Resources: Type & Occurrence

PRRE1003
Resources, Processes & Materials Engineering

LECTURE 2

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COMMONWEALTH OF AUSTRALIA

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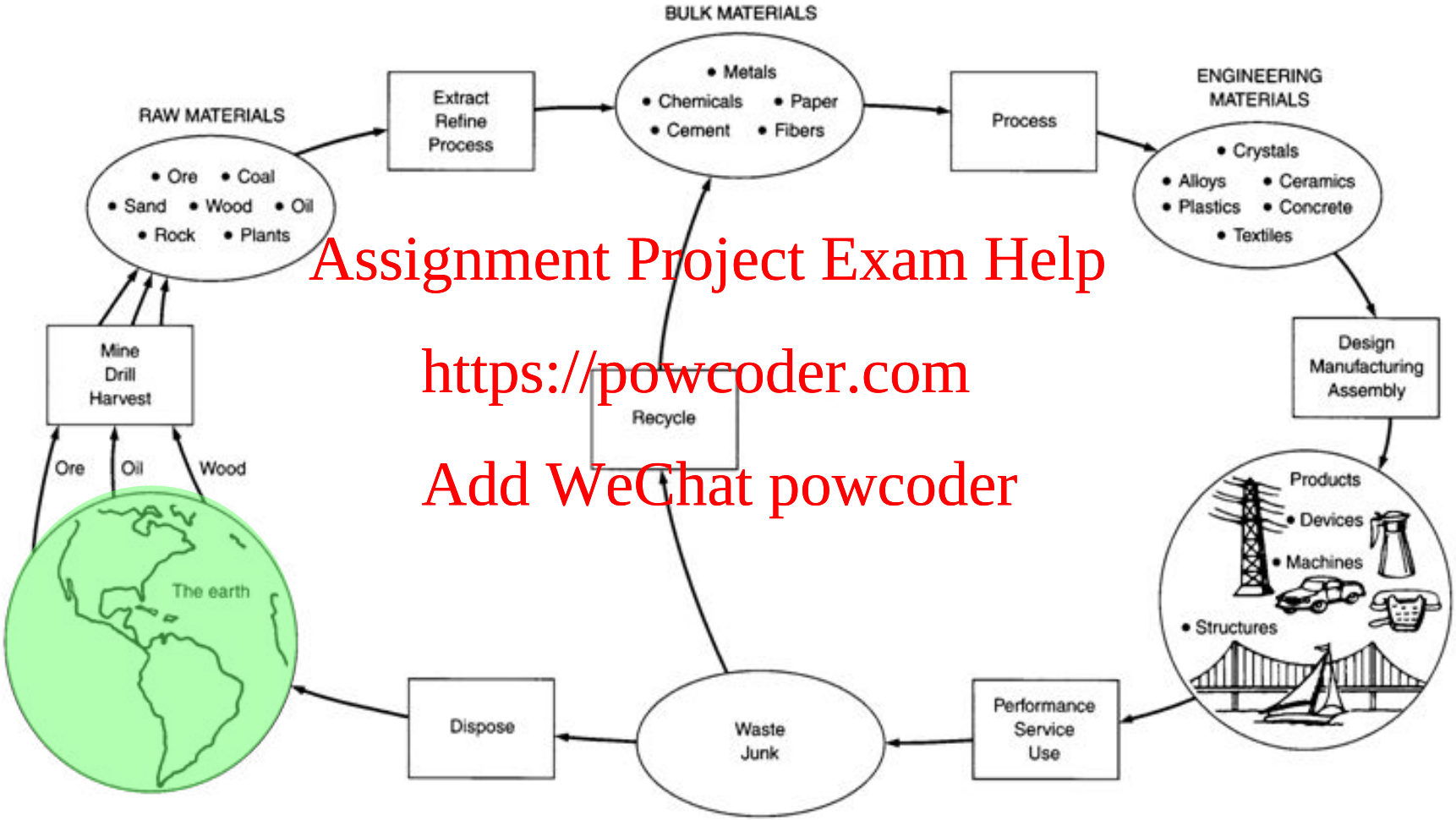
Lecture focus



Reproduced from "Materials and Man's Needs", National Academy of Sciences, Washington D.C., 1974.

Lecture 2 Outline

- Natural material and energy resources
  - Hydrocarbons (coal, biomass, oil, natural gas)
  - Mineral ores
  - Water
  - Other (food crops, wood, sand, plants, cotton, wool etc.)
  - Solar, wind, geothermal, nuclear
- Basic material and energy balances
  - renewable vs non-renewable material and energy resources

Hydrocarbon resources

Hydrocarbons are critically important resources, as they are the major source of the world's energy and also used for many of the bulk chemicals produced.

Hydrocarbons are thus named as they are organic resources made primarily of C and H. They are primarily used as fuel, because the reactions with air are highly exothermic and therefore generate a lot of heat. The main hydrocarbon resources are:

- Coal
- Oil
- Natural gas
- Biomass

Hydrocarbon Resources: Coal

Coal is formed from dead plant matter over a millions of years (66 to 299 million years), under high temperatures and pressures. It is a rock formed primarily from carbon with variable amounts of hydrogen, sulphur, oxygen and nitrogen. The amount of carbon, and thus coal rank, determines the properties of coal.

Lignite or brown coal has a lower amount of carbon and a higher amount of moisture than sub-bituminous coal, bituminous (black) coal or anthracite.

https://www.ga.gov.au/education/classroom-resources/minerals-energy/australian-energy-facts/coal

Australia has the 4th largest coal reserves in the world, having mined ~9100 million tonnes and ~2300 million tonnes of black and brown coal respectively, since the late1700s. 80% of Australia's coal is extracted from open-cut mines, which is cheaper than underground mining.

Hydrocarbon Resources: Coal

Table 5.1.32 Typical composition of solid fuels (Falbe, 1977).

	H_2O (wt%)	Volatile matter	C	H	O	N	S
		wt% (moisture- and ash-free)					
Wood, fresh	60–40	75–65	48–52	6.2–5.8	45–43	0.1–0.05	—
Peat, fresh	92–80	80–70	49–60	8–5	45–28	4–1	1–0.1
Lignite	63–30	60–47	65–73	8–5	30–16	1.5–0.5	3–0.5
Sub-bituminous (black) lignite	10–8	47–43	72–75	7–5.5	18–12	2–1	3–0.5
High volatile bituminous coal	8–3	45–35	75–85	6.6–5.6	12–7	1.8–1	1.8–0.5
Medium volatile bituminous coal	<1	34–19	85–88	5.6–4.5	7–3.2	1.8–1	1.8–0.6
Low volatile bituminous coal	<1	19–14	88–90	4.5–4.0	3.2–2.8	1.7–1	1.7–0.6
Semi-anthracite coal	<1	14–12	90–91	4.0–3.8	2.8–2.5	1.7–1	1.7–0.6
Anthracite	<1	<10	>92	<3.8	<2.5	1.7–1	1.7–0.6

