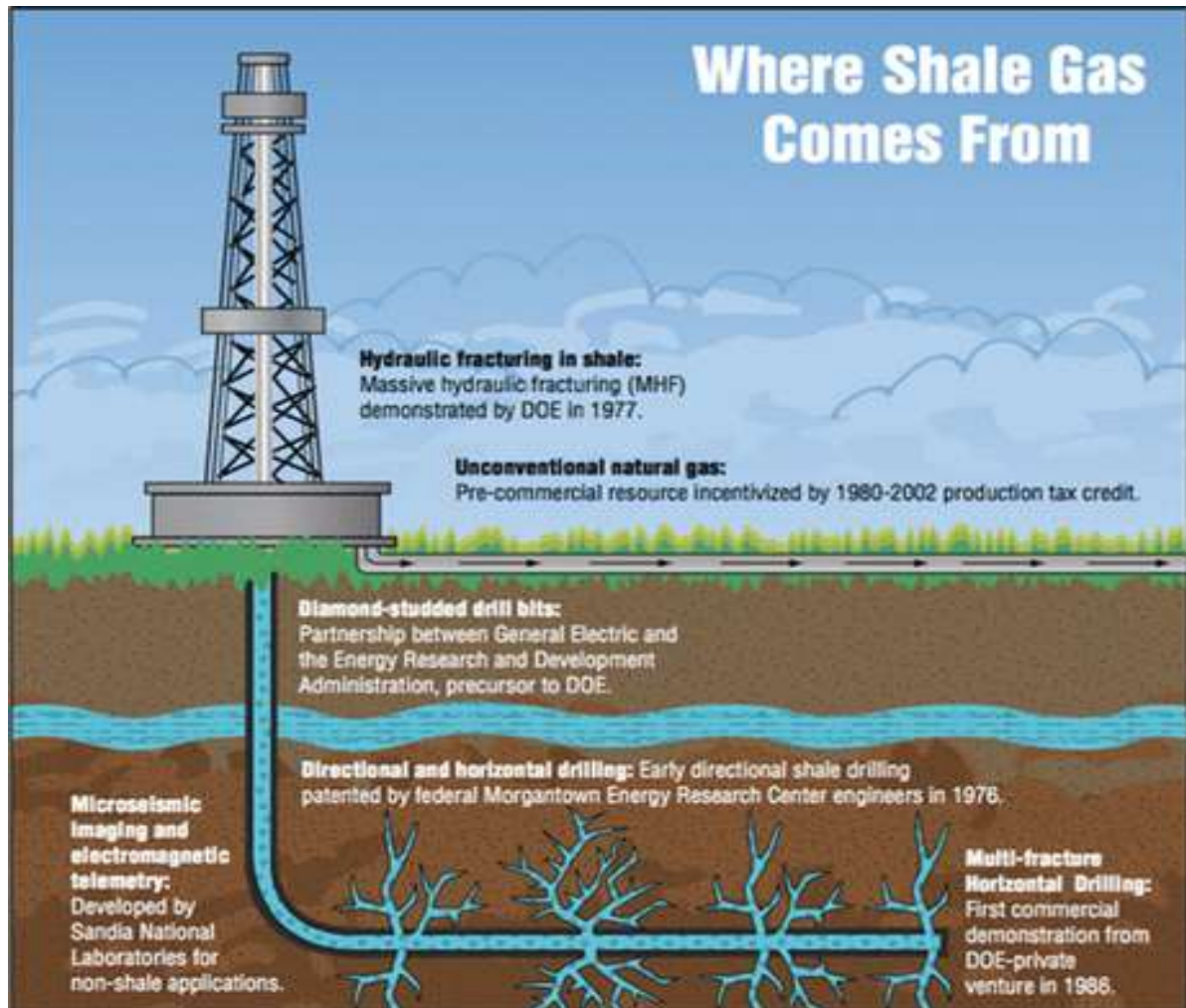


Figure.I.10: Diagram Showing the Origin and Extraction of Shale Gas

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How is shale gas extracted through hydraulic fracturing ('fracking')?

1. Site Preparation

- The process begins with selecting and preparing a drilling site above a shale formation.
- Roads, drilling pads, and water storage ponds are constructed.

2. Drilling the Well

- A vertical well is drilled deep into the earth (sometimes 2–3 km).
- When it reaches the shale layer, the well is then turned horizontally and drilled for 1–2 km through the shale.
- Steel casing and cement are installed along the wellbore to prevent leaks into groundwater.
- This combination of vertical and horizontal drilling allows access to more of the shale rock layer from a single well.

3. Hydraulic Fracturing ("Fracking")

- A high-pressure fluid mixture (about 90% water, 9% sand, and <1% chemical additives) is pumped down the well.
- The pressure causes tiny cracks (fractures) to form in the shale rock.
- These fractures are only a few millimeters wide but extend hundreds of meters through the rock.

4. Propping the Fractures Open

- The sand particles (called proppants) in the fracking fluid hold the cracks open once pressure is released.
- This keeps pathways open for gas to flow out of the rock.

5. Flowback and Production

- When the pumping stops, the pressure inside the well decreases.
- The trapped natural gas (mostly methane) begins to flow through the fractures and up the well to the surface.
- Some of the injected water (called flowback fluid) returns to the surface and is collected for treatment or recycling.

6. Processing and Transport

- The extracted gas is separated, cleaned, and processed to remove water and impurities.
- It is then transported via pipelines for use in power generation, heating, or industrial applications.

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I.5.2: Formation Process

The formation of natural gas goes through several stages. It begins with the accumulation of organic matter from dead plants and microorganisms in muddy environments, such as lakes and seas. Layers of sediment then cover this organic material, burying and compacting it over time. With continued exposure to heat and pressure over millions of years, the organic matter gradually transforms into hydrocarbons. Finally, the gas becomes trapped in tiny pores and fractures within shale rock, making it possible to extract later.

Stage	Description
Organic matter deposition	Dead plants and microorganisms accumulate in muddy environments (lakes, seas)
Burial and compaction	Layers of sediment cover the organic material
Heat and pressure	Over millions of years, organic material turns into hydrocarbons
Trapping in shale rock	Gas remains trapped in tiny pores and fractures of shale

Table. I.6: The Process of Natural Gas Formation from Organic Matter

I.5.3: Composition

The composition of natural gas is primarily methane (CH₄), which makes up about 70 - 90% of the gas. Small amounts of other hydrocarbons, such as ethane, propane, and butane, are also present. Additionally, trace gases like carbon dioxide, nitrogen, and hydrogen sulfide can be found in very small quantities.

- Methane (CH₄): 70 - 90%.
- Ethane, propane, butane: small amounts.
- Carbon dioxide, nitrogen, hydrogen sulfide: trace gases.

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I.5.4: Advantages and Disadvantages of Shale Gas

Natural gas offers several advantages. It enhances energy security by expanding domestic gas supplies, promotes economic growth through job creation and reduced gas imports, and produces lower CO₂ emissions compared to coal and oil. It also serves as a “bridge fuel,” helping the transition to renewable energy sources. However, there are environmental drawbacks. Hydraulic fracturing (fracking) consumes millions of liters of water per well and can lead to groundwater contamination from chemicals. Methane leaks, a potent greenhouse gas, may occur, and fracking can trigger small seismic events. Additionally, drilling sites and associated infrastructure require a large land footprint.

Advantages	Disadvantages / Environmental Impacts
Energy Security: Expands domestic gas supply.	Water Use: Fracking uses millions of liters of water per well.
Economic Growth: Creates jobs, reduces gas imports.	Water Pollution: Chemicals can contaminate groundwater.
Lower CO₂Emissions: Cleaner than coal and oil.	Methane Leaks: Powerful greenhouse gas.
Bridge Fuel: Helps transition to renewable energy sources.	Earthquakes: Small seismic events caused by fracking pressure.
	Land Use: Large surface footprint for drilling sites and roads.

Table.I.7: Advantages and Environmental Impacts of Natural Gas

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I.5.5: Main uses of shale gas

Shale gas is mainly used for electricity generation, industrial heating, petrochemicals, residential energy, transportation fuel, exports, and hydrogen production making it a key player in the modern energy mix.

1. Electricity generation

- The largest use of shale gas is as a fuel for power plants.
- It is burned to produce electricity, often replacing coal.
- Produces less CO₂, sulfur dioxide, and particulates than coal, making it a cleaner energy source.

2. Industrial fuel

- Used in industries such as cement, steel, glass, ceramics, and paper.
- Provides heat for boilers, furnaces, and kilns.
- Acts as a feedstock for hydrogen production.

3. Feedstock for petrochemical industry

Shale gas (especially its components like ethane, propane, and butane) is used to make:

- Ethylene and propylene → for plastics (like polyethylene, polypropylene)
- Ammonia → for fertilizers.
- Methanol → for chemicals and fuels.

4. Transportation Fuel

Compressed natural gas (CNG) and liquefied natural gas (LNG) derived from shale gas can power:

- Cars, buses, and trucks
- Ships and trains(in some regions)
- Cleaner and cheaper than gasoline or diesel.

5. Residential and Commercial Use

- Used for cooking, heating, and hot water in homes and businesses.
- Powers gas stoves, water heaters, and HVAC systems.

6. Export and Energy Security

- Shale gas can be liquefied (LNG) and exported to other countries.
- Helps nations reduce dependence on imported oil or gas.
- Contributes to energy diversification and economic growth.

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7. Hydrogen Production

Methane from shale gas can be used in steam methane reforming (SMR) to produce hydrogen, used in:

- Fuel cells
- Refineries
- Ammonia production

I.5.6: Global Shale Gas Production and Distribution

A- Production

Global shale gas production has grown rapidly in recent years, transforming the energy landscape. Countries like the United States, China, and Canada are leading producers, utilizing advanced technologies such as hydraulic fracturing and horizontal drilling to extract gas from shale formations. This increase in shale gas production has enhanced energy security, reduced dependence on imported fuels, and contributed to economic growth. However, it also raises environmental concerns, including water use, potential groundwater contamination, methane emissions, and induced seismic activity.

Country	Estimated Technically Recoverable Shale Gas (Tcf)	Notes
Tcf = Trillion cubic feet		
USA	1.161	Leading producer (Marcellus, Barnett, Eagle Ford)
China	1.115	Significant potential, complex geology
Argentina	802	Vaca Muerta formation
Algeria	707	High potential (Ahnet, Illizi, Berkine basins)
Canada	573	Montney, Horn River basins

Table. I.8: Estimated Technically Recoverable Shale Gas by Country (Trillion Cubic Feet)

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I.5.7: Shale Gas in Algeria

The energy sector represents a major industrial activity and economic contributor in Algeria. The country is the leading primary energy producer in Africa, with an annual generation of roughly six quadrillion British thermal units. The large energy production is due to the abundance of natural resources such as oil and natural gas, which are the main energy sources used in the country. In fact, despite Algeria's ambitious renewable energy plans, clean energy sources remain largely untapped as of 2021.

According to Algeria - Country Commercial Guide:

- In terms of market size, Algeria has the tenth-largest proven natural gas reserves globally, is the world's fourth-largest gas exporter, and has the world's third-largest untapped shale gas resources. It also ranks sixteenth in proven oil reserves and exports roughly sixty percent of its total production. All the country's proven oil reserves are onshore. According to Algeria's national oil company, Sonatrach, about two-thirds of the Algerian territory remains underdeveloped or unexplored, with an estimated 100 undeveloped discoveries.
- Given pressure from European Union customers to increase its supply of gas, Sonatrach and its international partners are intensifying oil and gas exploration. Simultaneously, Algerian authorities are calling for locally manufactured products and services for small and medium-sized oil and gas service projects. As a part of this push to further develop the local oil service industry, Sonatrach encourages Algerian oil and gas services companies to conclude subcontracts and licensing agreements with international oil and gas equipment manufacturers. For large projects, however, Sonatrach continues to rely on world-class Engineering, Procurement, and Construction (EPC) contractors, who routinely work with American equipment and service providers. U.S. equipment and service suppliers should work proactively with Sonatrach to be included in its approved vendor list and become familiar with the technical specifications for upcoming EPC projects.
- According to Algeria - Country Commercial Guide:
- In terms of market size, Algeria has the tenth-largest proven natural gas reserves globally, is the world's fourth-largest gas exporter, and has the world's third-largest untapped shale gas resources. It also ranks sixteenth in proven oil reserves and exports roughly sixty percent of its total production. All the country's proven oil reserves are onshore. According to Algeria's national oil company, Sonatrach, about

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two-thirds of the Algerian territory remains underdeveloped or unexplored, with an estimated 100 undeveloped discoveries.

- Given pressure from European Union customers to increase its supply of gas, Sonatrach and its international partners are intensifying oil and gas exploration. Simultaneously, Algerian authorities are calling for locally manufactured products and services for small and medium-sized oil and gas service projects. As a part of this push to further develop the local oil service industry, Sonatrach encourages Algerian oil and gas services companies to conclude subcontracts and licensing agreements with international oil and gas equipment manufacturers. For large projects, however, Sonatrach continues to rely on world-class Engineering, Procurement, and Construction (EPC) contractors, who routinely work with American equipment and service providers. U.S. equipment and service suppliers should work proactively with Sonatrach to be included in its approved vendor list and become familiar with the technical specifications for upcoming EPC projects.
- Sonatrach and its subsidiaries are the leading players in Algeria's oil and gas sector. They control roughly 80 percent of hydrocarbon production in Algeria, while IOCs account for the remaining 20 percent. Sonatrach's five main divisions include E&P, midstream, downstream liquefaction and separation, downstream refineries and petrochemicals, and sales. A special unit within Sonatrach, the Division Associations' office, develops projects with IOCs. In addition, Sonatrach has multiple specialized subsidiaries, including ENAFOR (drilling and extraction), ENTP (drilling, work-over activities, and rig transfer), ENGTP (civil engineering earthworks, welding, piping, and test control), ENSP (oil well services), ENAGEO (seismic and reservoir management), and GCB (oil services and civil engineering).
- Regarding competition, Algeria's oil and gas sector includes a mix of more than two dozen IOCs working on more than 30 significant projects. These IOCs partner with various local and international oil field services companies, and the Algeria Oil and Gas Energy Resource Guide provides a comprehensive list of these companies.
- Algeria holds one of the largest shale gas reserves in the world, estimated at ~707 trillion cubic feet (Tcf).
- **Main potential regions:**
 - Ahnet Basin (southwest)
 - Illizi Basin (southeast)
 - Timimoun and Berkine basins

Chapter I: Fossils Energies

- **Challenges:**

High cost of extraction

Water scarcity in desert areas

Environmental and social opposition (notably protests in In Salah, 2015)

- **Status:**

Pilot exploration projects started with foreign partners (e.g., Total, Shell, ENI).

