Processes: Hydrocarbon Processing

PRRE1003
Resources, Processes & Materials Engineering

LECTURE 8

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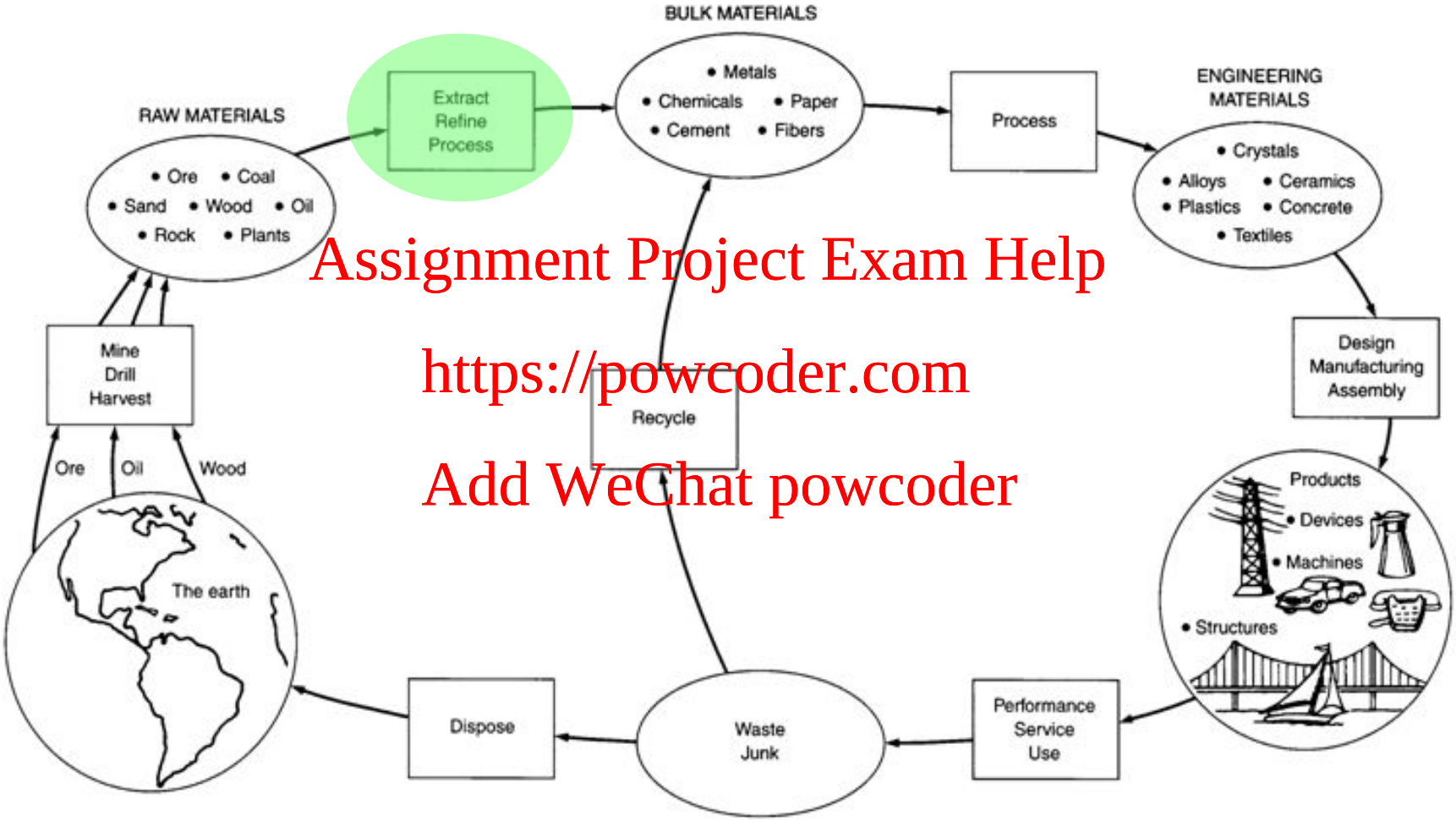
Lecture focus



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

Lecture Outline

- Hydrocarbon resources (crude oil, natural gas, coal, biomass) and extraction

- Hydrocarbon Processing of Raw Materials
  - production of electricity from hydrocarbon fuels
  - production of key bulk chemicals: ethylene
  - production of pharmaceuticals: Aspirin