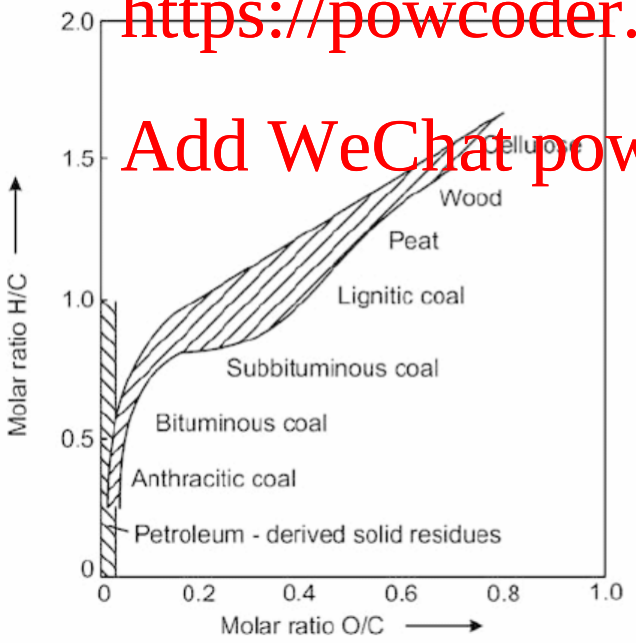
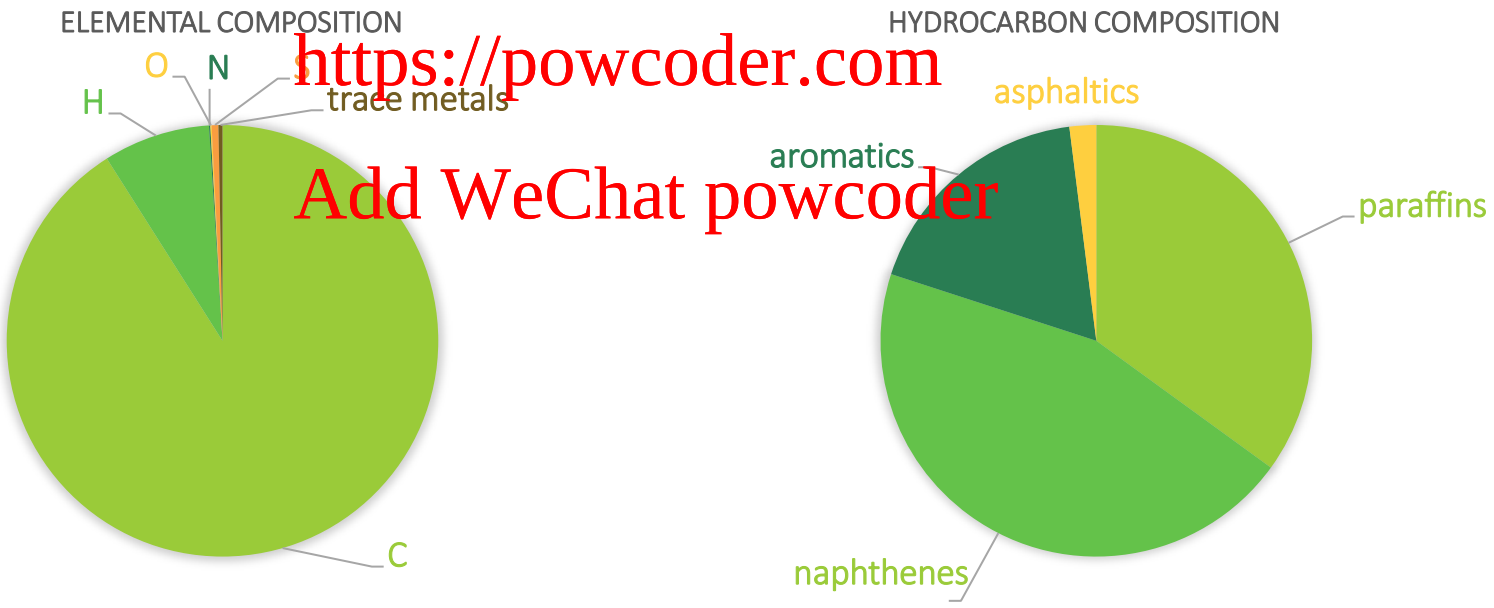


Figure 5.1.26 Molar C-H-O ratio of solid fuels.

Hydrocarbon Resources: Crude oil

Crude oil is liquid that occurs naturally, and consists mainly of hydrocarbons derived from the thermal and chemical alteration of organic matter buried in sedimentary basins.

The exact composition and therefore properties of crude oil varies from region to region, around the oilfields of the world. Raw crude oil is usually dark brown or black, although greenish or yellow petroleum liquids are not unusual in some oilfields.

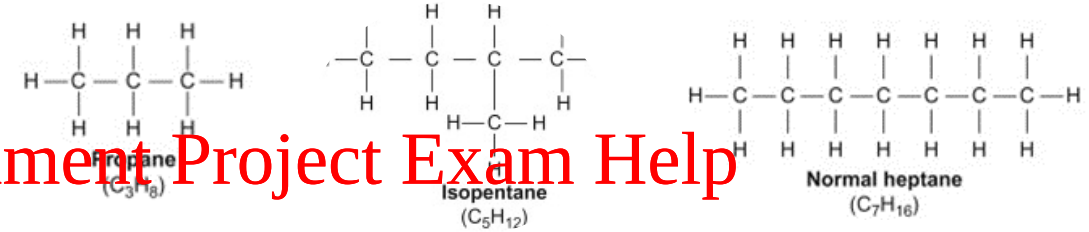


Hydrocarbon Resources: Crude oil

The three groups of hydrocarbons that occur naturally in crude oil, are:

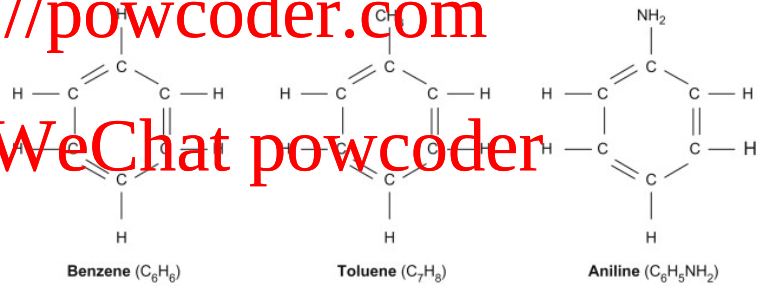
Paraffins, with general formula C_nH_{2n+2}

Examples:



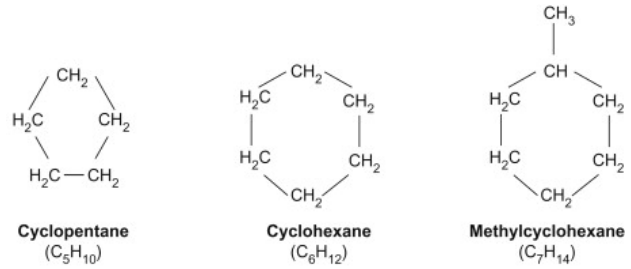
Aromatics

Examples:



Naphthenes, with general formula C_nH_{2n}

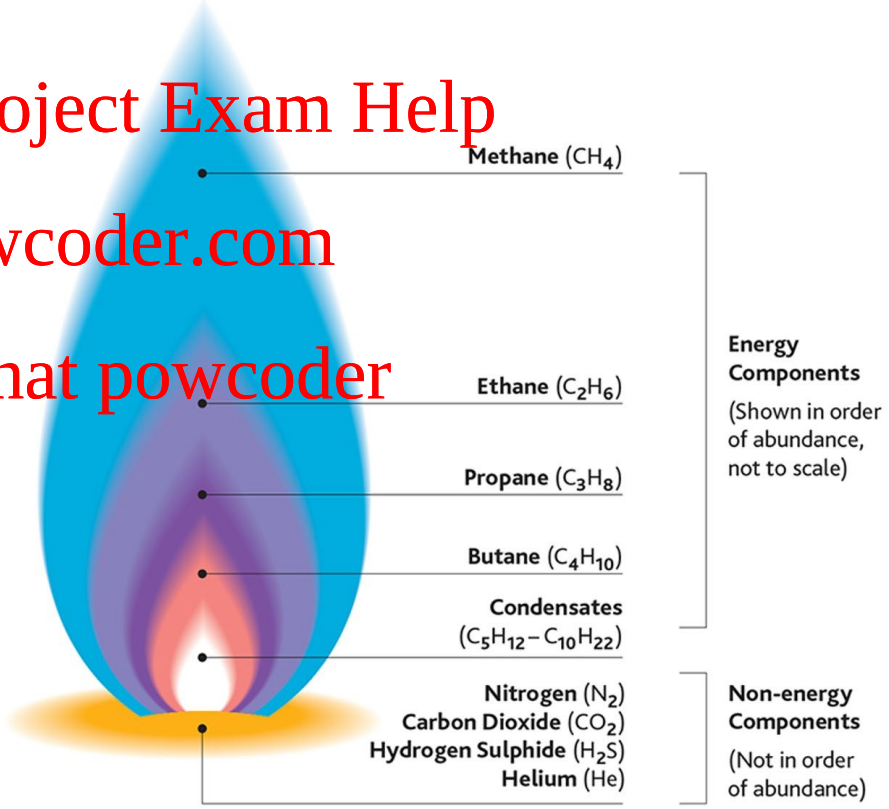
Examples:



Hydrocarbon Resources: Natural gas

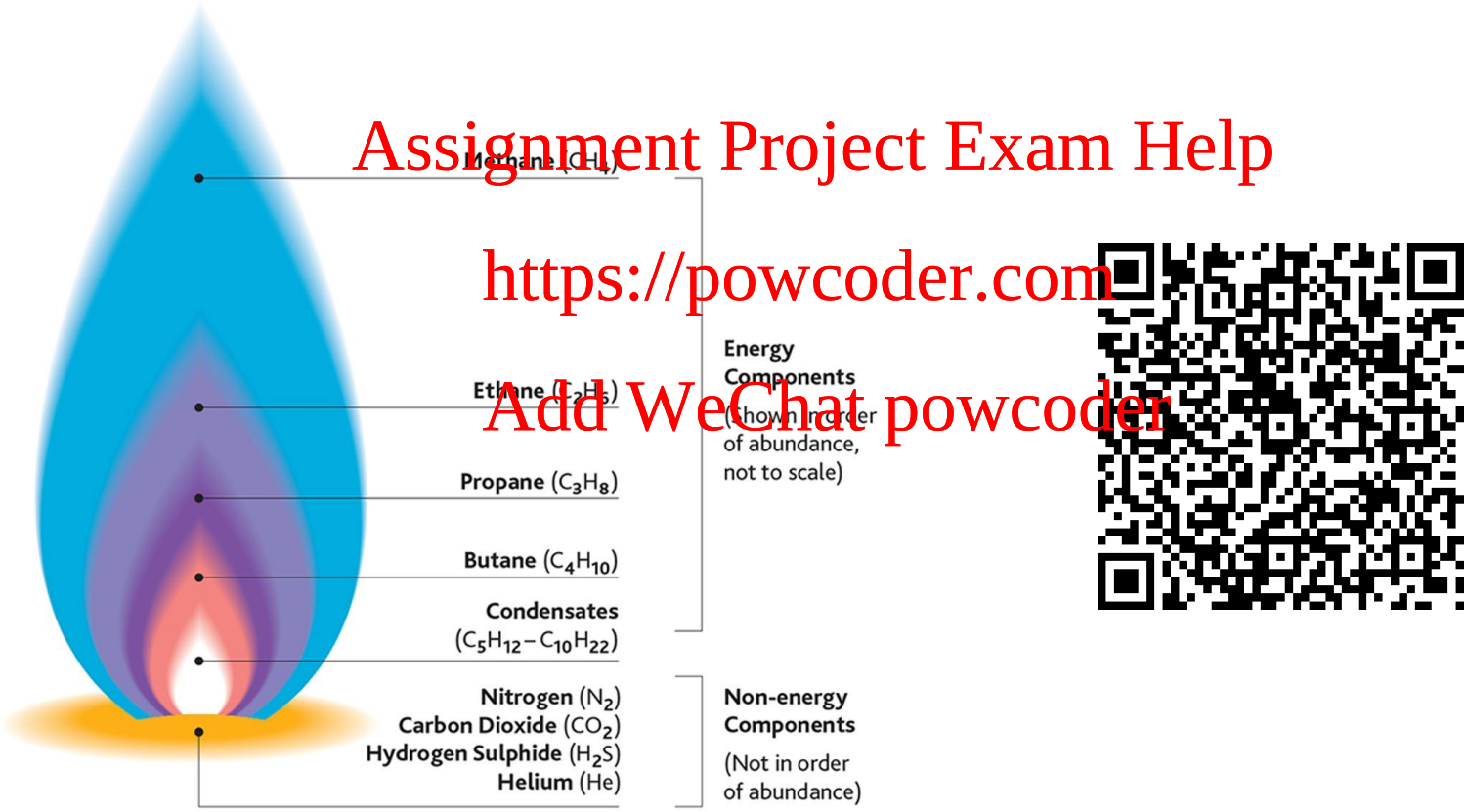
Natural gas is composed primarily of methane (CH_4) with other heavier hydrocarbons and carbon dioxide. It is also made by changes in organic matter, and can be found with oil in both conventional oilfields, or in unconventional deposits such as coal beds, shales, low quality reservoirs or gas hydrates.

Australian gas resources are abundant, both onshore and offshore, and it is the world's second largest exporter of liquefied natural gas (LNG).



Hydrocarbon Resources: Natural gas

- Write equations for the complete combustion of C_1-C_4 components of natural gas.



Hydrocarbon Resources: Biomass

Biomass is organic material that is derived from plants and animals, and is a broad term for many different resources:

- Wood
- Agricultural crops
- Waste from food, yards and garbage
- Animal manure and human sewerage

Wood and some garbage can be burnt directly as fuel, to provide energy in the form of heat. Other types of biomass are converted to a fuel gas (biogas), or into liquid biofuels such as ethanol and biodiesel.