Algeria is still evaluating economic feasibility and environmental impact before large-scale production.

I.5.8: Comparison: Conventional vs Shale Gas

Feature	Conventional Gas	Shale Gas
Location	Trapped in porous reservoirs	Trapped in shale rock
Extraction	Simple drilling	Horizontal drilling + fracking
Cost	Lower	Higher
Production rate	High	Declines faster
Environmental impact	Moderate	Higher (water, chemicals, seismic)

Table.I.9: Comparison between Conventional vs Shale Gas

Chapter I: Fossils Energies

Appendix

Q1: Define shale gas.

- Natural gas trapped in shale rock formations, extracted using horizontal drilling and hydraulic fracturing.

Q2: List two main extraction techniques.

- Horizontal drilling and hydraulic fracturing.

Q3: Name two environmental risks of shale gas.

- Water contamination and induced earthquakes.

Q4: Where is Algeria's main shale gas basins located?

- Ahnet, Illizi, and Berkine basins (southern Algeria).

Q5: Which technology is essential for extracting shale gas?

- Hydraulic fracturing (fracking)

Q6: The largest shale gas producer in the world is:

- USA

Q7: Main challenge for shale gas development in Algeria?

- Water scarcity

Q8: True / False:

- Shale gas is a renewable energy source. **False**
- Hydraulic fracturing uses water, sand, and chemicals. **True**
- Algeria has over 700 trillion cubic feet of shale gas reserves. **True**
- Shale gas extraction produces zero environmental risk. **False**

Chapter II: Fossils Energies and the Environment

II. 1: Introduction

II.2 : The Environment

II. 3: Definition of pollution and types

II. 4: Causes of air pollution

II. 5: Main pollutants from combust



II. 1: Introduction

Fossil fuels like coal, oil, and natural gas are the main sources of energy for many countries. However, their use has serious effects on the environment. Burning fossil fuels releases harmful gases that cause air pollution, global warming, and climate change. It also leads to water pollution and damage to natural habitats. ***How have fossil fuels affect the environment?***

When fossil fuels are burned, they release nitrogen oxides into the atmosphere, which contribute to the formation of smog and acid rain. Major sources of nitrogen oxide emissions include: Cars, trucks, and coal-fired power plants.

The use of fossil fuels releases large amounts of greenhouse gases (GHGs), primarily carbon dioxide (CO₂) and methane (CH₄), into the atmosphere. These emissions are the main drivers of global warming and climate change, leading to rising sea levels, extreme weather events, and disruptions to ecosystems. Additionally, fossil fuel exploitation contributes to air and water pollution, soil degradation, and biodiversity loss. Oil spills, mining operations, and gas flaring are among the most visible examples of the damage caused to natural habitats and human health.

Fossil fuels coal, oil and gas are by far the largest contributor to global climate change, accounting for over 75 per cent of global greenhouse gas emissions and nearly 90 per cent of all carbon dioxide emissions. As greenhouse gas emissions blanket the Earth, they trap the sun's heat.

Fossil fuel extraction and infrastructure development often results in significant environmental degradation, habitat destruction, and biodiversity loss.



Figure.II.1: Environmental impact of hydrocarbon combustion in industrial facilities.

II. 2 : The environment

II.2.1: What is the environment?

- The environment is everything that surrounds us, encompassing both living (biotic) and non-living (abiotic) things like air, water, land, plants, and animals. It includes the natural world and the physical, chemical, and biological factors that affect the life, development, and survival of an organism. The term can also refer to the specific conditions surrounding a person, like their social and physical surroundings, or to a broader concept like the interstellar medium in space.
- The environment is "the set of elements (biotic or abiotic) that surround an individual or a species and some of which contribute directly to meeting their needs.



Figure.II.2: The picture symbolizes people from different backgrounds coming together to protect and support the planet.

Chapter II: Fossils Energies and the Environment

- The notion of natural environment, often referred to only by the word 'environment', is essentially understood as the set of natural components of the **planet Earth**, such as **air**, **water**, and **soil**.



Figure.II.3: Soil



Figure.II.4: Water



Figure.II.5: Air

Chapter II: Fossils Energies and the Environment

In our society, threats to the environment are numerous. Among the main ones, we note the following: pollution, global warming, and the destruction of the ozone layer, overproduction and overconsumption.

For several years, humans have played a major role in the degradation of our environment, leading to a major imbalance in ecological balance. Human actions and activities in the environment cause pollution intentionally or unintentionally. Indeed, there are several kinds of pollution. The most important ones are: air pollution, water pollution, and soil pollution. The figures below show the air pollution, water pollution, and soil pollution.



Figure.II.6: Air, water, and soil pollution

II. 3: Definition of pollution and types

II.3.1: Definition of pollution

- Pollution is the introduction of harmful substances or energy into the environment that causes damage to living organisms, natural resources, and ecosystems. It can affect the air, water, and soil, and is mainly caused by human activities such as burning fossil fuels, industrial processes, and waste disposal.
- Pollution is the introduction of harmful materials into the environment. These harmful materials are called pollutants.
- Pollution is anything that makes the earth dirty and unhealthy, causing negative effects on living organisms, natural habitats, and the planet's balance. It is mainly caused by human activities such as burning fossil fuels, industrial production, and waste disposal. Pollution cause also by of the things people use every day come in packages, like food, games, school supplies, and electronics.

Major forms of pollution include air pollution, water pollution, and soil pollution.



Figure.II.7: Air pollution, water pollution, and soil pollution

II.3.2: Types of pollution

Pollution means making our environment dirty and unsafe. There are many types, like air pollution, water pollution, thermal pollution, soil pollution. Each one harms people, animals, and nature in different ways.

- **Air Pollution:** Air pollution is the contamination of air due to the presence of substances in the atmosphere that are harmful to the health of humans and other living beings, or cause damage to the climate or to materials. It is also the contamination of indoor or outdoor surrounding either by chemical activities, physical or biological agents that alters the natural features of the atmosphere. Air pollution happens when harmful gases, smoke, or dust mix with the air. It comes from smoke, gases, and chemicals released from vehicles, factories, and power plants. It leads to smog, acid rain, and respiratory diseases and it can cause breathing problems and harm the environment.

Composition of air pollution:

- Chemical pollutants: Fine particles, nitrogen oxides, ozone, carbon monoxide, sulphur dioxide, volatile organic compound (VOCs), etc.
- Biological pollutants: Pollens, mold spores.
- Particles: Various solid particles suspended in the air, whose size influences their dangerousness.

Health effects

- Worsening of lung and heart diseases.
- Increased risk of cancer.
- Impacts on vulnerable people (children, elderly, asthmatics).



Figure.II.8: Air pollution

Chapter II: Fossils Energies and the Environment

- **Water Pollution:** Pollution is the introduction of harmful materials into the environment. These harmful materials are called pollutants, often chemicals or microorganisms contaminate a stream, river, lake, ocean, aquifer, or other body of water, degrading water quality and rendering it toxic to humans or the environment. The main point source of pollution to water is from sewage and waste water treatment, while for diffuse pollution, main sources are from farming and fossil fuel power plants (via the air).

Impacts of water pollution

- Polluted water impacts both human health and the health of the planet. Pollution affects populations and ecosystems as a whole. Oil spills provide an example of the wide-ranging and lasting impacts that pollution can have on aquatic ecosystems and the people who depend on them. In April 2010, the Deepwater Horizon oil rig, owned and operated by Transocean and leased by oil company BP, exploded in the Gulf of Mexico, causing oil to gush from the ocean floor. In the following months, hundreds of millions of gallons of oil spewed into the gulf waters. The spill produced large plumes of oil under the sea and an oil slick on the surface as large as 57,000 square kilometers (149,000 square miles). It polluted at least 1,770 kilometers (1,100 miles) of shoreline.
- Many animals died from the Deepwater Horizon oil spill, including thousands of sea turtles, marine mammals, birds and fish. The oil spill killed an estimated 8.3 billion oysters, which provide significant environmental benefits, including filtering water and forming reefs that provide critical habitats for numerous species. The oil slick coated wetlands in the U.S. states bordering the Gulf of Mexico, killing marsh plants and aquatic organisms, such as oysters and fish. Birds, such as pelicans, became coated in oil and were unable to fly or regulate their temperature.



Figure.II.9: Water pollution, toxic water pours from a factory in South Volgograd, Russia.

- **Soil Pollution:** Soil pollution refers to the contamination of soil with anomalous concentrations of toxic substances. It is a serious environmental concern since it harbors many health hazards. Soil contamination, soil pollution, or land pollution as a part of land degradation is caused by the presence of xenobiotic (human-made) chemicals or other alteration in the natural soil environment. Also, soil pollution Occurs when toxic chemicals, pesticides, or industrial waste contaminate the ground, reducing soil fertility and harming plants and animals.

Human health

Contaminated or polluted soil directly affects human health through direct contact with soil or via inhalation of soil contaminants that have vaporized; potentially greater threats are posed by the infiltration of soil contamination into groundwater aquifers used for human consumption, sometimes in areas apparently far removed from any apparent source of above-ground contamination. Toxic metals can also make their way up the food chain through plants that reside in soils containing high concentrations of heavy metals. This tends to result in the development of pollution-related diseases.

Most exposure is accidental, and exposure can happen through:

- Ingesting dust or soil directly
- Ingesting food or vegetables grown in contaminated soil or with foods in contact with contaminants
- Skin contact with dust or soil
- Vapors from the soil
- Inhaling clouds of dust while working in soils or windy environments
- However, some studies estimate that 90% of exposure is through eating contaminated food.



Figure.II.10: Soil pollution

Chapter II: Fossils Energies and the Environment

- **Thermal Pollution:** Caused by excessive heat released into water bodies from industrial or power plant activities, disturbing aquatic ecosystems.
- Thermal pollution, sometimes called "thermal enrichment", is the degradation of water quality by any process that changes ambient water temperature. Thermal pollution is the rise or drop in the temperature of a natural body of water caused by human influence. Thermal pollution, unlike chemical pollution, results in a change in the physical properties of water. A common cause of thermal pollution is the use of water as a coolant by power plants and industrial manufacturers. Urban runoff storm water discharged to surface waters from rooftops, roads, and parking lots and reservoirs can also be a source of thermal pollution. Thermal pollution can also be caused by the release of very cold water from the base of reservoirs into warmer rivers.
- When water used as a coolant is returned to the natural environment at a higher temperature, the sudden change in temperature decreases oxygen supply and affects ecosystem composition. Fish and other organisms adapted to particular temperature range can be killed by an abrupt change in water temperature (either a rapid increase or decrease) known as "thermal shock". Warm coolant water can also have long term effects on water temperature, increasing the overall temperature of water bodies, including deep water. Seasonality affects how these temperature increases are distributed throughout the water column. Elevated water temperatures decrease oxygen levels, which can kill fish and alter food chain composition, reduce species biodiversity, and foster invasion by new thermophilic species.

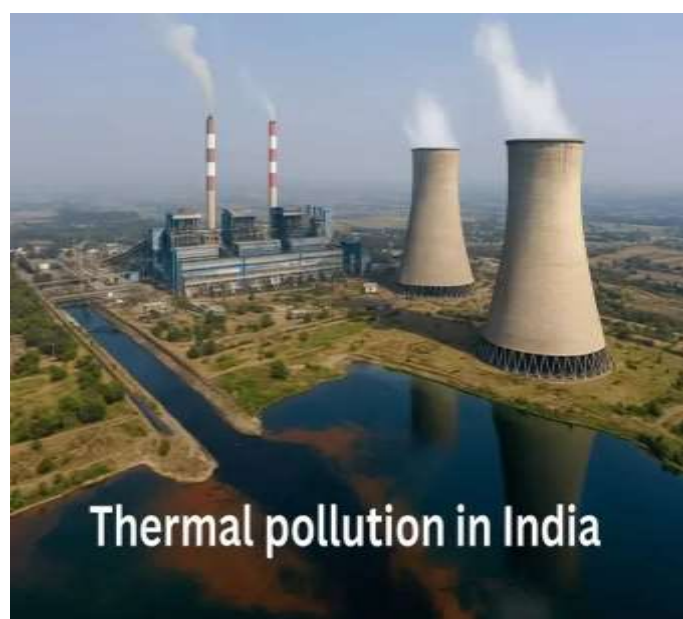
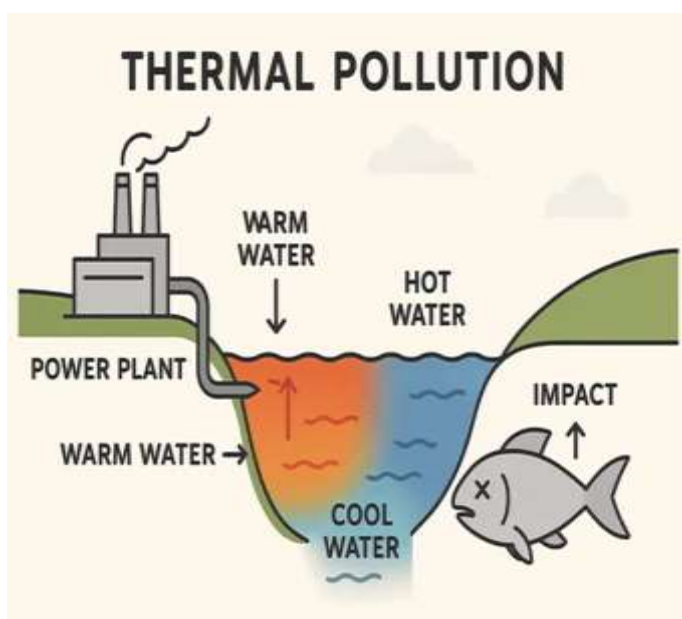


Figure.II.11: Thermal pollution

II. 4: Causes of air, water, soil pollution, and thermal pollution

II.4.1: Causes of air pollution

Air pollution can cause diseases, allergies, and even death to humans; it can also cause harm to other living organisms such as animals and crops, and may damage the natural environment (for example, climate change, ozone depletion or habitat degradation) or built environment (for example, acid rain). Air pollution can be caused by both human activities and natural phenomena. The causes of air pollution are mainly of human origin (transport, industries, residential heating, and agriculture) and, to a lesser extent, of natural origin (volcanic eruptions, forest fires, sand mist). These sources emit primary pollutants, which then transform to form secondary pollutants like ozone.

- **Human activities:** Road transport, industry, energy production, domestic heating, agriculture.
- **Natural phenomena:** Volcanic eruptions, forest fires, soil erosion.