Hydrocarbon Raw Materials

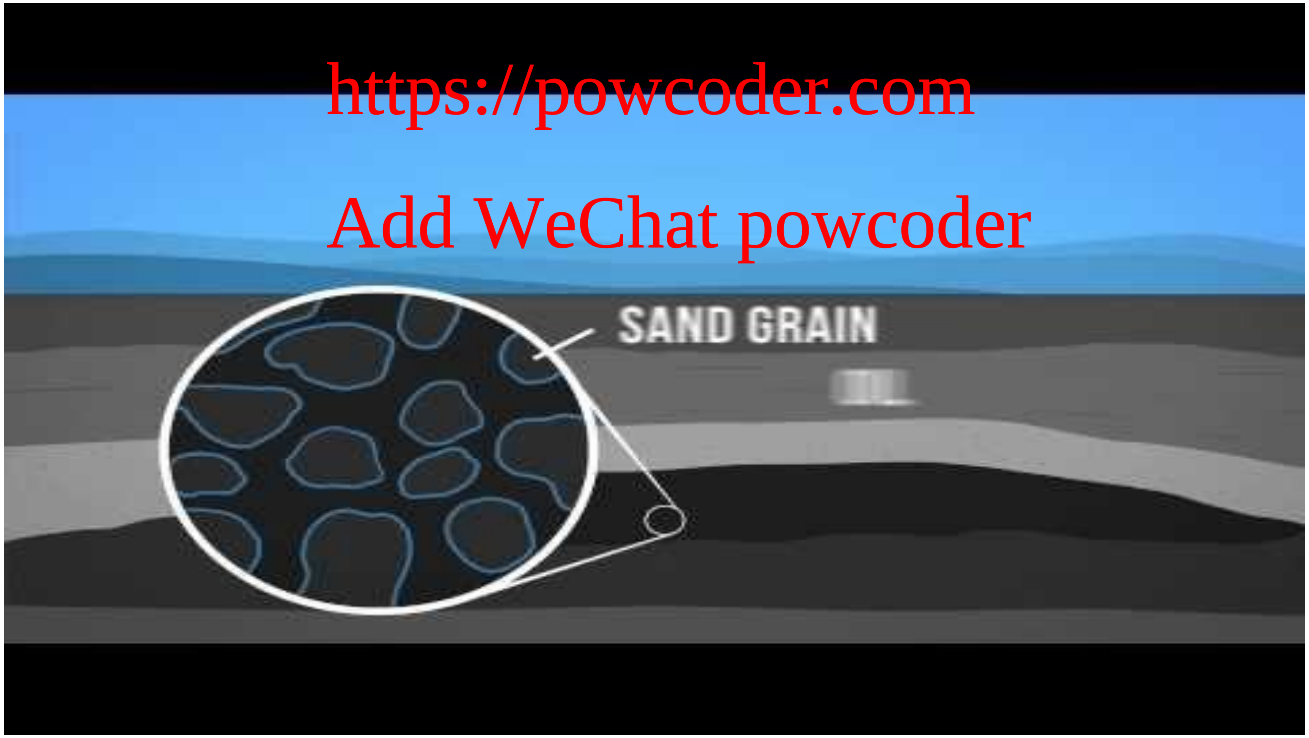
Crude oil, natural gas, coal, and biomass are raw material resources that together supply the bulk of the global energy needs, and also the production of key bulk chemicals required for further processing into end products. Although a lot of research into safe, reliable and cost-effective alternatives have intensified in the last two decades, these hydrocarbon raw material resources will continue to supply the majority of the world's energy at least for the next few decades.

Therefore, efficient and responsible use of these resources becomes a primary concern of engineers in particular.

Extraction of Crude Oil

After the exploration (lecture 5) and drilling (lecture 6) for oil and gas, the process of crude oil extraction begins. Crude oil is extracted from the reservoir (either on-shore or offshore) and then pumped to a refinery for processing into useful bulk chemicals.

A summary of the extraction process for crude oil can be found here (2:17 mins):