Bioenergy (all energy derived from biomass) is a significant source of renewable energy globally.

Learning Outcome Check

- What are the key global hydrocarbon resources, and why are they mainly used as sources of energy?
- Explain how coal is formed, and the different types of coal.
- What fraction of Australia's energy consumption arises from coal power?
- What are the key components in crude oil, and natural gas?
- Write simple, balanced equations for the complete combustion of a given hydrocarbon with O_2. What are the products of complete combustion?
- Why don't coal and biomass have a particular chemical formula?
- Give examples of types of biomass. Why is it often used as a source of energy?

Mineral resources

Minerals are vitally important to produce the vast majority of engineering materials, and therefore end products. For example, bauxite and iron ore are bulk materials that are used to produce variety of engineering materials such as iron, steel, aluminium, alloys which are crucial to the current global consumption and therefore demands.

As Australia is the world leader in the production of *bauxite* and *iron ore* (29% and 37% of global production respectively), the mining industry particularly in WA plays a significant role in the world's supply of these vitally important minerals along with several others. Australia also produces 47% of the world's lithium, which are used in battery manufacture and an increasingly important commodity in a high-tech world.

Mineral resources: iron ore

Minerals generally occur in variety of forms, together with other material (termed **gangue** material).

For example, iron occurs naturally as hematite (Fe_2O_3), magnetite (Fe_3O_4), limonite ($Fe_2O_3.3H_2O$) and sometimes as siderite ($FeCO_3$) and taconite (iron silicate). The gangue materials are primarily oxides such as SiO_2, MnO_2, CaO, MgO, Al_2O_3, phosphorus and sulphur compounds.

https://www.tec-science.com/material-science/steel-making/iron-ore-mining-and-dressing/

Mineral resources: bauxite

Aluminium occurs naturally as bauxite ore, which is mainly a mixture of the minerals gibbsite [$Al_2(OH)_3$], boehmite [γ-AlO(OH)], and diaspore [α-AlO(OH)]. Bauxite is not a mineral, but the ore which contains the above minerals, but also other material such as clay minerals and insoluble material, collectively known as *gangue* material.

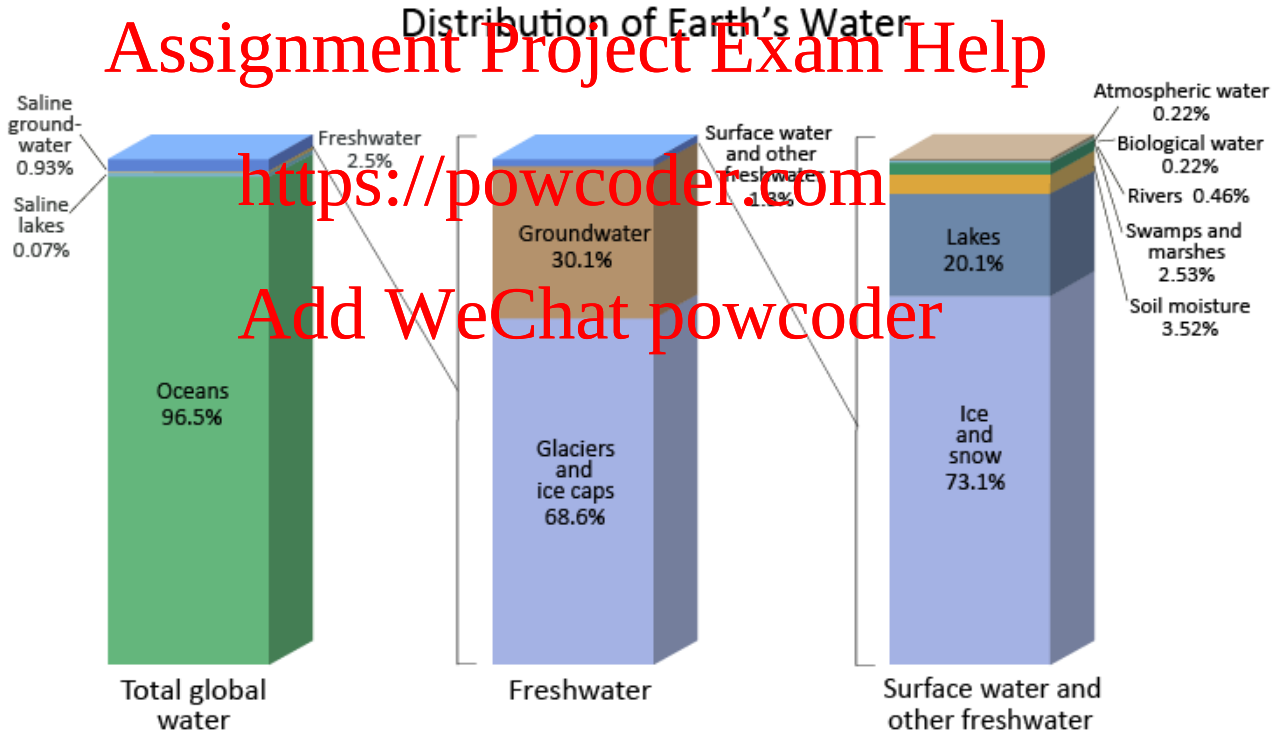
https://mineralseducationcoalition.org/minerals-database/aluminum/

Learning Outcome Check

- Distinguish between the terms *mineral*, *ore* and *gangue*.
- What are the key minerals in bauxite ores?
- What are the key minerals in iron ores?
- Why is it important to know the gangue material present in different ores?

Water resources

Water is one of the world's primary material resources, and many parts of the world have a scarcity of water that endangers human life. As engineers, we have a primary responsibility in identifying and implementing sustainable life on earth through judicious and intelligent use of our material resources.