We have listed 10 common air pollution causes along with their effects:

1. **The Burning of fossil fuels:** Most of the air pollution takes place due to the incomplete burning of fossil fuels. These include coal, oil, and gasoline to produce energy for electricity or transportation. The release of CO at a high level indicates how much fossil fuel is burned. This also emits other toxic pollutants like nitrogen oxides into the air. Inhaling air induced with pollutants due to the burning of natural gas and fossil fuel reduces the heart's ability to pump enough oxygen. Hence causing one to suffer from various respiratory and heart illnesses. Furthermore, the nitrogen oxides are responsible for acid rain and the formation of smog.
2. **Industrial emission:** Industrial activities emit several pollutants in the air that affect the air quality more than we can even imagine. Particulate matter 2.5 and 10, NO₂, SO₂, and CO are key pollutants that are emitted from industries that use coal and wood as their primary energy source for the production of their goods.
3. **Indoor air pollution:** Use of toxic products also called Volatile Organic Compounds (VOCs), inadequate ventilation, uneven temperature, and humidity level can cause indoor air pollution, whether you are in an office, school, or at your comfortable home. House air pollution can take place due to ignorant factors, for instance, smoking tobacco inside a room or leaving mold-infected walls untreated. The use of wood stoves or space heaters is capable of increasing the humidity level which can directly affect the health of a person in no time. Carcinogens and toxins from indoor air pollution cause 17% of deaths from lung cancer.

- 4. Wildfires:** Climate change is not just increasing wildfire but also spiking air pollution. Burning stubble and farm residue is also a major contribution to wildfire. It causes increased PM_{2.5} in the air which collides with other harmful substances like chemical gas and pollen creating smog. Smog makes the air hazy and people find it difficult to breathe. Visibility also decreases as a result of this smog. Difficulty in breathing, irritation in the eyes, nose, and throat, itchiness in the respiratory tract, etc. are all symptoms of inhaling smog.
- 5. Microbial decaying process:** Manufacturing, chemical, and textiles industries release a large number of CO, hydrocarbons, chemicals, and organic compounds which contaminate our environment. Bacteria and fungi play a fundamental role in the biogeochemical cycles in nature. They are the key indicators of abnormal environmental conditions. Decaying of these microorganisms present in the surroundings releases methane gas which is highly toxic. Breathing toxic gas like methane may lead to death.
- 6. Transportation:** Cars on the roads are increasing day by day. There is no denying that vehicle pollution is the major contributor to air pollution, especially in urban cities, where car ownership rates are more as compared to rural areas. When the car burns gasoline, it emits pollutants in the air which is as harmful as smoking 10 cigarettes a day. Most Vehicle emits are: Carbon monoxide, Hydrocarbons, Nitrogen oxide, and Particulate Matter (PM_{2.5} and PM₁₀).
- 7. Open burning of garbage waste:** Exposure to open burning of garbage waste can pose serious health risks including: cancer, liver issues, impairment of the immune system, reduced reproductive functions, and can also affect the developing nervous system. Open air garbage burning releases toxins such as black carbon, soot, and carcinogens. It actively contributes to the greenhouse effect, and in turn to climate change. Black carbon and soot gets deposited on the ice peaks, which results in their meltdown.
- 8. Construction and Demolition:**
 - a.** Construction and demolition sites are a rich source of PM and other air pollutants including VOCs, etc.
 - b.** People living near these sites experience various health concerns like difficulty in breathing, irritation in the eyes, nose, and throat, etc.
 - c.** The workers and personnel working on-site are exposed to these air pollutants every day. These pollutants affect their health to a great extent as well.
 - d.** Therefore, it becomes important to monitor the air quality at construction and demolition sites to comply with the standards.

- e. It is important to maintain the air quality at these sites, so as to maintain the air quality standards and limit the excessive usage of toxin and PM generating activities.
- 9. Agricultural Activities:** Agricultural activities have had a serious impact on the decreasing air quality. To begin with, pesticides and fertilizers are the main sources that contaminate the surrounding air. Nowadays, pesticides and fertilizers are mixed with new invasive species which are not found in nature, for quick growth of the crops and vegetation. Once they are sprayed over, the smell and the effect of the pesticides are left in the air. Some mix with water and some seeps into the ground which not only destroys the crops but also causes numerous health-related issues.
- 10. Use of chemical and synthetic products:** Talking about air pollution, we always consider outdoor air pollution dangerous for our lives but never talk about indoor air pollution. Household products cause indoor air pollution which is 10 times more harmful than outdoor air pollution. We spend more than 90% of our lives indoors, which makes the indoor air pollution impacts more serious and concerning. Volatile Organic Compounds (VOCs) found in paints, cleaners and personal care products such as perfume and deodorants are a reason for common health issues. These are silent killers that can cause risks like asthma or other respiratory issues and lung disease are other issues caused by inhaling poor house air quality.
- a. Other sources include cooking, smoking, furniture, paints, hobby craft, furnaces; coal powered heaters, and many more. Indoor air pollution has caused over 4 million premature deaths per year.
 - b. This is responsible for various lung and heart diseases in children and old people such as bronchitis, pneumonia, and aggravation of asthma.

II.4.2: Causes of water pollution

- Sometimes pollution can originate from a single, defined source. This is known as point-source pollution. For example, wastewater treatment plants can produce point-source pollution. Around 80% of wastewater enters the environment untreated. This number jumps to over 95% for some low-income countries. Wastewater encourages the growth of germs, like bacteria, viruses and parasites that can cause illness in humans. Pharmaceuticals can also end up in wastewater and threaten aquatic life and human health. Factories can also produce point-source pollution, discharging waste like oil into waterways. Oil spills in the ocean can have devastating, long-term impacts to ecosystems and human health as well as significant economic consequences.
- In many cases, pollution does not originate from a single source. Instead, pollution from numerous sources combines in a way that makes it difficult to determine the source. This is called nonpoint-source pollution, and it can come from urban, agricultural and industrial sources. Pollution from rain washing waste into waterways, or runoff, is typically considered nonpoint-source pollution.
- Another type of water pollution is garbage. The Citarum River in Indonesia, for example, has so much garbage floating in it that you cannot see the water. This floating trash makes it difficult to fish in the Citarum River. Aquatic animals, including fish and turtles, in garbage-infested waters can mistake trash for food. Plastic bags and other trash can kill many aquatic creatures. Chemical pollutants in trash can also make water toxic for both fish and the people who use the river as a drinking water source. Since 2008, around 60% of the fish species that used to inhabit the Citarum River are no longer there. The fish that remain often have high levels of chemical toxins in their flesh. People who eat fish contaminated with chemicals can absorb these toxins as they eat.
- Water can become polluted with radioactive waste, which can persist in the environment for thousands of years and cause extensive health consequences. In 2011, the Great Tohoku Earthquake caused a tsunami that led to the release of radioactive materials from the Fukushima Tokyo Electric Power Company (TEPCO) Daiichi nuclear reactor site. Radioactive materials from Fukushima entered the groundwater and the Pacific Ocean, and became part of rainwater. These radioactive materials were even found in tuna on the west coast of North America.
- A major source of water pollution is fertilizer used in agriculture. Fertilizer is a substance that is added to soil to make plants grow larger and faster. Fertilizers usually contain large amounts of the elements nitrogen and phosphorus, which help plants

grow. Rainwater washes fertilizer into streams and lakes. This creates an excess of nutrients in the water, called eutrophication, and it can have major impacts to ecosystems by disrupting oxygen levels in the water.

II.4.3: Causes of soil pollution

Soil pollution can be caused by the following (non-exhaustive list):

1. Micro plastics
2. Oil spills
3. Mining and activities by other heavy industries
4. Accidental spills may happen during activities, etc.
5. Corrosion of underground storage tanks (including piping used to transmit the contents)
6. Acid rain
7. Intensive farming
8. Agrochemicals, such as pesticides, herbicides and fertilizers
9. Petrochemicals
10. Industrial accidents
11. Road debris
12. Construction activities
13. Exterior lead-based paints
14. Drainage of contaminated surface water into the soil
15. Ammunitions, chemical agents, and other agents of war
16. Waste disposal
17. Oil and fuel dumping
18. Nuclear wastes
19. Direct discharge of industrial wastes to the soil
20. Discharge of sewage
21. Landfill and illegal dumping
22. Coal ash
23. Electronic waste
24. Contaminated by rocks containing large amounts of toxic elements.
25. Contaminated by Pb due to vehicle exhaust, Cd, and Zn caused by tire wear.
26. Contamination by strengthening air pollutants by incineration of fossil raw materials

***N.B:** The most common chemicals involved are petroleum hydrocarbons, solvents, pesticides, lead, and other heavy metals.*

II.4.4: Causes of thermal pollution

Both human and natural factors can contribute to thermal pollution. However, the single biggest cause of thermal pollution is cooling for industrial machinery and power plants. Water is an effective and free cooling agent, which is why many industrial operations pull in cold water to cool down their machinery and let warm water flow back into natural bodies of water.

Top examples of thermal pollution caused by humans include:

1. Power plants that use fossil fuels such as coal or natural gas release large quantities of heated water into nearby bodies of water.
2. Urbanization creates asphalt and concrete surfaces that absorb and retain heat and can result in warm runoff water.
3. Deforestation removes shading provided by trees and can quickly elevate water temperatures.
4. Agricultural practices can cause excessive nutrient runoff that promotes algal blooms, which then decompose in water while releasing heat.
5. Thermal pollution also has some natural causes, such as geothermal vents hot springs, and even volcanoes that introduce extra heat into bodies of water. There are also some “natural” causes of thermal pollution that one could argue are indirectly caused by human activity, including forest fires and weather phenomena like heat waves.
6. Soil erosion: This can increase the depth of water bodies, making them more exposed to sunlight.

II. 5: Main pollutants due to combustion

The burning of fuels such as coal, oil, natural gas, wood, or biomass produces a number of pollutants, depending on the fuel type and combustion efficiency. The main pollutants due to combustion are: carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO₂), particulate matter, and volatile organic compounds (VOCs). Other pollutants include carbon dioxide (CO₂), formaldehyde, and polycyclic aromatic hydrocarbons (PAHs). The specific pollutants depend on the fuel, combustion temperature, and efficiency, but all can negatively impact human health and the environment.

1. Carbon Monoxide (CO)

Source: An odorless, colorless gas resulting from incomplete combustion of carbon-containing fuels.

Effect: Toxic gas; binds with hemoglobin in blood, reducing oxygen transport.

2. Carbon Dioxide (CO₂)

Source: Complete combustion of carbon in fuel.

Effect: Major greenhouse gas, contributing to global warming.

3. Nitrogen Oxides NO_x

Source: High-temperature combustion (e.g., engines, power plants) where nitrogen and oxygen from the air react.

Effect: Contribute to smog, acid rain, and respiratory problems.

4. Sulfur Dioxide (SO₂)

Source: Combustion of sulfur-containing fuels (coal, oil, and diesel).

Effect: Causes acid rain, respiratory irritation, and environmental damage.

5. Particulate Matter (PM₁₀, PM_{2.5})

Source: Incomplete combustion of solid or liquid fuels.

Effect: Penetrates deep into lungs; causes respiratory and cardiovascular diseases.

6. Volatile Organic Compounds (VOCs)

Source: Incomplete combustion of fuels, especially hydrocarbons.

Effect: React with NO_x to form ground-level ozone (a key component of smog).

7. Polycyclic Aromatic Hydrocarbons (PAHs)

Source: Incomplete combustion of organic matter (e.g., wood, coal, diesel).

Effect: Many are carcinogenic and mutagenic.

8. Unburned Hydrocarbons (UHCs)

Source: Incomplete combustion in engines and stoves.

Effect: Contribute to smog and ozone formation.

Chapter III: Carbon monoxide « CO »

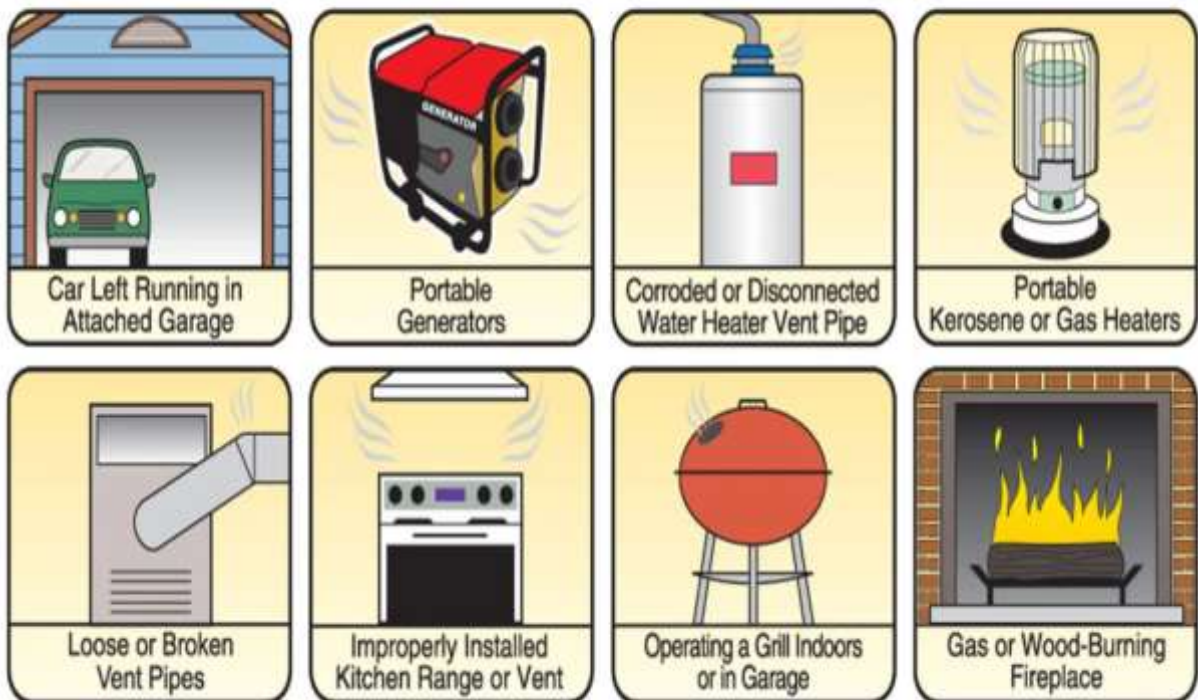
II. 1: Introduction

III. 2: Physical properties of carbon monoxide

III. 3: Effects on living things

III. 4: Main mechanisms of CO formation

SOURCES OF CARBON MONOXIDE IN A HOME



III. 1: Introduction

What is carbon monoxide?