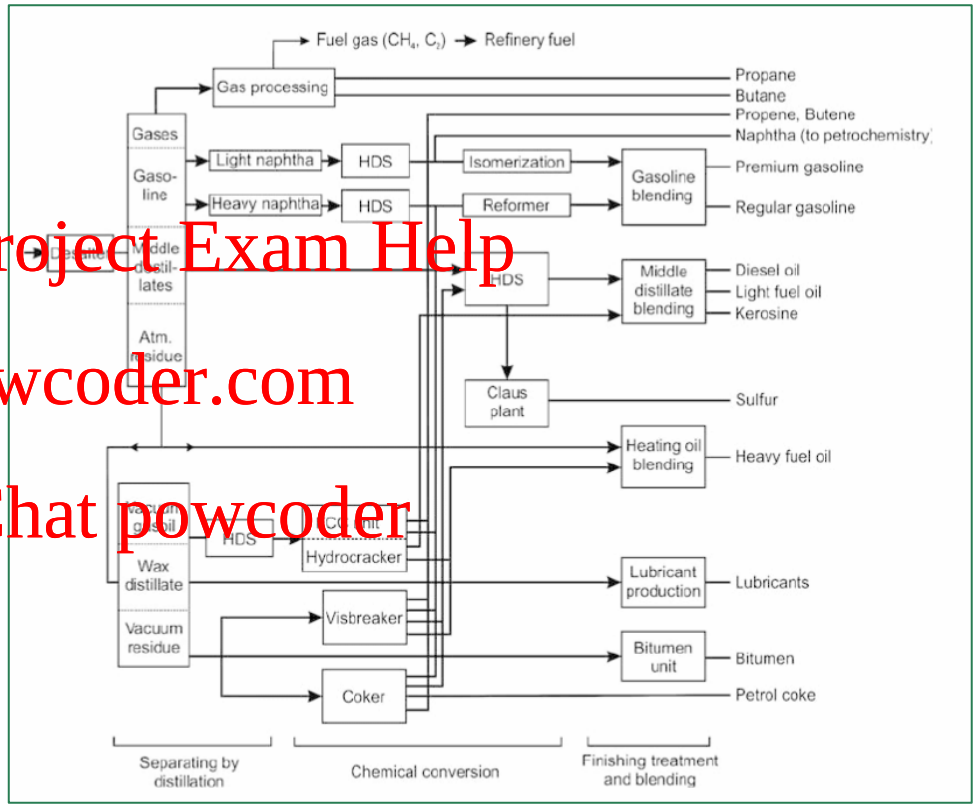


https://www.youtube.com/watch?v=UPAqfTNiais

Crude Oil Processing: Refinery

After the extraction of crude oil from the reservoir (either on-shore or offshore) it is refined in a petroleum refinery into useful bulk chemicals and end products, such as petrol (known as gasoline in some parts of the world), diesel fuel, kerosene, asphalt etc. A quick overview of a petroleum refinery is shown below (4:21 mins):

https://www.youtube.com/watch?v=GYRwWyG3Qqw



Simplified flowsheet of a crude oil refinery (from *Chemical Technology: An Integral textbook*, chapter 5)

- Why does crude oil need refining?
- Which of the refinery products in the flowsheet above are ***bulk materials*** (chemicals) and which are ***end products***?

Crude Oil Processing: Refinery

https://www.youtube.com/watch?v=GYRwWyG3Qqw

- Why does crude oil need refining?
- Which of the refinery products in the flowsheet above are *bulk materials* (chemicals) and which are *end products*?