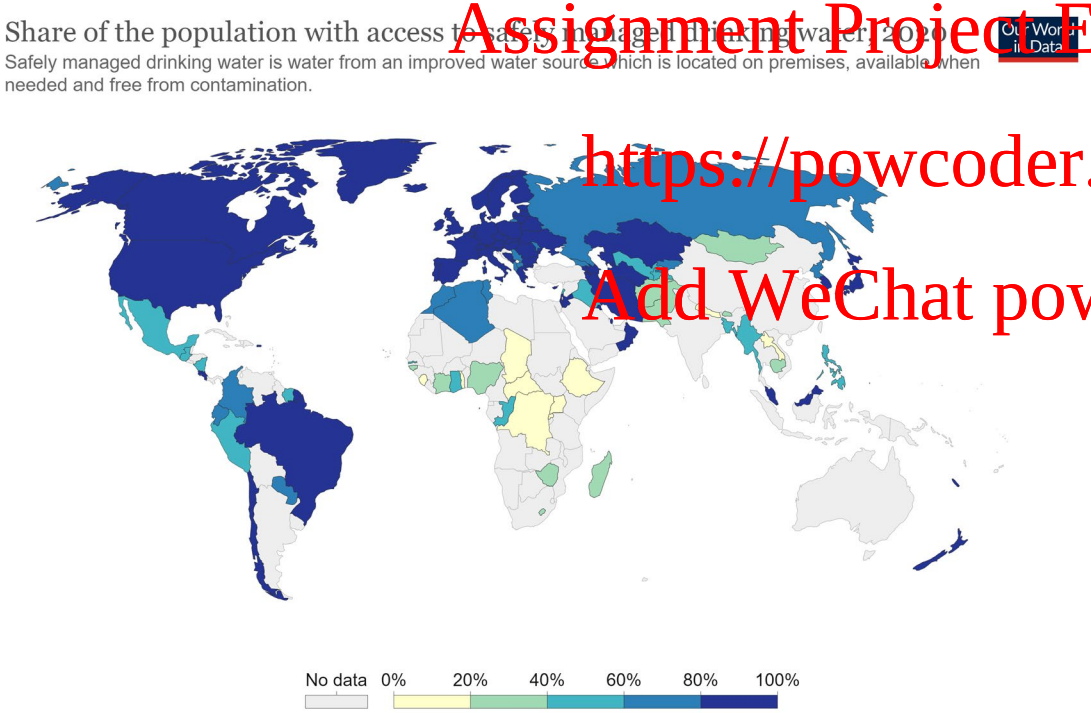


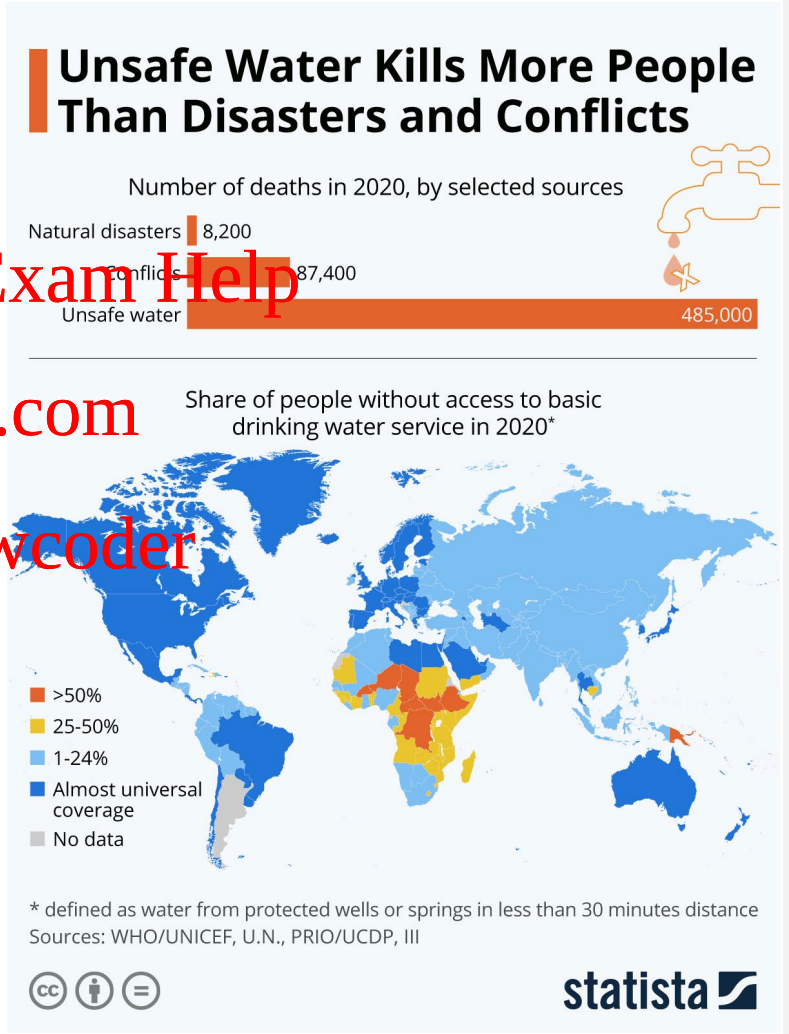
Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.

Water resources

Availability of clean, freshwater is a significant global problem.

- What sort of processes can we use to make water suitable for consumption ?