Carbon monoxide (CO) is a colorless, odorless gas. It results from the incomplete combustion of carbon-containing fuels such as natural gas, gasoline, or wood, and is emitted by a wide variety of combustion sources, including motor vehicles, power plants, wildfires, and incinerators. Nationally and, particularly in urban areas, the majority of outdoor CO emissions to ambient air come from mobile sources. Carbon monoxide can also be formed through photochemical reactions in the atmosphere from methane and non-methane hydrocarbons, other volatile organic hydrocarbons in the atmosphere, and organic molecules in surface waters and soils. There are also a number of indoor sources of CO that contribute to total exposure.

Carbon monoxide (CO) intoxication is one of the most common types of poisoning in the modern world and a leading cause of death by poisoning in the United States, including intentional suicides and unintentional exposures from home heating, automobile exhaust, and smoke inhalation. When not fatal, a spectrum of encephalopathy ranges from reversible dysfunction to severe irreversible dementia. Other features may include a parkinsonian syndrome and a delayed neuropsychiatric syndrome. Statistics on acute, nonfatal CO encephalopathy and the delayed CO-induced neuropsychiatric syndrome are imprecise. Sequelae of low-level exposure may be misdiagnosed or overlooked.

CO is a tasteless, odorless, nonirritating but highly toxic gas. Because of these properties and because it often lacks a unique clinical signature, CO is difficult to detect and can mimic other common disorders. Therefore, the true incidence of CO poisoning is unknown and many cases probably go unrecognized. CO has been termed the unnoticed poison of the 21st century. An environmental CO exposure is suggested when more than one person, animals, or both are affected; by a history of fire, presence of fireplace or combustion appliances, or occupation; and by the relation of symptoms to a possible exposure.

CO is a byproduct of the incomplete combustion of hydrocarbons. Common sources include motor vehicle exhaust exposure in a poorly ventilated garage or areas close to garages and combustion appliances (e.g., heating units) in which partial combustion of oils, coal, wood, kerosene, and other fuels generate CO. A common scenario is that of a heating unit used only occasionally and not well maintained. Retrograde flow can occur in residential, occupational, or institutional settings in the presence of pressure problems and chimney or equipment malfunction. CO poisoning with immediate deaths may occur during a building fire or from fuel powered generators and heaters, especially in poorly ventilated spaces. The

Chapter III: Carbon monoxide « CO »

latter causes are often reported during winter storms, hurricanes, earthquakes or other disasters after a power outage has occurred.

The fatal effects of CO exposure are well recorded in past and recent history. For example, the ancient Greeks and Romans used CO to execute criminals. The death of two Byzantine emperors was related to CO produced by the burning of coal in braziers, the usual method of indoor heating then. In World War II, wood used widely as fuel caused many cases of acute or chronic CO poisoning. An article published in 2005 reported the death of one person among nine exposed to CO accidentally because of a faulty apartment house heating unit.

CO was first prepared by the French chemist Joseph- Marie-François de Lassone in 1776. Because it burned with a blue flame, he mistakenly thought it to be hydrogen. In 1880, William Cruikshank identified it as a compound containing carbon and oxygen. In the middle of the 19th century, Claude Bernard recognized that CO causes hypoxia by interaction with hemoglobin (Hb). He poisoned dogs with the gas, noticing the scarlet appearance of their blood. Toward the end of the 19th century, John Scott Haldane demonstrated that a high partial pressure of oxygen can counteract the interaction between Hb and CO despite the high affinity for this interaction.

Endogenous sources of CO include the heme degradation to bile pigments, catalyzed by heme oxygenase. Constitutive and inducible isoforms (heme oxygenase-1, heme oxygenase-2) of the enzyme are known. Endogenously produced CO serves as a signaling molecule involved in multiple cellular functions, such as inflammation, proliferation, and apoptosis. CO, like nitric oxide, is a recently defined gaseous neurotransmitter in the central nervous system (CNS). Endogenous and exogenous sources of CO are contained in **Table.III.1** below.

Chapter III: Carbon monoxide « CO »

Endogenous

Normal heme catabolism by heme oxygenase

Increased heme in hemolytic anemia or sepsis

Exogenous

Incomplete combustion of carbonaceous fossil fuel

Propane-powered vehicles

Gas-powered furnaces, ovens, fireplaces

House fires

Heaters

Automobile exhaust

Boat exhaust

Indoor grills

Camp stoves

Cigarettes smoke

Table.II.1: Sources of carbon monoxide

III.2: Source of carbon monoxide

The most common source of carbon monoxide is the partial combustion of carbon-containing compounds. Numerous environmental and biological sources generate carbon monoxide. In industry, carbon monoxide is important in the production of many compounds, including drugs, fragrances, and fuels. CO may be emitted from tobacco smoke and generated from malfunctioning fuel-burning stoves (wood, kerosene, natural gas, propane) and fuel-burning heating systems (wood, oil, natural gas) and from blocked flues connected to these appliances

III. 3: Physical properties of carbon monoxide

III.3.1: Carbon monoxide structure

Carbon monoxide is a poisonous, flammable gas that is colorless, odorless, tasteless, and slightly less dense than air. Carbon monoxide is the simplest member of the oxocarbon family. It consists of only two atoms, one carbon atom, and another oxygen atom that consists of two bonds. In the structure of carbon monoxide, the carbon atom is connected to an oxygen atom with a triple bond. In reality, a double bond between the two atoms is formed by the mutual sharing of electrons resulting in the two bonds while the third bond is formed when the oxygen atom donates a lone pair of electrons to the carbon for completing its octet and forms a bond. The molecule is asymmetric with a non-zero dipole moment.

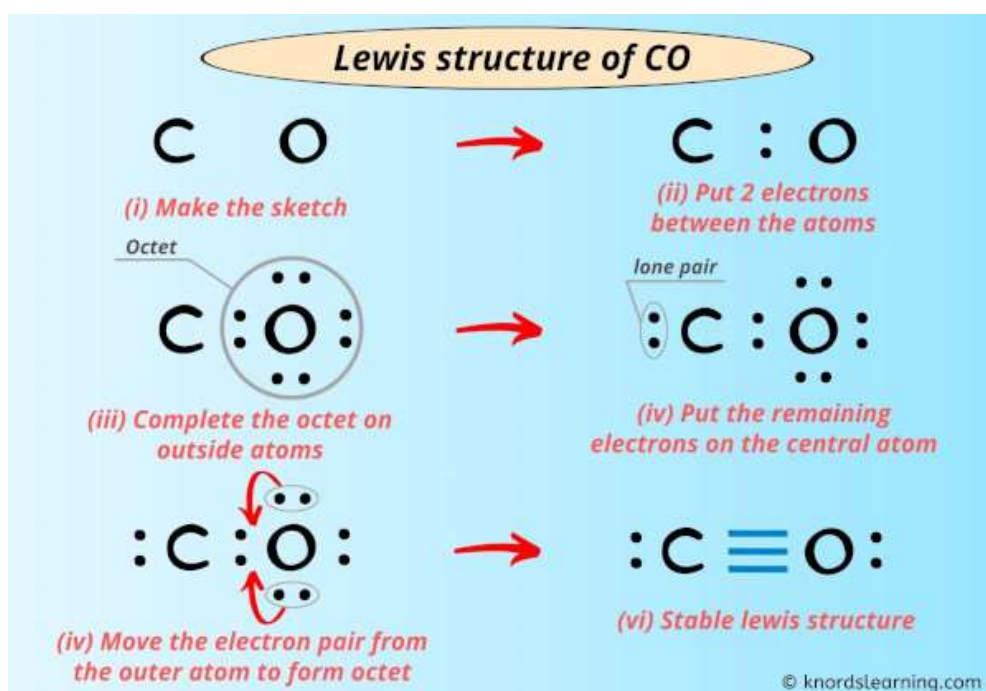


Figure.III.1: Lewis structure of CO

III.3.2: Physical and Chemical properties

Carbon monoxide is a colourless and odourless gas. Carbon monoxide is the simplest oxocarbon and is isoelectronic with other triply bonded diatomic species possessing 10 valence electrons, including the cyanide anion, the nitrosonium cation, boron monofluoride and molecular nitrogen. It has a molar mass of 28.01 g/mol, with a density of 789 kg/m³, which, according to the ideal gas law, makes it slightly less dense than air, whose average molar mass is 28.8.

Chapter III: Carbon monoxide « CO »

The carbon and oxygen are connected by a triple bond that consists of a net two pi bonds and one sigma bond. The bond length between the carbon atom and the oxygen atom is 112.8 pm. This bond length is consistent with a triple bond, as in molecular nitrogen (N₂), which has a similar bond length (109.76 pm) and nearly the same molecular mass. Carbon–oxygen double bonds are significantly longer, 120.8 pm in formaldehyde, for example. The boiling point (82 K) and melting point (68 K) are very similar to those of N₂ (77 K and 63 K, respectively). The bond-dissociation energy of 1072 kJ/mol is stronger than that of N₂ (942 kJ/mol) and represents the strongest chemical bond known.

The ground electronic state of carbon monoxide is a singlet state since there are no unpaired electrons.

Here's a summary of the physical and chemical properties of carbon monoxide (CO):

Physical Properties

- Carbon monoxide is a colorless, odorless gas.
- It is easily ignited.
- The molecular mass of carbon monoxide is 28.010 g/mol with a density of 789 kg/m³.
- It is a colourless and odourless gas.
- The melting and boiling points of carbon monoxide are -205.02 °C (68.13 K) and -191.5 °C (81.6 K), respectively.
- It is just lighter than air and a flame can flash back to the source of leak very easily.
- It is sparingly soluble in water. However, it is more soluble in chloroform, acetic acid, ethyl acetate, ethanol, benzene, etc.

Chemical Properties

- It is a highly poisonous and flammable gas.
- High-temperature reactions between carbon monoxide and water vapour result in the production of carbon dioxide and hydrogen; this method has been used to produce hydrogen that can be combined with nitrogen to create ammonia.
- Carbon monoxide creates alkali formates with caustic alkalies, which can then be changed into either formic acid or alkali oxalates to create oxalic acid.
- Carbon monoxide reacts with some metals to produce carbonyl compounds, many of which are flammable; nickel has been purified via this reaction.

- The production of methanol begins with carbon monoxide and hydrogen, which are also used to create olefin-derived aldehydes and alcohols as well as mixtures of liquid hydrocarbons appropriate for use as fuels.

III. 3: Effects on living things

What kinds of harmful effects can carbon monoxide cause?

Carbon monoxide is harmful because it binds to hemoglobin in the blood, reducing the ability of blood to carry oxygen. This interferes with oxygen delivery to the body's organs. The most common effects of CO exposure are fatigue, headaches, confusion, and dizziness due to inadequate oxygen delivery to the brain. For people with cardiovascular disease, short-term CO exposure can further reduce their body's already compromised ability to respond to the increased oxygen demands of exercise, exertion, or stress. Inadequate oxygen delivery to the heart muscle leads to chest pain and decreased exercise tolerance. Unborn babies whose mothers experience high levels of CO exposure during pregnancy are at risk of adverse developmental effects. The greatest risk from exposure to carbon monoxide are unborn babies, infants, elderly people, and people with anemia or with a history of heart or respiratory disease are most likely to experience health effects with exposure to elevated levels of CO.

How does carbon monoxide affect the environment?

U.S. EPA conducted an extensive literature search as part of the review of the National Ambient Air Quality Standard for Carbon Monoxide that was completed in 2011, and did not identify any evidence for ecological effects of CO at levels at or near ambient. Consequently, there is no secondary (welfare) standard for CO.

CO contributes indirectly to climate change because it participates in chemical reactions in the atmosphere that produce ozone, which is a climate change gas. CO also has a weak direct effect on climate. For these reasons, CO is classified as a short-lived climate forcing agent, prompting CO emission reductions to be considered as a possible strategy to mitigate effects of global warming.

Is carbon monoxide a problem indoors?

Indoor CO levels can be considerably higher than outdoors. There are a number of potential sources of CO indoors, including gas stoves, malfunctioning or improperly vented gas appliances (i.e., water heaters, furnaces, clothes dryers), space heaters, fireplaces, tobacco smoke, and car or truck exhaust that enters from attached garages.

During the cold season CO poisoning cases tend to increase. These are most often related to elevate indoor CO levels resulting from use of improperly vented space heaters and use of gas ranges to heat the house. Over 400 people die each year in the U.S., due to CO poisoning. Of these, 13 to 36 individuals have died each year since 2000 from non-fire-related CO poisoning in California. Because of the health risk of CO poisoning, California has mandated installation of CO detectors in all housing units in the state.

How does carbon monoxide affect the environment?

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How to protect yourself and measure carbon monoxide (CO)?

Regarding indoor exposure to carbon monoxide (CO) here are some preventive measures you can take to protect yourself from carbon monoxide poisoning:

Before the winter period

Check the heating system (boiler, stove, etc.), the hot water production system, but also have your chimney swept by a qualified professional.

Taking action and protecting yourself from carbon monoxide (CO)

- Air each room in the home for at least 10 minutes every day and never block air inlets and outlets.
- Install an air quality sensor (equipped with a carbon monoxide detector) to monitor carbon monoxide.
- Do not cook indoors with outdoor appliances (braziers, barbecues...) and do not heat a room with them.

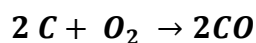
- Never run space heaters continuously: they are designed for brief and intermittent use only.

III. 4: Main mechanisms of CO formation

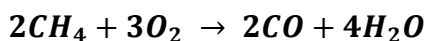
Understanding the main mechanisms of carbon monoxide (CO) formation is important in chemistry, combustion science, and environmental studies. Carbon monoxide is formed mainly during the incomplete combustion or partial oxidation of carbon-containing materials. This happens when there isn't enough oxygen (O₂) to completely convert carbon (C) into carbon dioxide (CO₂).

- 1- ***Incomplete combustion of carbon or hydrocarbons:*** This is the most common mechanism of CO formation.

Reaction pathway:



Or for the *hydrocarbons* (e.g: methane):



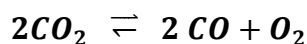
Occurs when oxygen supply is limited (poor ventilation, faulty engines, inefficient burners, etc.). Seen in automobile exhausts, stoves, heaters, furnaces, and fires

Example:

A car engine that doesn't burn fuel completely emits CO along with CO₂ and hydrocarbons.

- 2- ***Thermal Decomposition of Carbon Dioxide (CO₂):*** At very high temperatures (above 1000 °C), CO₂ can partially decompose to CO and O₂

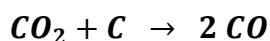
Reaction:



Occurs in high-temperature zones of flames, furnaces, or combustion chambers

- 3- ***Reduction of Carbon Dioxide by Carbon (Boudouard Reaction):*** Solid carbon (e.g., coke or charcoal) reduces CO₂ to CO at high temperatures.