Crude Oil Processing

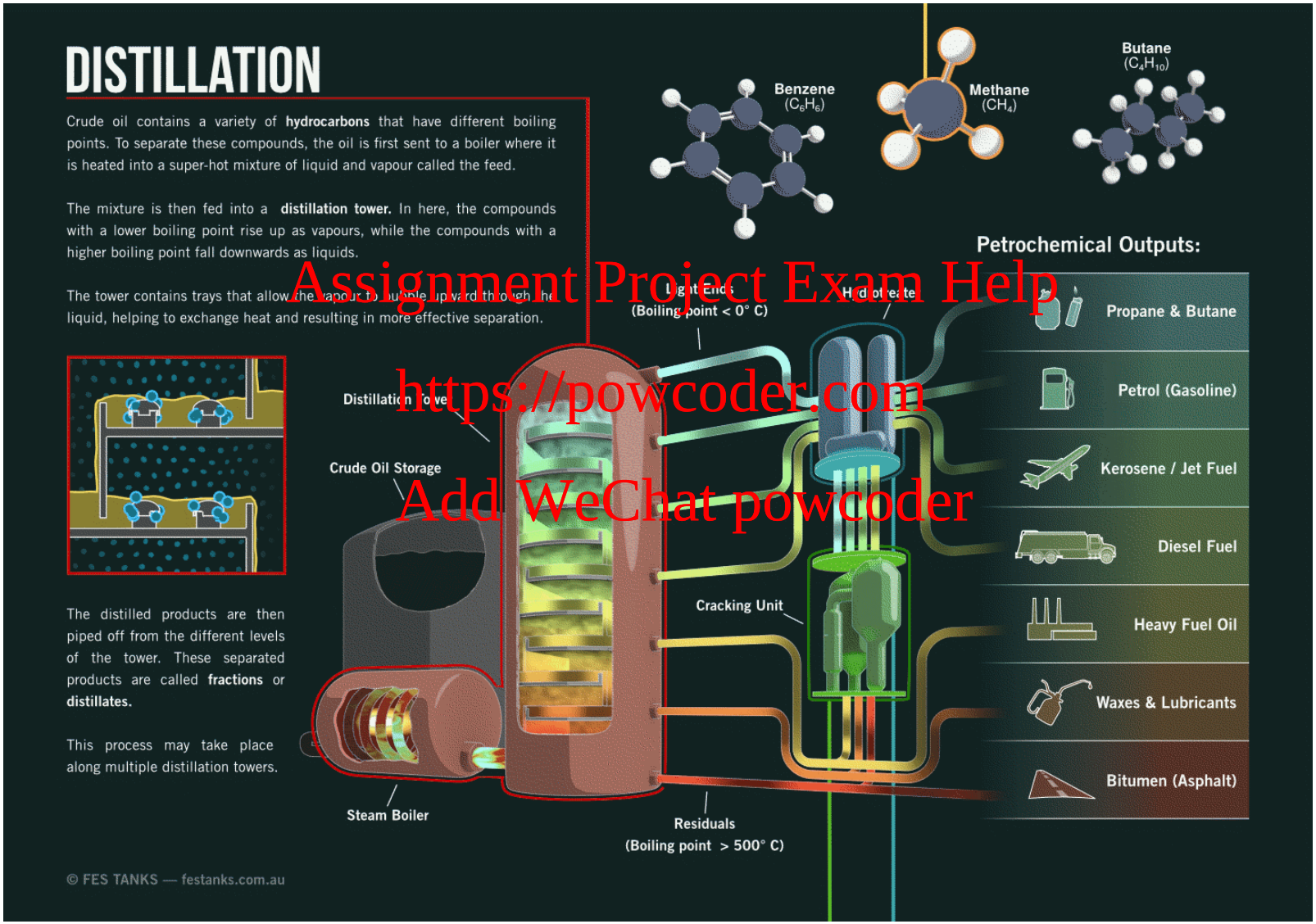
Key Unit Operations and Terminology

Cracking – the process by which heavy hydrocarbon molecules are broken up into lighter molecules, using heat. Sometimes the use of higher pressures and catalysts are necessary.

Sweetening – the process by which CO_2 and H_2S are removed from **sour gas**. The most common sweetening processes use amines to absorb CO_2 and/or H_2S, although other processes are also available. MEA (monoethanolamine), DEA(diethanolamine), DGA (diglycolamone) and MDEA methyldiethanolamine) are the most commonly used amines for gas sweetening.

Reforming – the process of re-arranging the chemical structure of some hydrocarbons to form more useful products. For example, naphtha reforming into gasoline (petrol).

Crude Oil Processing: Distillation



https://www.festanks.com.au/crude-oil-refining-in-australia-infographic/

Crude Oil Processing: Distillation

Distillation is a separation process, to produce hydrocarbons of different fractions, on the basis of differences in their boiling points. Fractional distillation is the one of the first processes that crude oil undergoes in a petroleum refinery.

Lighter hydrocarbons are more volatile than heavier hydrocarbons, and therefore exit the top section of the distillation column.

Distillation fraction	Number of C atoms	Boiling point range (°C)	Example
Gases			
Napthas			
Kerosenes			
Gas Oils			
Lubricants			
Fuel Oil			
Asphalt			

Crude Oil Processing: Distillation

Example:

Propane, iso-octane and kerosene are all used as fuels in combustion.

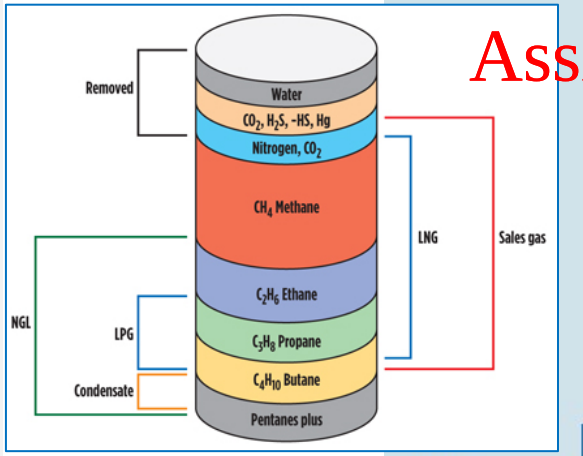
Write down the balanced equations for combustion of each product. What is the theoretical oxygen requirement for each fuel, per mole, and per g? The MWs of each fuel are 44 g/mol, 114 g/mol and 170 g/mol respectively.