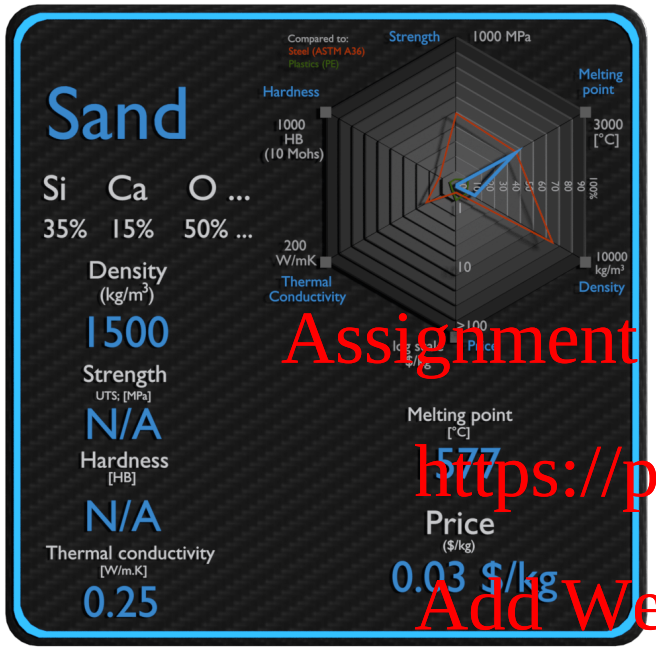
Air resources

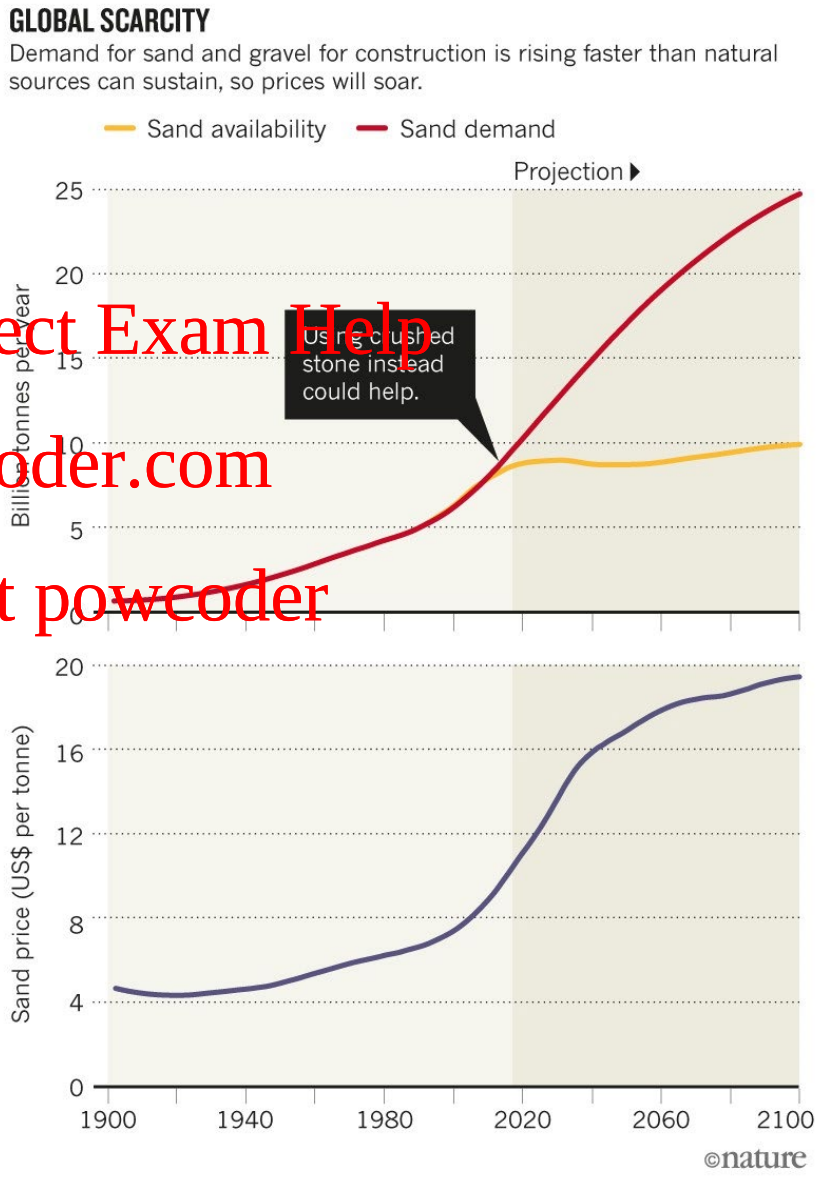
Air is generally not considered a resource as it is abundantly available and the likelihood that it will be in short supply at any stage is negligible.

However, air is usually compressed and used globally in most industries either as reactant (in combustion), or for pneumatic purposes in machinery, or as coolant. It is usually recycled back into the atmosphere, or in the case of reaction, the products can be varied.

Air quality can be a concern in many countries around the world, mainly due to greenhouse gas emissions. As engineers, we also have a responsibility to ensure that industrial processes do not pose a threat to life or livestock, and to mitigate global warming due to negative impacts on air quality by greenhouse gases. This is a very serious and urgent issue, and should underpin the design and implementation of industrial systems.

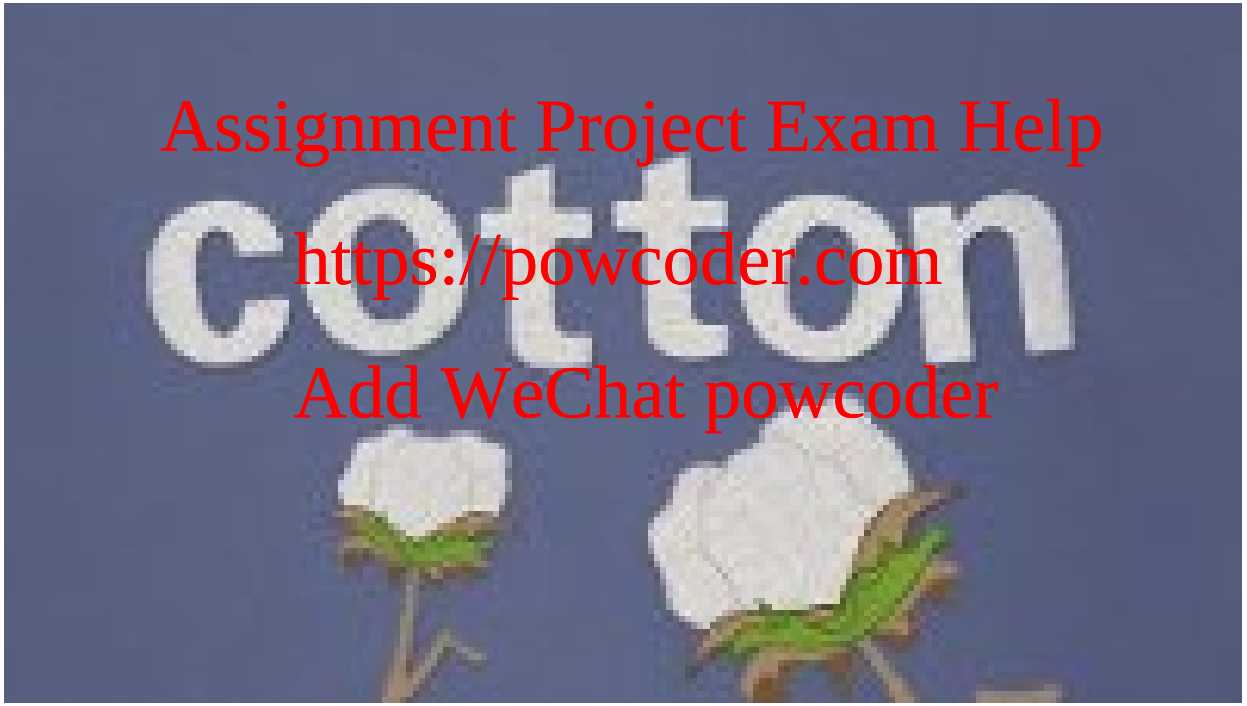
Sand





- Sand and gravel are the most-extracted materials in the world (by weight)
- Key ingredient for concrete, roads, glass and electronics
- Asia-Pacific region highest extraction rate
- Global demand for sand has created “sand mafia” involved in illegal trade, environmental damage ad even murder

Cotton



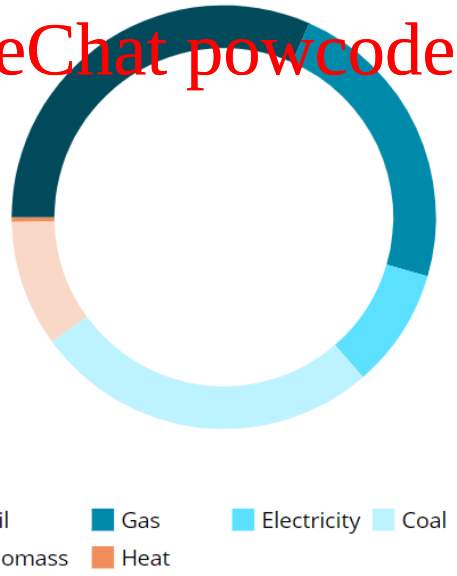
Learning Outcome Check

- The following resources are not primarily used as energy resources. What is a key use for each of these?
  * Air
  * Sand
  * Water
  * Cotton
- For each resource identified, what extraction processes are required to convert them into raw materials that are ready to be used?

Energy Resources

As mentioned previously, as much of the world's material resources (coal, natural gas, oil, biomass) tend to be used primarily for energy production, the term *energy resource* may be used interchangeably for these material resources.