Reaction:

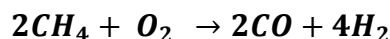


Chapter III: Carbon monoxide « CO »

Occurs in blast furnaces, coal gasification, and industrial processes where carbon and CO₂ coexist at high heat (700–1000 °C).

- 4- **Partial Oxidation of Hydrocarbons:** When hydrocarbons (fuels) react with less than the stoichiometric amount of oxygen, partial oxidation occurs, forming CO instead of CO₂.

Example (methane):



Used deliberately in syngas production (for fuels and methanol synthesis).

- 5- **Biomass and Organic Matter Combustion:** When wood, biomass, or organic waste burns in oxygen-deficient environments (e.g., campfires, indoor burning), incomplete combustion yields CO.

Simplified Reaction:

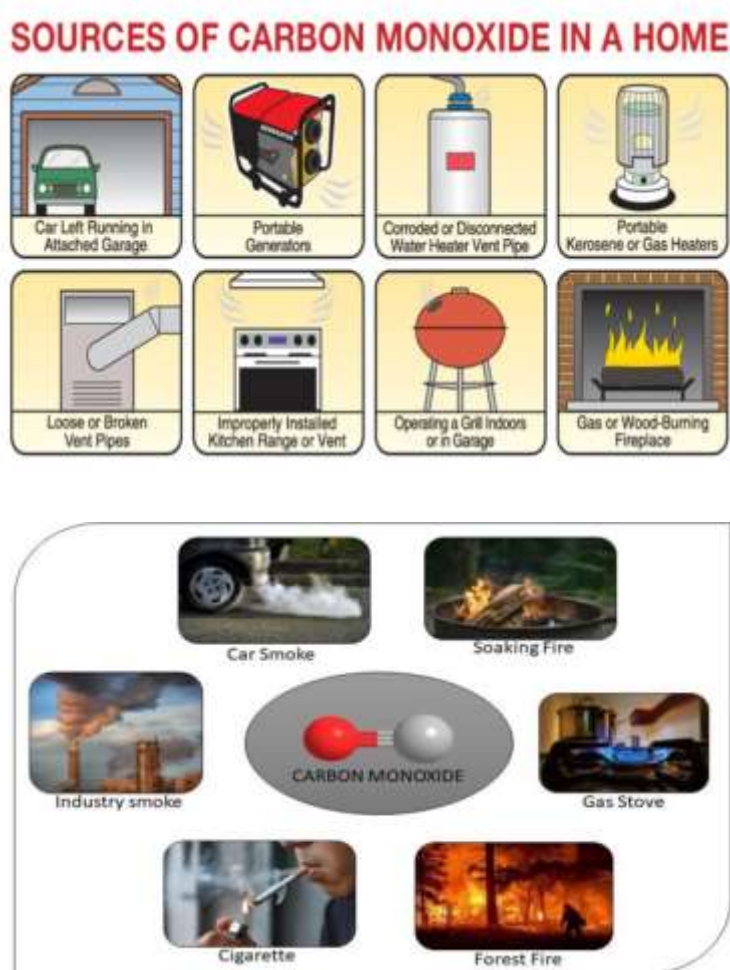
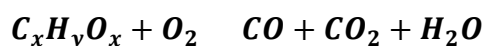


Figure.III.2: Sources of carbon monoxide

Frequently Asked Questions – FAQs

Q1: What is carbon monoxide poisoning?

When high concentrations of carbon monoxide are inhaled by humans from the atmosphere, CO starts binding with the haemoglobin 200 times greater than the oxygen which causes CO build-up in the bloodstream. As a result, the ability of blood to carry oxygen is hampered which leads to lethargy, headaches, disorientation, and dizziness. The condition is called carbon monoxide poisoning.

Q2: How is carbon monoxide produced?

There are several methods to produce carbon monoxide but it is mainly produced when there is not enough oxygen or heat to make carbon dioxide during the partial combustion of carbon-containing substances or incomplete combustion of natural gases like gasoline.

Q3: Why carbon monoxide is dangerous?

CO is very toxic as it can form complex with haemoglobin in the red blood cells. Haemoglobin combines with oxygen to form oxyhaemoglobin. Oxyhaemoglobin (formed in lungs) is carried to different cells where it gives its oxygen. CO has stronger affinity for haemoglobin than oxygen. Due to this, the oxygen carrying capacity of blood is destroyed; this results in suffocation and finally death.

Q4: What appliances can cause carbon monoxide?

Carbon monoxide is a combustion by-product. Popular home appliances, such as gas or oil furnaces, gas refrigerators, gas clothing dryers, gas ranges, gas water heaters or space heaters, fireplaces, charcoal grills, and wood burning stoves are made.

Q5: How does carbon monoxide affect the human body?

Carbon monoxide has positive and adverse effects on humans. Increased levels of carbon monoxide in red blood cells decrease the amount of oxygen haemoglobin carries throughout the body. The effect is that vital organs like the brain, nervous tissues, and the heart don't get enough oxygen to function properly.

Q6: How do you get rid of carbon monoxide?

Breathing in pure oxygen is the only way to treat the CO poisoning. The procedure raises blood oxygen levels and helps keep CO out of the body. The doctor will put an oxygen mask over the mouth and nose and ask you to inhale it.

Q7: Can you recover from carbon monoxide poisoning?

The majority of people who experience moderate carbon monoxide poisoning rapidly recover when they step into fresh air. Moderate or extreme contact of carbon monoxide induces impaired vision, confusion, unconsciousness, hallucinations, chest pain, and shortness of breath, low blood pressure, and coma.

Chapter IV: Nitrogen Oxides « NO »

Chapter IV: Nitrogen Oxides « NO »

IV. 1: Introduction

IV.2: Nitrogen origin

IV.3: Properties of Nitrogen

IV. 4: NO and N₂O formation reactions

IV. 5: Commercial production and uses

IV. 6: Influence of pressure on NO emissions



Nitrogen

Element Symbol: N
Atomic Number: 7
Atomic Weight: 14.007
Discovery: Daniel Rutherford (1772)
Electrons: [He] 2s² 2p³
Group: Group 15 (pnictogen)
Period: Period 2
Appearance: Colorless gas, liquid, and solid
Uses: Fertilizers, cryogenics, propellants, food preservation, inert atmospheres



food preservation



cryogenics



sciencenotes.org

IV. 1: Introduction

Nitrogen is one of the most common non-hydrocarbons in natural gas, whose physical properties are much like hydrocarbons rather than other non-hydrocarbons. The major source of nitrogen is the atmosphere. It exists as a colorless, odorless, nontoxic gas and makes up about 78 percent of the atmosphere. Nitrogen is also found in the Earth's crust as part of organic matter and humus.

History, from the Latin word *nitrum*, Greek *Nitron*, native soda; and *genes*, forming. Nitrogen was discovered by chemist and physician Daniel Rutherford in 1772. He removed oxygen and carbon dioxide from air and showed that the residual gas would not support combustion or living organisms.

The word "nitrogen" comes from the French word "*nitrogène*," which was coined in 1790 by Jean-Antoine-Claude Chaptal. Chaptal derived the word from the Greek words "*nitron*" (nitre) and "*genēs*" (forming). The word "nitrogen" was first used in English in 1794.

Fritz Haber found a way of making nitrogen compounds from the air. They have two main uses: fertilizers and explosives. His process enabled Germany to produce vast quantities of armaments.

Elemental nitrogen is usually produced from air by pressure swing adsorption technology. About 2/3 of commercially produced elemental nitrogen is used as an inert (oxygen-free) gas for commercial uses such as food packaging, and much of the rest is used as liquid nitrogen in cryogenic applications. Many industrially important compounds, such as ammonia, nitric acid, organic nitrates (propellants and explosives), and cyanides, contain nitrogen.

Nitrogen occurs in all organisms, primarily in amino acids (and thus proteins), in the nucleic acids (DNA and RNA) and in the energy transfer molecule adenosine triphosphate. The human body contains about 3% nitrogen by mass, the fourth most abundant element in the body after oxygen, carbon, and hydrogen. The nitrogen cycle describes the movement of the element from the air, into the biosphere and organic compounds, then back into the atmosphere. Nitrogen is a constituent of every major pharmacological drug class, including antibiotics. Many drugs are mimics or prodrugs of natural nitrogen-containing signal molecules: for example, the organic nitrates nitroglycerin and nitroprusside control blood pressure by metabolizing into nitric oxide. Many notable nitrogen-containing drugs, such as the natural caffeine and morphine or the synthetic amphetamines, act on receptors of animal neurotransmitters.

IV.2: Nitrogen origin

Nitrogen originates from stars through nucleosynthesis, where helium fuses into heavier elements. On Earth, atmospheric nitrogen likely arrived via comets or meteorites containing primordial ammonia that was processed during the solar system's formation. Today, the majority of Earth's atmospheric nitrogen is a result of this initial delivery and ongoing geological processes.

IV.2.1: Cosmic origin

- Nitrogen was created in stars through the process of nucleosynthesis.
- During a star's life, helium atoms fuse to form heavier elements, including nitrogen.

IV.2.2: Earth's acquisition

When Earth formed 4.5 billion years ago, it collected nitrogen from:

- Nitrogen was likely delivered to early Earth through impacts from comets and meteorites.
- Minerals found in meteorites show a similar isotopic signature to Earth's atmospheric nitrogen, suggesting a shared origin in the primordial solar system.
- Scientists believe that ammonia ice in the early solar system was heated by shock waves, releasing nitrogen to react with metals and eventually becoming part of planets like Earth.

Over time, nitrogen accumulated in the atmosphere because:

- It's chemically stable (N_2 is very inert).
- It wasn't easily lost to space.
- It wasn't heavily consumed by early chemical reactions.
- Nitrogen on Earth came from volcanic gases, planetary formation materials, and space impacts.

This led to our modern atmosphere being 78% nitrogen.

Commercial nitrogen (the nitrogen sold in tanks or used in industry) is produced mainly by separating nitrogen from air.

IV. 3: Properties of Nitrogen

Nitrogen is a common normally colorless, odorless gas at room temperature that is relatively inert due to the triple bond in its N_2 molecule. It has five electrons in its outer shell, so it is trivalent in most compounds. Key properties include an atomic number of 7, an atomic mass of approximately 14.007 g/mole, and an electron configuration of $[He] 2s^2 2p^3$. Its melting point is approximately $-210^\circ C$ and its boiling point is approximately $-195.8^\circ C$.

IV. 3.1: Physical properties

- Appearance: Colorless, odorless gas
- Melting Point: $-210^\circ C$
- Boiling Point: $-195.8^\circ C$
- Density (at $0^\circ C$, 1 atm): 1.2506g/l
- State at $20^\circ C$: Gas

IV. 3.2: Atomic and electronic properties

- Atomic Number: 7
- Mass: 14.007g/mole
- Electron Configuration: $[He] 2s^2 2p^3$
- Electronegativity: 3.04 on the Pauling scale
- Group: 15
- Period: 2
- Key Isotope: ^{14}N
- Isotopes: 4
- Vanderwaals radius : 0.092 nm

IV. 3.2: Chemical properties

- Reactivity: Relatively inert under standard conditions due to a strong triple bond in the N_2 molecule.
- Bonding: Forms a triple covalent bond in its diatomic molecule $N \equiv N$.
- Oxoacids: Forms several oxoacids, including nitrous acid HNO_2 and nitric acid HNO_3 .
- Reactions: Reacts with some reactive metals at high temperatures to form nitrides (e.g., magnesium nitride, Mg_3N_2).

Chapter IV: Nitrogen Oxides « NO »

IV. 3.3: Anomalous Properties of Nitrogen

The following unique properties distinguish nitrogen from other elements in its group, affecting its chemical behavior and bonding.

- **Small Size and High Electronegativity:** Nitrogen is smaller and has a higher electronegativity than other group members.
- **High Ionisation Enthalpy:** Nitrogen has a higher ionisation enthalpy.
- **Lack of d Orbitals:** Unlike heavier group members, Nitrogen does not have available d orbitals.
- **Multiple Bonds:** Nitrogen can form multiple bonds with itself and other small, highly electronegative elements (e.g., C, O).
- **Diatomic Molecule:** Exists as a diatomic molecule (N_2) with a triple bond, leading to a high bond enthalpy ($941.4 \text{ kJ mol}^{-1}$).
- **Single Bond Weakness:** The single N–N bond is weaker than the single P–P bond due to the high interelectronic repulsion caused by the small bond length, which results in a weaker catenation tendency.
- **Covalency Limitation:** The absence of d orbitals limits nitrogen's covalency to four.