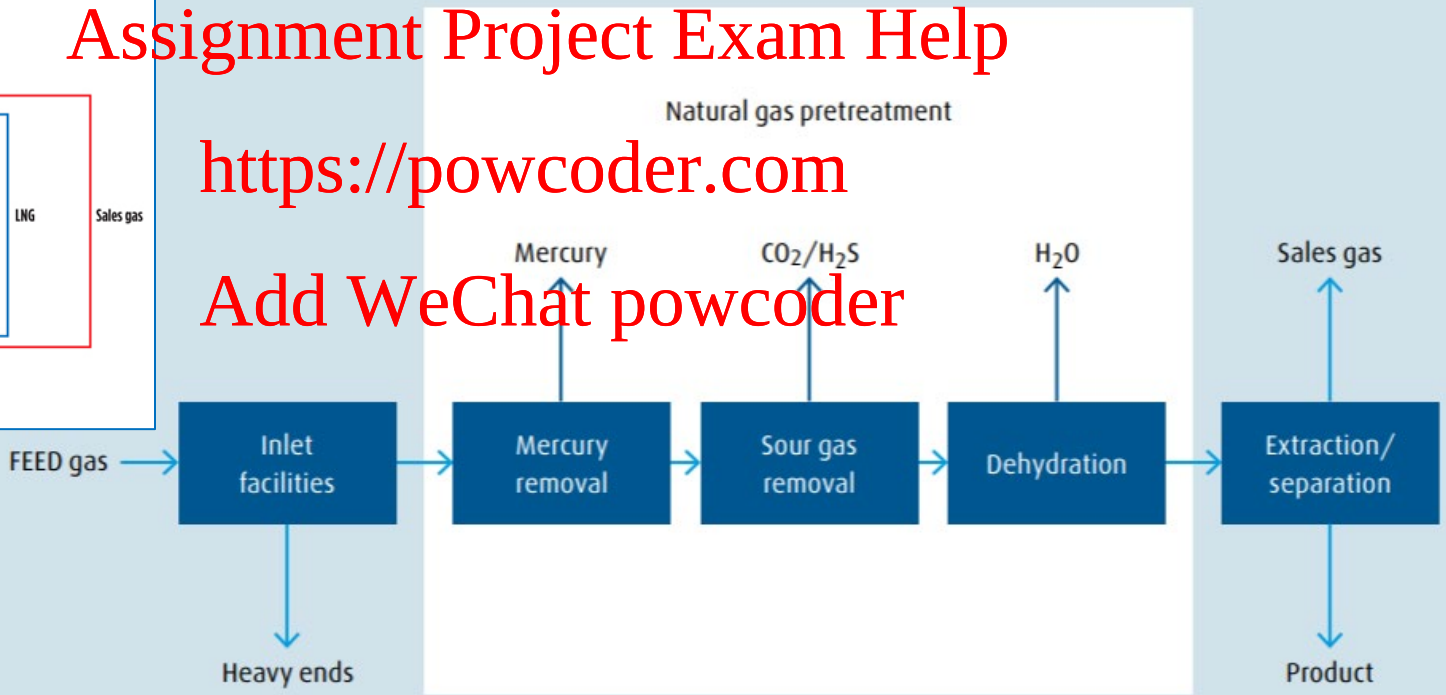
Learning Outcome Check

- After exploration for crude oil reservoirs, drilling is needed to extract crude oil as a raw material, and it is processed at a petroleum refinery. What is the purpose of a petroleum refinery, and what are the key products (list 6-8)?
- What property of the hydrocarbons in crude oil is used to separate them, using distillation?
- Order the products of distillation according to their boiling point and/or carbon atoms.
- Write a balanced equation for the complete combustion of a given hydrocarbon.