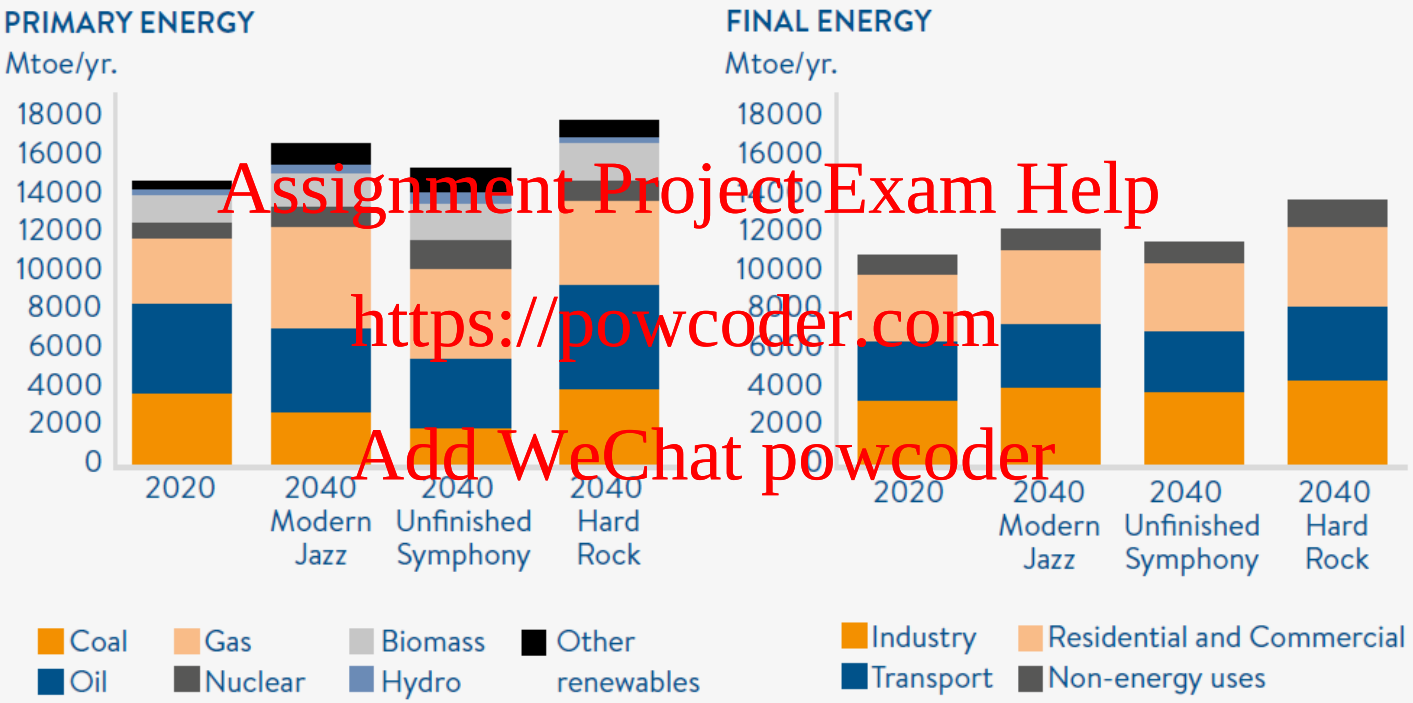
However, energy resources have a much wider meaning in a global context. They include renewable and non-renewable sources of energy to meet the global power consumption. Currently, fossil fuels constitutes approximately 2/3 of the world's energy consumption.



https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

Energy Resources: the role of fossil fuels

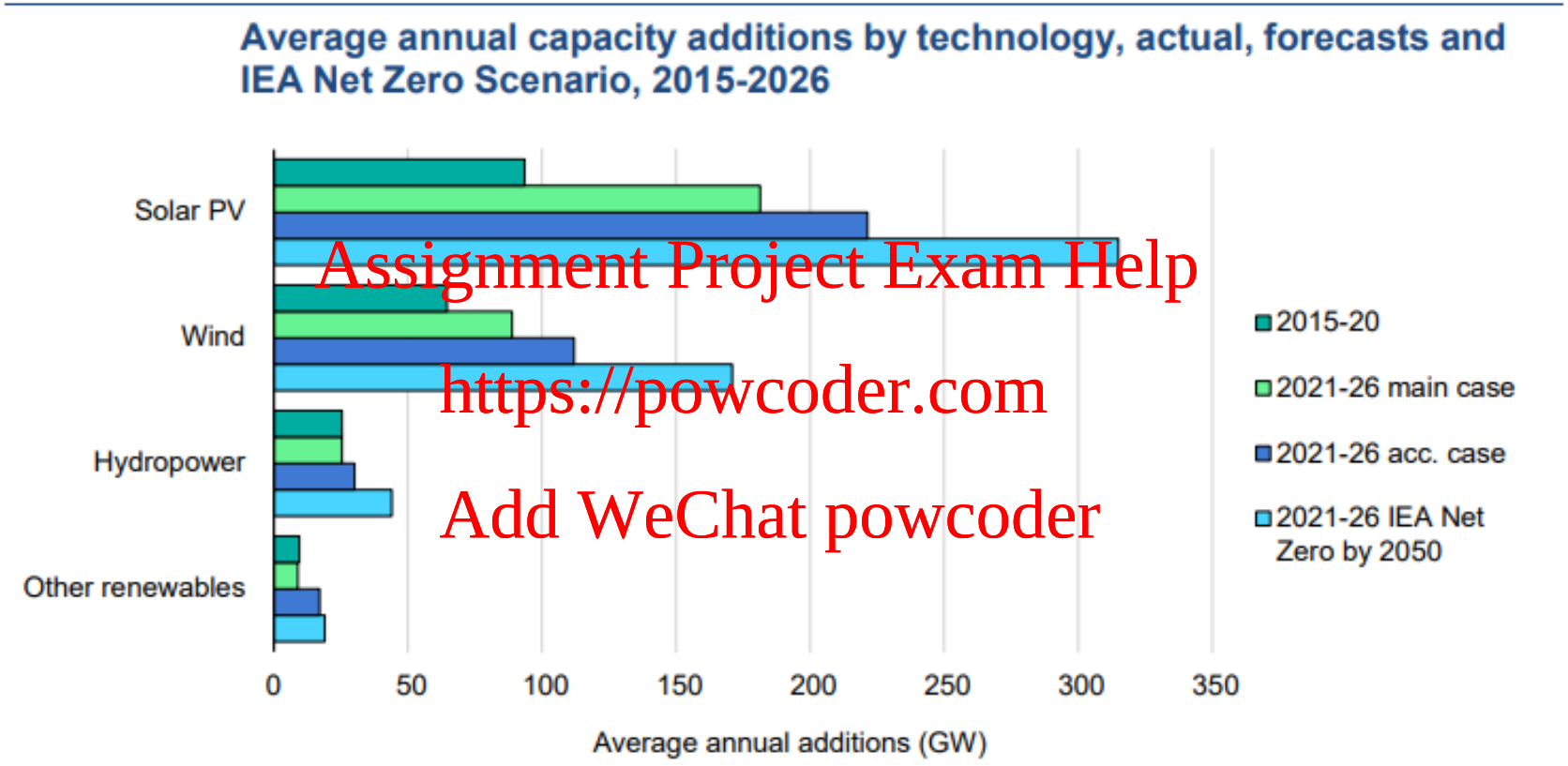
Figure 3. Primary Energy by Source (Mtoe/yr.) and Final Energy by Demand Sector (Mtoe/yr.)