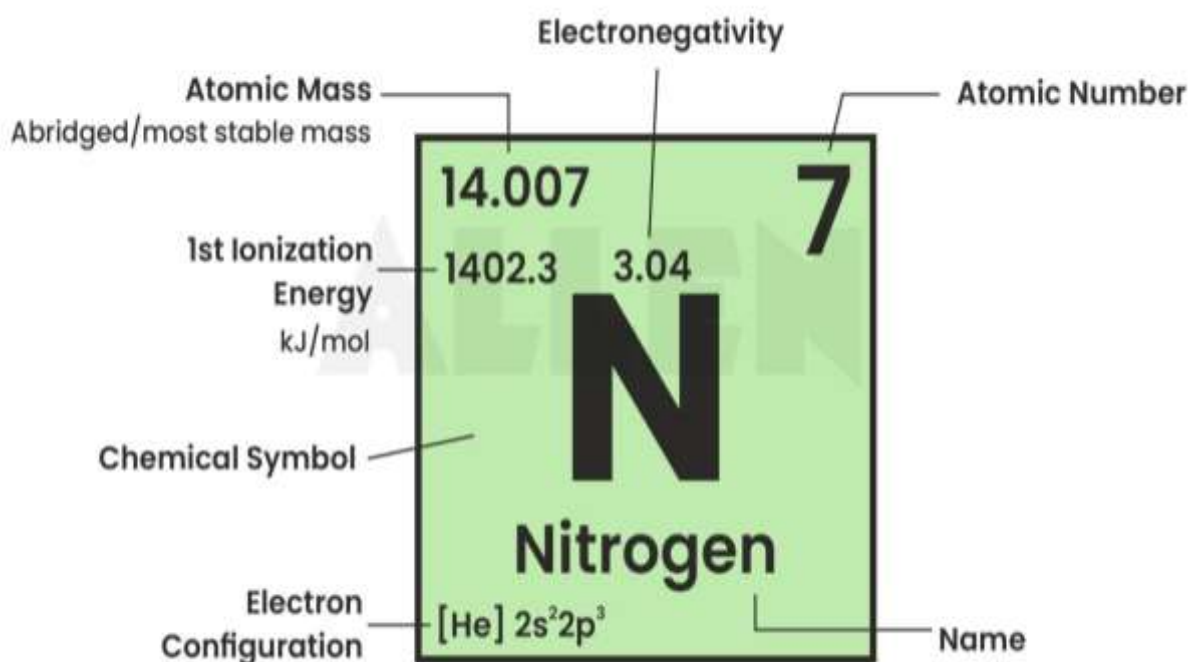


Figure.IV.1: the Square of an element from the periodic table of chemical elements

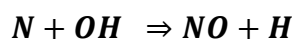
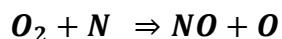
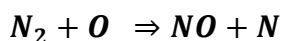
IV. 4: NO and N₂O formation reactions

According to scientific publication reported by Franz Winter et al., in October 1999. Entitled: NO and N₂O Formation during the Combustion of Wood, Straw, Malt Waste and Peat. The NO and N₂O formation behavior of six biofuels (spruce wood, beech wood, alder wood, straw, malt waste, peat) was studied in a formation-rate unit under conditions relevant to a fluidized-bed combustor and a grate-furnace. The concentrations of CO₂, CO, CH₄, other hydrocarbons, NO, N₂O, HCN, and NH₃ were measured in the flue gas, shortly after the burning fuel particles. Most of the fuel nitrogen was released during devolatilization (66–75%). Relatively high conversions to NO were found. N₂O was formed but also rapidly destroyed by the reaction: $N_2O + H \rightarrow N_2 + OH$. HCN was also formed in quantities similar to NH₃ even during wood combustion. The HCN/NH₃ ratios seemed to depend on the fuel H/N ratios. The experimental results supported the hypothesis that the nitrogen of wood and other biofuels also exists in heterocyclic structures. With the proposed NO and N₂O formation mechanism the effects of fuel nitrogen content, temperature and oxygen partial pressure can be explained.

Nitric oxide (NO) is formed primarily by the high-temperature reaction of nitrogen (N₂) with oxygen (O₂) during combustion $N_2 + O_2 \Rightarrow 2NO$ and from the oxidation of nitrogenous compounds in fuels. Nitrous oxide (N₂O) is formed through a separate pathway, with common reactions including the direct reaction of nitrogen with oxygen $2N_2 + O_2 \Rightarrow 2N_2O$ or the reaction between ammonia NH₃ and nitric oxide (NO).

IV. 4.1: NO formation: NO is mainly produced at high temperatures, where atmospheric nitrogen (N₂) and oxygen (O₂) react.

- **Thermal NO_x:** High temperatures in combustion (>1300⁰C) cause atmospheric nitrogen (N₂) to break apart and react with oxygen (O₂).

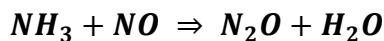


- **Fuel NO_x:** Occurs when nitrogen bound in the fuel (like in oil combustion) reacts with oxygen during combustion.
- **From other nitrogenous compounds:** During devolatilization, nitrogen in fuel can be released as volatile species like HCN, which then gets oxidized to form NO.

Chapter IV: Nitrogen Oxides « NO »

IV. 4.2: N₂O reactions: N₂O (laughing gas) forms at lower temperatures and oxygen-limited conditions, often during combustion, soil processes, or industrial reactions.

- **Selective Catalytic Reduction (SCR):** In the presence of a catalyst, ammonia (NH₃) and nitric oxide (NO) react to form (N₂O).



- **Biological processes:** In the nitrogen cycle, (N₂O) is a byproduct of nitrification (oxidation of ammonia) and denitrification (reduction of nitrate) by bacteria and other microorganisms.
 - Nitrification: $NH_2OH \Rightarrow N_2O$
 - Denitrification: Nitric oxide (NO) and (N₂O) are formed as intermediates during the reduction of nitrate.
- **Combustion intermediates:** In some combustion conditions, species like isocyanates (from fuel devolatilization) react with NO or O₂ to form (N₂O).

According to scientific publication reported by Julia M. Otte et al, in July 2019. Entitled: N₂O formation by nitrite-induced (chemo) denitrification in coastal marine sediment. Processes forming N₂O include: (1) nitrification (oxidation of ammonia to nitrate), (2) denitrification (reduction of nitrate to NO, N₂O or N₂)⁸ by fungi, archaea, and bacteria, (3) dissimilatory nitrate reduction to ammonium (DNRA), (4) nitrifier-denitrification (ammonia oxidation to nitrite followed by the reduction of nitrite to nitric oxide) and (5) nitrite-induced (chemo)denitrification, e.g. by ferrous iron (Fe(II)). Nitrous oxide is also produced by anaerobic methane-oxidizing bacteria, ammonia-oxidizing archaea, and anammox bacteria.

IV. 5: Commercial production and uses

Commercial production of nitrogen is largely by fractional distillation of liquefied air. The boiling temperature of nitrogen is $-195.8\text{ }^{\circ}\text{C}$ ($-320.4\text{ }^{\circ}\text{F}$), about $13\text{ }^{\circ}\text{C}$ ($-23\text{ }^{\circ}\text{F}$) below that of oxygen, which is therefore left behind. Nitrogen can also be produced on a large scale by burning carbon or hydrocarbons in air and separating the resulting carbon dioxide and water from the residual nitrogen. On a small scale, pure nitrogen is made by heating barium azide, $\text{Ba}(\text{N}_3)_2$. Various laboratory reactions that yield nitrogen include heating ammonium nitrite (NH_4NO_2) solutions, oxidation of ammonia by bromine water, and oxidation of ammonia by hot cupric oxide.

Nitrogen has diverse applications, including agricultural fertilizers, food and beverage preservation, electronics manufacturing, and cryogenics. It is also used in the oil and gas industry, pharmaceutical production, fire suppression systems, and various manufacturing processes like steelmaking and welding.

IV. 5.1: Agriculture and Food

- **Fertilizers:** Used in the production of fertilizers for crop growth and as a component of pesticides.
- **Food preservation:** The food and beverage industry uses nitrogen to create a modified atmosphere for packaging, which displaces oxygen and extends shelf life for products like meat, coffee, and bread.

IV. 5.2: Manufacturing and Industrial

- **Electronics:** Used in the semiconductor industry to create an inert atmosphere, preventing unwanted chemical reactions during production.
- **Chemical industry:** A key component in creating ammonia, which is then used to produce nitric acid, nylon, dyes, and explosives.
- **Metalworking:** Employed in welding, steelmaking, and to prevent oxidation in processes like casting and heat treatment.
- **Oil and gas:** Used to displace oxygen in fuel tanks, for enhanced oil recovery, and in pressure testing.
- **Tire inflation:** The tires of some vehicles, particularly aircraft, are inflated with nitrogen for more stable pressure.

Chapter IV: Nitrogen Oxides « NO »

IV. 5.3: Other Applications

- **Cryogenics:** Liquid nitrogen is used as a cryogenic coolant for a wide range of applications, from flash-freezing food to medical procedures.
- **Pharmaceuticals:** Used to blanket chemical reactions, protect sensitive ingredients, and provide a safe, inert environment for drug production.
- **Fire suppression:** Inert gas systems use nitrogen to displace oxygen in a fire-prone area, which suffocates the fire without damaging equipment.
- **Laboratories and analytical chemistry:** Used for purging, sample preparation, and in chromatography to reduce the volume of liquid samples.



Figure. IV.2: Some uses of nitrogen

IV. 6: Influence of pressure on NO emissions

NO_x is contained in coal combustion gas. It is a pollutant and a cause of acid rain. During the past 20-30 years, NO_x from coal burning in the atmospheric pressure has been widely investigated in efforts to develop the technology to control these emissions. The rate of combustion was found to increase with pressure in the chemical-reaction control regime, but is less affected by pressure in the pore diffusion influence and is invariant with pressure in gas-film diffusion control regimes.

The effect of pressure on NO_x emission, as well as on N₂O emission, was studied experimentally. It was found that with increasing pressure, NO_x emission decreased extremely, when char combustion rate was controlled by reactant gas diffusion into the char particle at high temperatures. NO_x reduction with carbon in char particles decreased the emission of NO_x from char. Pressure increased the diffusion time of NO_x in char, and consequently increased the reduction of NO_x. Increasing the temperature increased NO_x emission from char combustion, but the effect of increased temperature was weak when pressure was high. Other factors influencing NO_x reduction, such as char reactivity, temperature, and particle size, can have co-effects on NO_x emissions in char pressurized combustion. It was also observed that no N₂O was formed in considerable in the char particle.

1. According to the literature:

- Richard et al, first studied N_xO_y emission from pressurized char combustion. They reported that NO, N₂O, and the total N_xO_y decreased with pressure, whereas NO₂ increased slightly with pressure. No explanation for this was provided in detail.
- Croiset studied NO and N₂O emissions during char pressurized combustion and reported that NO and N₂O were reduced with increasing pressure.
- Jensen et al reported NO_x reduction in coal and char pressurized combustion in real boiler.

2. According to previous study reporter by Shiying Lin et al in 2002

The effect of pressure on NO_x emission during char particle combustion was examined in chemical-reaction control and diffusion control regimes. A fixed bed was used for batch testing under 0.1-1.6 MPa. It was found that with increasing pressure, NO_x emission decreased extremely, when char combustion rate was controlled by reactant gas diffusion into the char particle at high temperature. The extent to which NO_x was reduced in char particles strongly influenced the NO_x emission from char pressurized combustion. Pressure increased residence time for diffusion of NO_x throughout the char particle and consequently further increased the reduction of NO_x in the char particle. Both pressure and temperature strongly influenced the conversion of fuel-N in char to NO_x. When pressure was raised from 0.1 to 1.1

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MPa, the conversion of fuel-N to NO_x fell from 0.18 to 0.06 at 973 K, and from 0.68 to 0.13 at 1173 K. NO_x emissions were lower when large char particles were combusted than when small ones were combusted. It was also observed that practically no N₂O was formed in to any extent in the char particle.

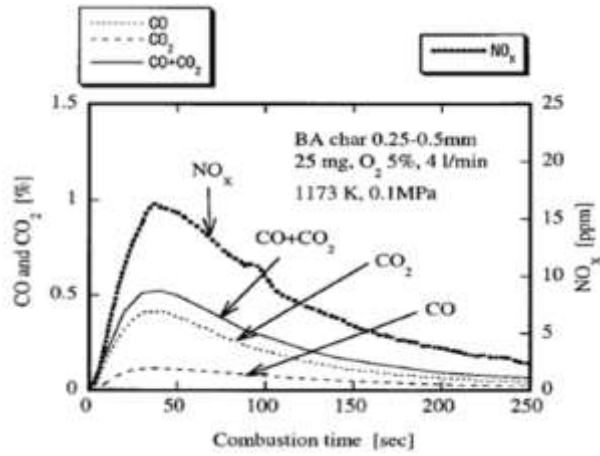


Figure. IV. 3. NO_x, CO, and CO₂ emission during pressurized char combustion (0.1 MPa).

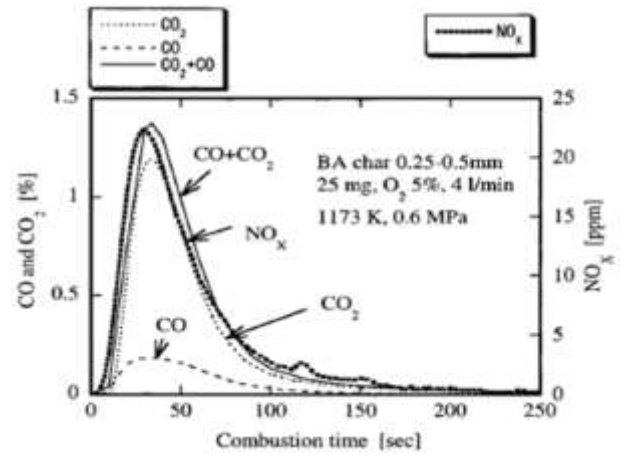


Figure. IV .4. NO_x, CO, and CO₂ emission during pressurized char combustion (0.6 MPa).

Figures IV.3, 4, and 5 show the emission results of each of the gases during char combustion at pressures of 0.1, 0.6, and 1.1 MPa, respectively. O₂ in supply gas was 5%, and the O₂ partial pressures were 0.05, 0.3, and 0.55 MPa, corresponding to the pressure of 0.1, 0.6, and 1.1 MPa, respectively. During char combustion, CO and CO₂ emissions increased with time, peaked at 40, 30, and 28 s for 0.1, 0.6, and 1.1 MPa, and then decreased with time. The peak heights of CO and CO₂ emissions increased with pressure between 0.1 and 0.6 MPa (**Figures IV .5 and 6**), but did not significantly change with pressure between 0.6 and 1.1 MPa (**Figures IV. 4 and 5**).

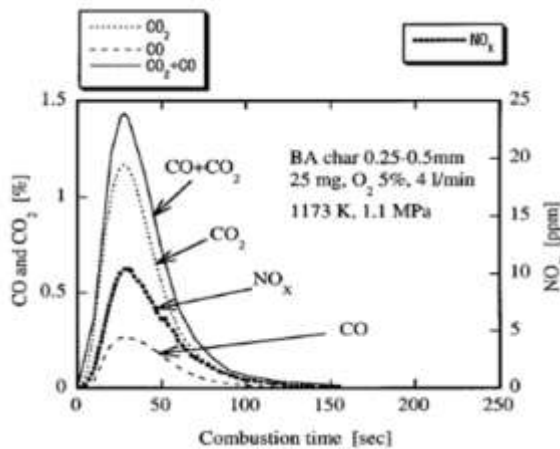


Figure IV.5. NO_x, CO, and CO₂ emission during pressurized char combustion (1.1 MPa).

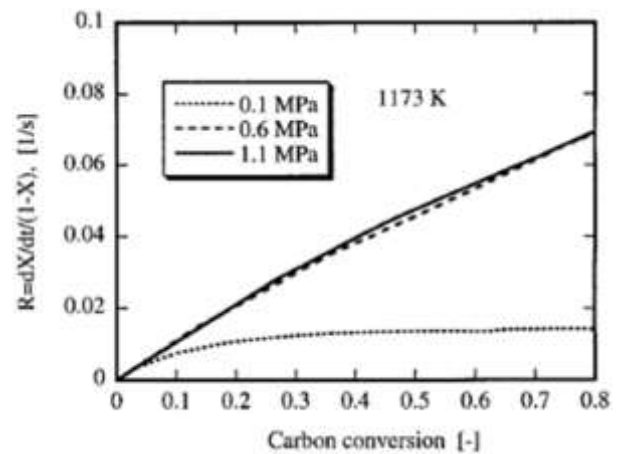


Figure IV.6. Rates of char combustion under various pressures.