Natural Gas Processing

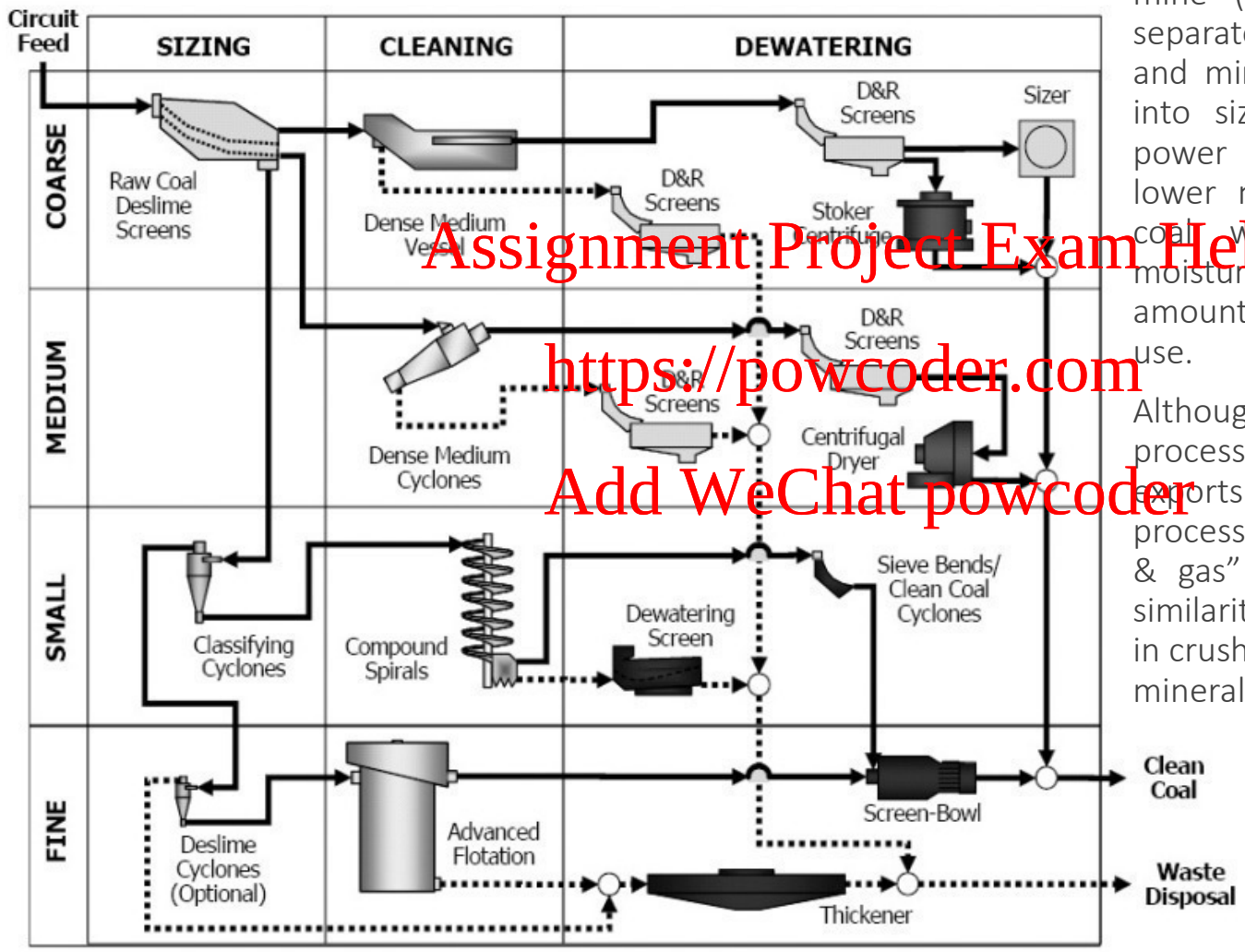
Although natural gas is the cleanest fossil fuel with the lowest CO_2 emissions, it still needs to be cleaned before use. This is a highly simplified block diagram to show the key processing steps in natural gas processing plants. Each block represents a mini-plant with multiple unit operations.





https://www.leamericas.com/en/images/Natural%20Gas%20Processing%20Plants_tcm136-4271.pdf