Source: The World Energy Council, Paul Scherrer Institute, Accenture Strategy
Note: Other renewables comprise wind, solar PV, solar thermal and geothermal. Non-energy uses are dominated by industrial feedstocks (for petrochemical production, for example). The energy carriers are coal (including hard coal and lignite), gas and oil, including crude oils and oil products such as additives, ethane and naphtha.

https://www.worldenergy.org/assets/downloads/2019_Scenarios_Full_Report.pdf

Energy Resources: the role of renewables



Note: acc. case = accelerated case.

https://iea.blob.core.windows.net/assets/5ae32253-7409-4f9a-a91d-1493ffb9777a/Renewables2021-Analysisandforecastto2026.pdf

Learning Outcome Check

- Why are some *material* resources also reported as *energy* resources?
- Compare the current (2020) and future (2040) forecasts for key energy resources. What is the energy mix?
- Which resources are considered *renewable energy resources*?
- In the next 5 years, which renewable energy resource is forecast to grow the fastest?
- What factors may influence these future energy forecasts?

Material Balances

The **Law of Conservation of Mass** and the **First Law of Thermodynamics** form the basis of understanding the flow of material and energy resources across various industries, and also for the classification of renewable and non-renewable resources.

The Law of Conservation of Mass was initially conceptualised by ancient Greeks. However, Antoine Lavoisier formally proposed this Law in 1789, stating that mass/matter is neither created not destroyed in a closed system, i.e. it is conserved. This Law is commonly known as *material balance*, and can be stated mathematically as follows to the earth as a system:

Mass ACCUMULATED = mass IN – mass OUT

When applied to the earth as a system, over a finite period of time (i.e. 50-100 years), it can be seen that the accumulated mass of fossil fuels is negative, i.e. it is depleted. These materials (which are also sources of energy) are therefore called **non-renewables**, because their usage depletes the global resource over the finite period of time. Conversely, **renewables** are resources that the earth can replenish in a finite period of time.

Material Balances

A simple material balance can be written as follows, on a defined system, over a defined period of time.

The rate of change of mass with time is given by:

$$\frac{dm}{dt} = \dot{m}_{in} - \dot{m}_{out}$$

where m = mass of material, and t = time

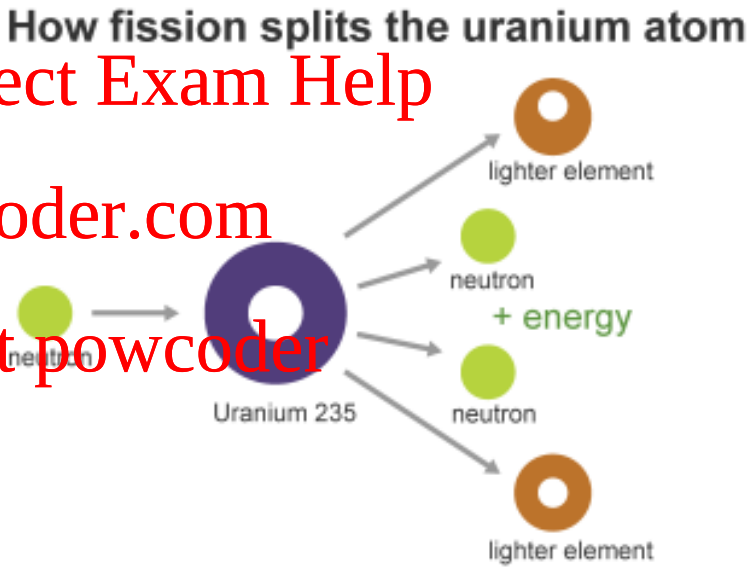
- If water flows into a tank at a rate of 5 g/s and flows out of the tank at a rate of 4 g/s, what is the rate of accumulation of water in the tank?

Non-Renewable Energy Resources

On a global scale, a *renewable* resource is one that has does not have a net negative accumulation in a finite period of time.

Non-renewable energy resources are:

- Coal
- Oil
- Natural Gas
- Nuclear
- Other petroleum products



Source: Adapted from National Energy Education Development Project (public domain)

https://www.eia.gov/energyexplained/nuclear/

Nuclear energy can be produced by either nuclear fission, or fusion, although nuclear power is normally generated through nuclear fission of uranium-235.

Learning Outcome Check

- Write a simple material balance, and explain each term in your own words.
- Apply a material balance to simple problem.
- How is the material balance used to explain the concept of *non-renewable* and *renewable*, as applied to materials used as fuel?

Energy Balances

The First Law of Thermodynamics states that energy can neither be created nor destroyed, and is often known as the principle of energy conservation.

Applied to global energy, the energy balance over a finite period of time becomes:

Energy ACCUMULATED = energy IN – energy OUT

The earth has several renewable sources of energy:

- Solar
- Wind
- Hydropower
- Geothermal*
- Biomass*

** there is some speculation about the renewability of these resources*

Energy Balances

When we speak about fossil fuels, or biomass, being *energy* resources, we mean that some or all of these *material* resources are used in combustion/gasification processes to ultimately produce energy.

How do these resources produce energy? The bonds between C-H and C-O are broken and new bonds are formed by the products. The net energy change is negative, which means that energy is released, usually in the form of heat at high temperatures. This heat is then used in heat engine cycles to produce electricity, or as heat for hot water.

- What are the different types of energy you can identify?

Types of Energy

Energy exists in various forms, but can be broadly classified in energy that is stored or contained by a mass, and energy that is in transit. Energy can also be converted from one form into another (although the 2nd Law of Thermodynamics tells us what the boundaries of those conversions are!).

Identify which of these energy forms are energies in transit (i.e., they are not stored or contained by a body, but either enter or leave a system):

- Potential energy
- Kinetic energy

- Heat
- Electrical energy
- Shaft work
- Internal energy

Energy Balances

- Identify the energy inputs and outputs for the following equipment, or processes (heat, internal energy, work, kinetic energy, potential energy).

Hint: Identify your system boundary and figure out what goes in, and what goes out

A. A kettle

B. A refrigerator

C. A car running on internal combustion engines

D. A power plant running on coal combustion

Learning Outcome Check

- Explain the Law of Conservation of Energy in your own words.
- Identify the different types of energy, as energy stored, or energy in transit.
- How can we apply this Law to the earth as a whole?

Lecture Summary

✓Natural material and energy resources

- Hydrocarbons (coal, biomass, oil, natural gas)
- Mineral ores
- Water
- Other (food crops, wood, sand, plants, cotton, wool etc.)
- Solar, wind, geothermal, nuclear

✓Basic material and energy balances

- renewable vs non-renewable material and energy resources