Chapter IV: Nitrogen Oxides « NO »

The char combustion rates were calculated from CO and CO₂ emissions as shown in **Figure IV.6**. The rate at 0.1 MPa was a volumetric rate, which was roughly constant during the char combustion, and the rates at 0.6 and 1.1 MPa were surface rates, which increased during char combustion. The results also showed that combustion rate tended to increase with pressure between 0.1 and 0.6 MPa but did not change between 0.6 and 1.1 MPa.

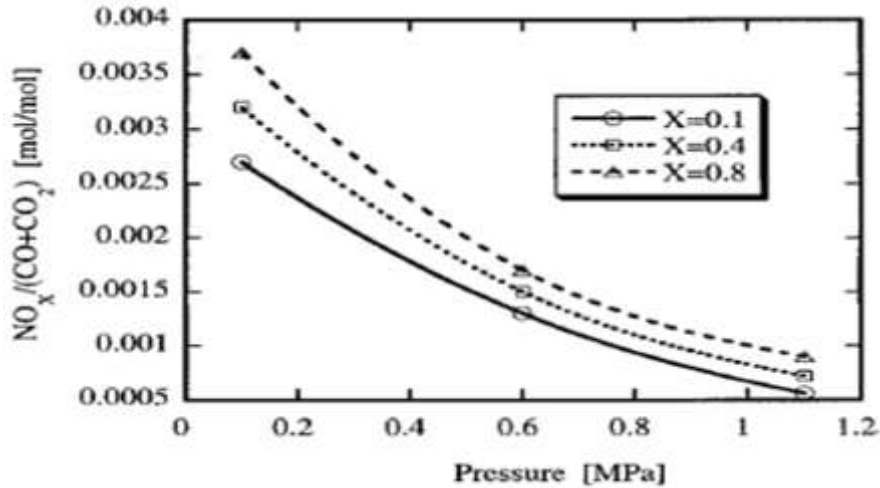


Figure IV.7. Variation of NO_x / (CO + CO₂) ratio with pressure

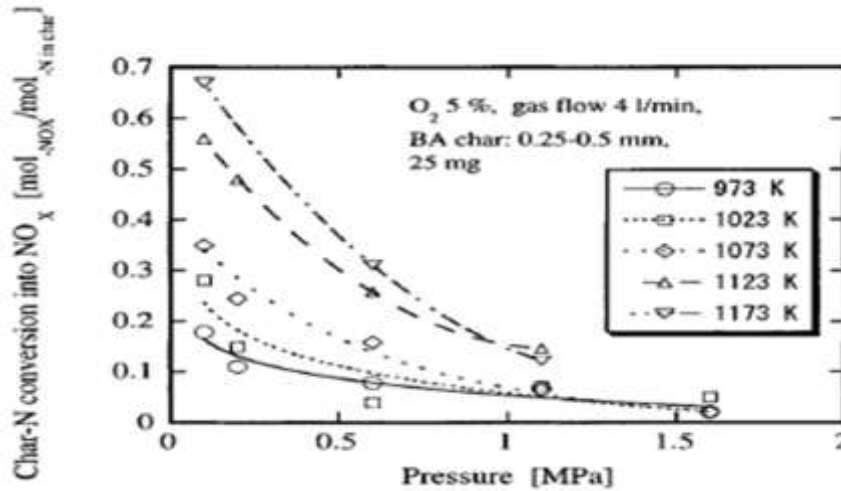


Figure IV. 8. Effects of temperature and pressure on NO_x conversion during char combustion.

By plotting the NO_x / (CO + CO₂) ratio vs pressure as shown in **Figure IV. 7**, it can be seen that the NO_x / (CO + CO₂) ratio was approximately proportional with pressure $P^{-0.61}$ - $P^{-0.64}$. However, with carbon conversion, especially at high carbon conversion, the NO_x / (CO + CO₂) ratio increased in each pressure condition. **Figure IV. 8** show the tendency of fuel-N in char to convert to NO_x under various temperatures and pressures. It can be seen that this tendency is strongly influenced by both temperature and pressure. Under atmospheric

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conditions, with temperature increasing, conversion of fuel-N to NO_x increased. Under elevated pressure, conversion to NO_x increased with temperature but less than it did under atmospheric conditions. Pressure strongly influenced the conversion of fuel-N to NO_x. When pressure increased from 0.1 to 1.1 MPa, the conversion of fuel-N to NO_x was reduced from 0.18 to 0.06 for 973 K, and from 0.68 to 0.13 for 1173 K.

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 1: Introduction

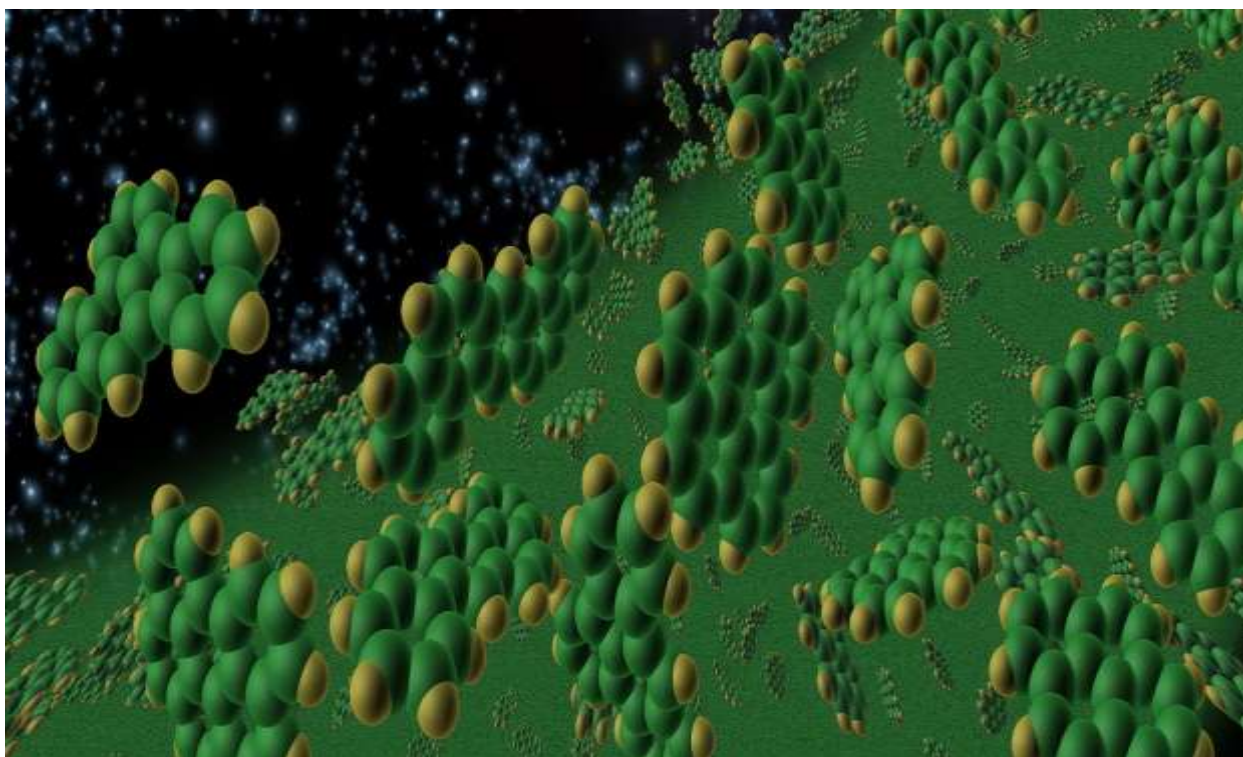
V. 2: Physical properties of PAHs

V. 3: Sources of PAHs

V. 4: Mechanisms of PAHs formation

V. 5: Effects of PAHs on living beings

V.6: Precautions



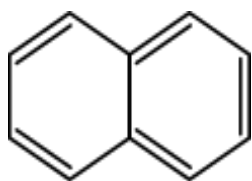
Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 1: Introduction

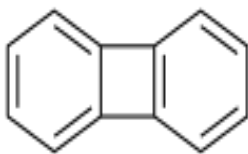
Polycyclic aromatic hydrocarbons (PAHs) are a class of chemicals that occur naturally in coal, crude oil, and gasoline. They also are produced when coal, oil, gas, wood, garbage, and tobacco are burned. PAHs generated from these sources can bind to or form small particles in the air. High-temperature cooking will form PAHs in meat and in other foods. Naphthalene is a PAH that is produced commercially in the United States to make other chemicals and mothballs. Cigarette smoke contains many PAHs.

Polycyclic aromatic hydrocarbons have two or more single or fused aromatic rings with a pair of carbon atoms shared between rings in their molecules. The term "PAH" refers to compounds consisting of only carbon and hydrogen atoms. PAHs containing up to six fused aromatic rings are often known as "small" PAHs, and those containing more than six aromatic rings are called "large" PAHs. The majority of research on PAHs has been conducted on small PAHs due to the availability of samples of various small PAHs.

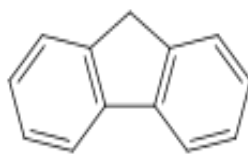
A polycyclic aromatic hydrocarbon (PAH) is any member of a class of organic compounds that is composed of multiple fused aromatic rings. Most are produced by the incomplete combustion of organic matter by engine exhaust fumes, tobacco, incinerators, in roasted meats and cereals, or when biomass burns at lower temperatures as in forest fires. The simplest representative is naphthalene, having two aromatic rings, and the three-ring compounds anthracene and phenanthrene. PAHs are uncharged, non-polar and planar. Many are colorless. Many of them are also found in fossil fuel deposits such as coal and in petroleum. Exposure to PAHs can lead to different types of cancer, to fetal development complications, and to cardiovascular issues. Polycyclic aromatic hydrocarbons are discussed as possible starting materials for abiotic syntheses of materials required by the earliest forms of life. The following of PAHs that vary in the number and arrangement of their rings:



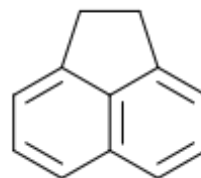
Naphthalene



Biphenylene

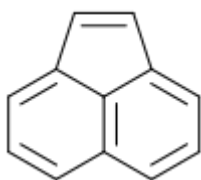


Fluorene

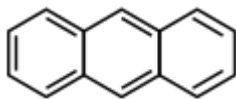


Acenaphthene

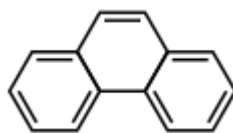
Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)



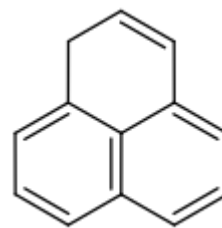
Acenaphthylene



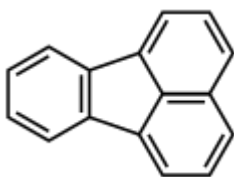
Anthracene



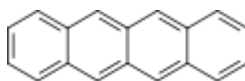
Phenanthrene



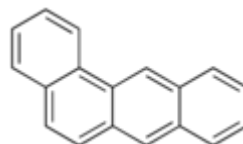
Phenalene



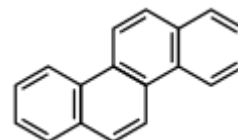
Fluoranthene



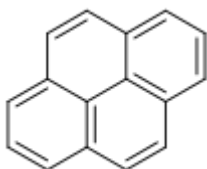
Tetracene



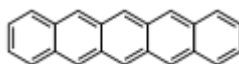
Benz - anthracene



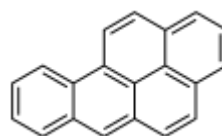
Chrysene



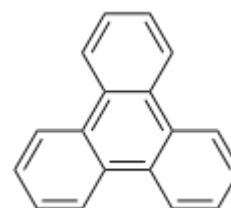
Pyrene



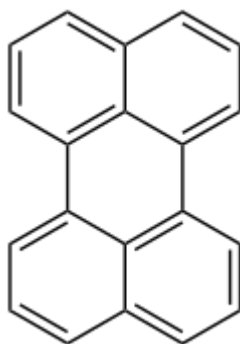
Pentacene



Benzo - pyrene



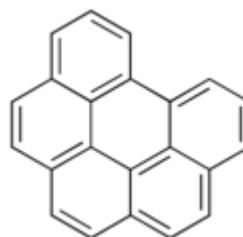
Triphenylene



Perylene



Corannulene



Benzo - perylene



Coronene

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)



Ovalene



Hexabenzocoronene



Hexa-cata-
hexabenzocoronene



Circumcoronene

Most PAHs, like naphthalene, anthracene, and coronene, are planar. This geometry is a consequence of the fact that the σ -bonds that result from the merger of sp^2 hybrid orbitals of adjacent carbons lie on the same plane as the carbon atom. Those compounds are achiral, since the plane of the molecule is a symmetry plane.

In rare cases, PAHs are not planar. In some cases, the non-planarity may be forced by the topology of the molecule and the stiffness (in length and angle) of the carbon-carbon bonds. For example, unlike coronene, corannulene adopts a bowl shape in order to reduce the bond stress. The two possible configurations, concave and convex, are separated by a relatively low energy barrier (about 11 kcal/mole).

In theory, there are 51 structural isomers of coronene that have six fused benzene rings in a cyclic sequence, with two edge carbons shared between successive rings. All of them must be non-planar and have considerable higher bonding energy (computed to be at least 130 kcal/mole) than coronene; as of 2002, none of them had been synthesized.

PAHs enter the environment through various routes and are usually found as a mixture containing two or more of these compounds, e.g. soot. However, some PAHs are manufactured and these pure PAHs usually exist as colorless, white, or pale yellow solids.

How are people exposed to PAHs?

PAHs are commonly found in the environment. However, the main way people are exposed to PAHs is from smoking, motor vehicle exhaust, wood smoke, fumes from asphalt roads or through the food they eat, Eating foods on which PAH particles have settled from the air. In some cases, passing through the skin. Drinking water can also become contaminated with PAHs, often due to hazardous waste. Drinking contaminated water can result in exposure.

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 2: Physical properties of PAHs

Polycyclic aromatic hydrocarbons (PAHs) are neutral, nonpolar, and hydrophobic organic compounds that exist as solids at room temperature. Their physical properties, such as low water solubility, low vapor pressure, and high melting/boiling points, increase with molecular weight and the number of fused rings. Chemically, their stability makes them resistant to degradation and prone to electrophilic substitution reactions rather than addition reactions, as they maintain their aromatic character.