Coal Processing



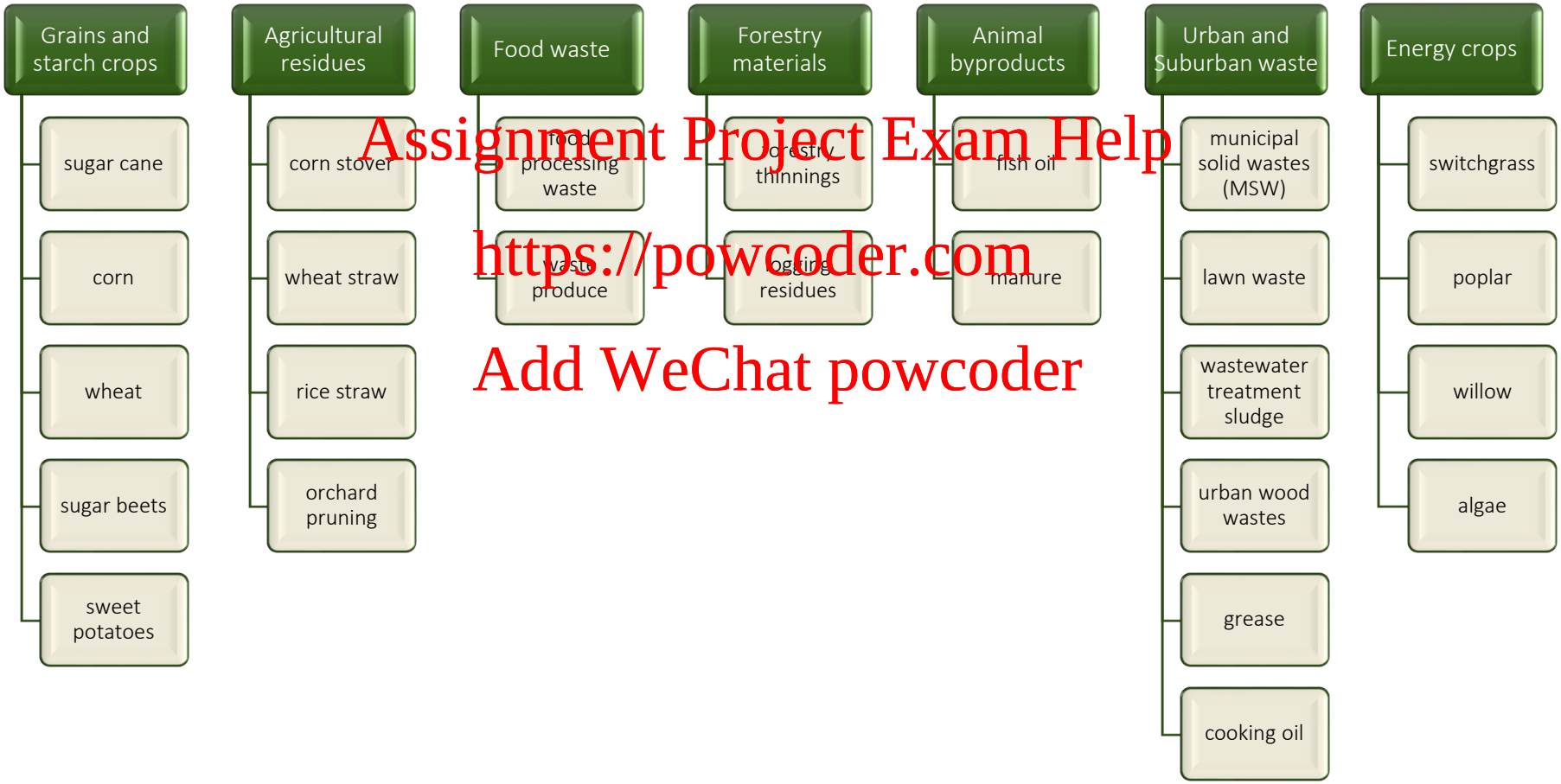
Raw, as-mined is also known as run-of-mine (ROM) coal. It needs to be separated from other contaminants and minerals and also crushed down into sizes appropriate for coal-fired power plants. Black coal has a much lower moisture content than brown coal, which can have up to 70% moisture and usually a significant amount of energy for drying before use.

Although coal is a hydrocarbon, the processing of coal and reporting of exports usually falls under the "mineral processing" industry instead of the "oil & gas" industry. This is due to the similarities between coal and minerals, in crushing and washing processes that minerals rocks undergo.