V. 2.1: Physical properties

- **Appearance:** Typically colorless to yellow solids at room temperature.
- **Polarity:** Nonpolar, meaning they are not readily soluble in water.
- **Solubility:** Low solubility in water, which decreases as molecular weight increases. They are soluble in organic solvents and lipids.
- **Volatility:** Low vapor pressure, meaning they do not evaporate easily, especially high molecular weight PAHs.
- **Melting and boiling points:** Generally have high melting and boiling points, which increase with molecular weight. Most have a boiling point above 300°C.

V. 2.2: Chemical properties

- **Stability:** The stability of the aromatic ring system makes them relatively unreactive.
- **Reactivity:** Prefer electrophilic substitution reactions over addition reactions because substitution allows the aromatic system to remain intact, a key feature of their stability.
- **Redox behavior:** Can form radicals and anions when treated with alkali metals, and larger PAHs can form dianions.
- **Molecular structure:** Composed of two or more fused benzene rings. They are often categorized into low molecular weight (2-3 rings) and high molecular weight (4+ rings) groups, which influences their properties.
- **Persistence:** Their chemical stability and low water solubility contribute to their persistence in the environment.

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 2.3: Others general characteristics of PAHs

- PAHs are highly lipophilic and therefore very soluble in organic solvents. PAHs also manifest various functions such as light sensitivity, heat resistance, conductivity, emittability, corrosion resistance, and physiological action.
- PAHs possess very characteristic UV absorbance spectra. Each ring structure has a unique UV spectrum, thus each isomer has a different UV absorbance spectrum. This is especially useful in the identification of PAHs. Most PAHs are also fluorescent, emitting characteristic wavelengths of light when they are excited (when the molecules absorb light). Aqueous solubility decreases for each additional ring.

V. 3: Sources of PAHs

Polycyclic aromatic hydrocarbons (PAHs) are primarily sourced from the incomplete combustion of organic materials like coal, oil, gas, wood, and tobacco. Both natural sources, such as forest fires and volcanic eruptions, and man-made sources, like vehicle exhaust, industrial processes, and burning waste, produce PAHs. PAHs can also be found naturally in crude oil and coal and in products derived from them, like asphalt.

V. 3.1: Natural sources

- Forest and grass fires: Natural fires are a significant source of PAHs in the atmosphere.
- Volcanic eruptions: Volcanic activity is another natural source of PAHs.
- Crude oil and coal: These fossil fuels contain naturally occurring PAHs.

V. 3.2: Man-made sources

- Combustion of fuels:
 - Vehicles exhaust (cars, trucks, aircraft, ships, trains)
 - Burning of coal, oil, and gas for power generation, heating, and industry
 - Burning of wood and garbage
- Industrial processes:
 - Steel manufacturing
 - Oil refining
 - Aluminum production
 - Wood preservation

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 3.3: Other sources:

- Charbroiled foods: The cooking process, especially grilling, can produce PAHs.
- Tobacco smoke: Smoking tobacco is a source of PAHs.
- Products: PAHs are found in products like coal-tar sealants, asphalt, some inks, and plastics.

V. 4 Mechanisms of PAHs formation

In nature, PAHs are produced by: (1) Diagenesis of organic matter at low temperatures, (2) During formation of petroleum and coal, (3) Incomplete or insufficient combustion at moderate to high temperatures (pyrolysis), and (4) Biosynthesis.

PAHs form through mechanisms like HACA (H-abstraction-acetylene addition), which adds acetylene units to aromatic rings, and radical reactions, where radicals like cyclopentadienyl add to aromatic compounds. Other mechanisms include HAVA (H-abstraction-vinyl acetylene addition), DA (Diels-Alder reactions), and the formation of PAHs from precursors during incomplete combustion and pyrolysis. These processes build larger PAH molecules from smaller ones. Key formation mechanisms:

V. 4.1: HACA mechanism (H-abstraction-acetylene addition)

- This is a dominant pathway for PAH growth, especially in combustion.
- It involves adding acetylene C_2H_2 to an existing aromatic radical, followed by cyclization.
- Example: Acetylene adds to a phenyl radical to form a phenyl-acetylene molecule $C_6H_5C_2H_2$, which can then react with acetylene to grow into larger molecules like naphthalene ($C_{10}H_8$).

V. 4.2: Radical reactions

- These involve reactions between various free radicals, such as cyclopentadienyl radicals and other aromatic molecules.
- The reactions link smaller aromatic and non-aromatic units together.
- Example: Cyclopentadienyl radicals reacting with benzene to form phenol or with naphthalene to form benzofuran.

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 4.3: Other mechanisms

- **HAVA mechanism:** H-abstraction-vinylacetylene addition is another pathway for PAH growth.
- **DA mechanism:** Diels-Alder reactions involving molecules like acetylene and biphenyl can form PAHs like phenanthrene and pyrene.
- **Incomplete combustion and pyrolysis:** These processes produce PAHs from the thermal breakdown of organic materials like coal, oil, and biomass. High-molecular-weight compounds can form from lower-molecular-weight precursors through pyrosynthesis.

V. 5: Effects of PAHs on living beings

Polycyclic aromatic hydrocarbons (PAHs) can have harmful effects on living organisms, including humans, leading to an increased risk of cancer, respiratory problems like asthma, cardiovascular diseases, reproductive issues, and developmental problems. These effects occur because PAHs are metabolized into reactive intermediates that can damage DNA, trigger oxidative stress, and disrupt the endocrine and immune systems.

V. 5.1: Health effects

- **Cancer:** Long-term exposure to PAHs is linked to various cancers, including lung, skin, bladder, and gastrointestinal cancers. Some studies show increased cancer risk in workers exposed to PAHs.
- **Respiratory and cardiovascular diseases:** PAHs can reduce lung function and exacerbate asthma. They are also associated with cardiovascular problems such as atherosclerosis, hypertension, and heart disease.
- **Reproductive and developmental issues:** Exposure to PAHs can impair fertility in both males and females and has been linked to adverse birth outcomes like low birth weight and premature birth. Prenatal exposure is also associated with developmental disorders in children, such as lower IQ and behavioral problems.
- **Immune system effects:** PAHs can suppress the immune system, potentially increasing susceptibility to infections and influencing the development of autoimmune diseases and allergic reactions.
- **Neurotoxicity:** Some PAHs can affect the nervous system and may disrupt circadian rhythms, which are crucial for many physiological processes.
- **Other effects:** PAHs can cause genotoxicity (DNA damage) and affect bone homeostasis.

Chapter V: Polycyclic Aromatic Hydrocarbons (PAHs)

V. 5.2: Vulnerability

- Children are particularly vulnerable to the effects of PAHs due to behaviors like playing in contaminated soil and hand-to-mouth activity.
- Exposure during pregnancy poses significant risks to fetal development.

V. 5.3: Exposure routes

- PAHs can enter the body through inhalation, ingestion (from contaminated food or water), and skin contact.
- Sources of exposure include tobacco smoke, vehicle exhaust, industrial emissions, and some contaminated foods.

V. 5.3: Environmental pollution and degradation: PAHs typically disperse from urban and suburban non-point sources through road runoff, sewage, and atmospheric circulation and subsequent deposition of particulate air pollution. Soil and river sediment near industrial sites such as creosote manufacturing facilities can be highly contaminated with PAHs. Oil spills, creosote, coal mining dust, and other fossil fuel sources can also distribute PAHs in the environment. Two- and three-ringed PAHs can disperse widely while dissolved in water or as gases in the atmosphere, while PAHs with higher molecular weights can disperse locally or regionally adhered to particulate matter that is suspended in air or water until the particles land or settle out of the water column. PAHs have a strong affinity for organic carbon, and thus highly organic sediments in rivers, lakes, and the ocean can be a substantial sink for PAHs.

V.6: Precautions

How can people reduce their exposure to PAHs?

1. Reduce PAHs in your diet

- Reduce or stop use of cigarettes, cigars, or vape devices
- Limit consumption of roasted or toasted foods (cereals, grains, etc.)
- Limit grilled and smoked foods
- Choose leaner cuts of meat to reduce the amount of fat dripping and burning
- Raise the grill grate higher over the flames to reduce the amount of charring
- Remove blackened portions from meat and fish

2. Reduce PAHs from air

- When cooking, use the stove vent hood or open a nearby window.
- Reducing use of plug-in air fresheners (or check the label to see if they are free of naphthalene).
- Use cedar balls instead of traditional mothballs.
- Routinely ventilate your home by opening windows.
- If you use a wood burning stove for heat, look into options for cleaner burning stoves.

3. Reduce PAHs from water

Some PAHs are regulated in drinking water. PAH contamination of drinking water is relatively rare, especially once water has gone through water treatment plants which contain activated carbon filters to remove organic contaminants such as PAHs.

4. Reduce PAHs from soil



Chapter IV: Actions for a healthy planet_ United States Recommendations

Actions for a healthy planet_ United States Recommendations

Every one of us can make choices to protect nature, tackle climate change, and take care of our planet. (Illustration: United Nations Department of Global Communications)

The Sustainable Development Goals spell out how we can protect our environment and slow climate change, from forests to oceans to everywhere in between. Think about your electricity use and your travel. Check your dinner table. Reuse whatever you can. The possibilities for action are many and add up fast.

Greenhouse gas emissions per person vary greatly among countries. In the United States of America and the Russian Federation per capita emissions are almost three times the world averages of 6.6 tons of CO₂ equivalent, while in India and the African Union they are less than half the world average. Globally, the 10 per cent of the population with the highest income account for nearly half of all emissions. Here are some actions to reduce your impact on the environment.

1. Save energy at home

Much of our electricity and heat are powered by coal, oil and gas. Use less energy by reducing your heating and cooling use, switching to LED light bulbs and energy-efficient electric appliances, washing your laundry with cold water, or hanging things to dry instead of using a dryer. Improving your home's energy efficiency, through better insulation for instance or replacing your oil or gas furnace with an electric heat pump can reduce your carbon footprint by up to 900 kilograms of CO₂ per year.

2. Change your home's source of energy

Ask your utility company if your home energy comes from oil, coal or gas. If possible, see if you can switch to renewable sources such as wind or solar. Or install solar panels on your roof to generate energy for your home. Switching your home from oil, gas or coal-powered energy to renewable sources of energy, such as wind or solar can reduce your carbon footprint by up to 1.5 tons of CO₂ per year.

3. Walk, bike or take public transport

The world's roadways are clogged with vehicles, most of them burning diesel or gasoline. Walking or riding a bike instead of driving will reduce greenhouse gas emissions and help your health and fitness. For longer distances, consider taking a train or bus. And carpool whenever possible. Living car-free can reduce your carbon footprint by up to 2 tons of CO₂ per year compared to a lifestyle using a car.

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4. Switch to an electric vehicle

If you plan to buy a car, consider going electric, with more and cheaper models coming on the market. In many countries, electric cars help reduce air pollution and cause significantly fewer greenhouse gas emissions than gas or diesel-powered vehicles. But many electric cars still run on electricity produced from fossil fuels, and the batteries and engines require rare minerals which often come with high environmental and social costs. Switching from a gasoline or diesel-powered car to an electric vehicle can reduce your carbon footprint by up to 2 tons of CO₂ per year. A hybrid vehicle can save you up to 700 kilograms of CO₂ per year.

5. Consider your travel

Airplanes burn large amounts of fossil fuels, producing significant greenhouse gas emissions. That makes taking fewer flights one of the fastest ways to reduce your environmental impact. When you can, meet virtually, take a train, or skip that long-distance trip altogether. Taking one less long-haul return flight can reduce your carbon footprint by up to almost 2 tons of CO₂.

6. Reduce, reuse, repair and recycle

Electronics, clothes, plastics and other items we buy cause carbon emissions at each point in production, from the extraction of raw materials to manufacturing and transporting goods to market. To protect the climate, buy fewer things, shop second-hand, and repair what you can. Plastics alone generated 1.8 billion metric tons of greenhouse gas emissions in 2019 3.4 per cent of the global total. Less than 10 per cent is recycled, and once plastic is discarded, it can linger for hundreds of years. Buying fewer new clothes and other consumer goods can also reduce your carbon footprint. Every kilogram of textiles produced generates about 17 kilograms of CO₂.

7. Eat more vegetables

Eating more vegetables, fruits, whole grains, legumes, nuts, and seeds, and less meat and dairy, can significantly lower your environmental impact. Producing plant-based foods generally results in fewer greenhouse gas emissions and requires less energy, land, and water. Shifting from a mixed to a vegetarian diet can reduce your carbon footprint by up to 500 kilograms of CO₂ per year (or up to 900 kilograms for a vegan diet).

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8. Throw away less food

When you throw food away, you're also wasting the resources and energy that were used to grow, produce, package, and transport it. And when food rots in a landfill, it produces methane, a powerful greenhouse gas. So purchase only what you need, use what you buy and compost any leftovers. Cutting your food waste can reduce your carbon footprint by up to 300 kilograms of CO₂ per year.

9. Plant native species

If you have a garden or even just a plant or two outside your home, check for native species. Use a plant identification app to help. And then think about replacing non-natives, especially any considered invasive. Plants, animals and insects depend on each other. Most insects will not eat non-native plants, which means birds and other species lose a food source. Biodiversity suffers. Even a single tree or shrub can offer a refuge just remember to skip insecticides and other chemicals.

10. Clean up your environment

Humans, animals and plants all suffer from land and water contaminated by improperly discarded garbage. Use what you need, and when you have to throw something out, dispose of it properly. Educate others to do the same, and participate in local clean-ups of parks, rivers, beaches and beyond. Every year, people throw out 2 billion tons of trash. About a third causes environment harms, from choking water supplies to poisoning soil.

11. Make your money count

Everything we spend money on affects the planet. You have the power to choose which goods and services you support. To reduce your environmental impact, choose products from companies who use resources responsibly and are committed to cutting their gas emissions and waste. If you have money that is being invested for you, through a pension fund for instance, it may be supporting fossil fuels or deforestation. Making sure your savings are invested in environmentally sustainable businesses can greatly reduce your carbon footprint.

12. Speak up

Speak up and get others to join in taking action. It's one of the quickest and most effective ways to make a difference. Talk to your neighbors, colleagues, friends, and family. Let business owners know you support bold changes from plastics-free products and packaging to zero-emissions vehicles. Appeal to local and world leaders to act now. Climate

Chapter IV: Actions for a healthy planet_ United States Recommendations

action is a task for all of us. And it concerns all of us. No one can do it all alone but we can do it together.

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