https://www.at-minerals.com/en/artikel/at_2009-12_Clean_coal_781038.html

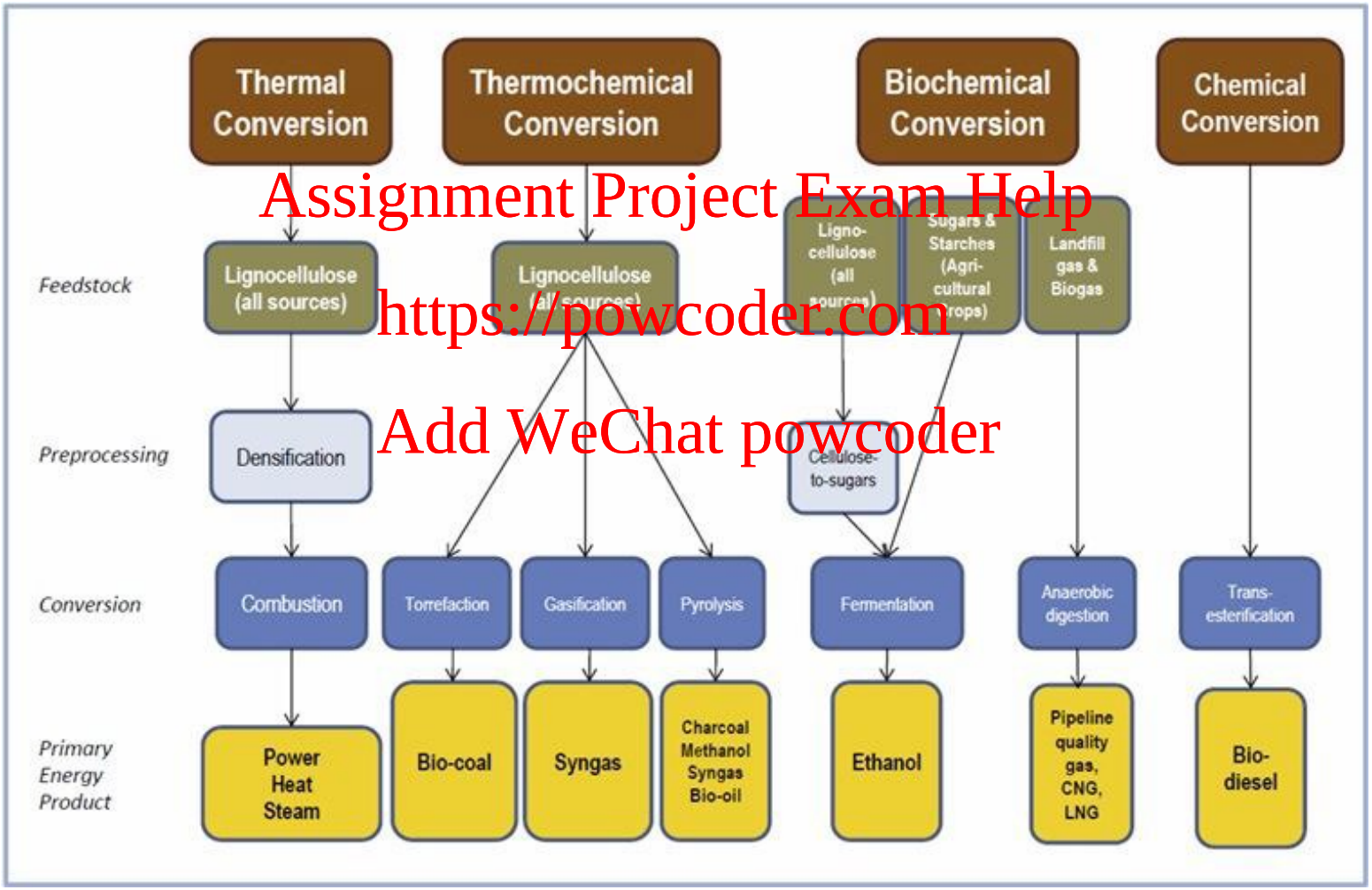
Biomass Processing

Biomass is not a single resource, but made up of a variety of feedstocks:



Biomass Processing

Biomass is mainly categorised as *woody* (lignocellulose) or *non-woody* biomass which have different processing needs for conversion into useful products, which are mainly fuels.



https://www.e-education.psu.edu/eme444/print/book/export/html/405

Case Study: Production of Electricity from Biomass

Biomass is a diverse resource, and can be used in several ways to produce electricity, heat and fuel. Woody biomass, high in lignocellulose, can also be used in different ways to generate electricity:

- Combustion – reaction with stoichiometric or excess oxygen
- Gasification – reaction with either limited oxygen, or steam

Direct fired combustion is the most common method of producing electricity, in biomass-powered plants. The biomass is burned directly to produce high-pressure steam, which drives a turbine generator to make electricity. Sometimes, the extracted steam is also used for manufacturing or for heating buildings.

https://www.youtube.com/watch?v=40ztd8uoU9Q

Case Study: Production of Electricity from Biomass

https://www.youtube.com/watch?v=40ztd8uoU9Q

Case Study: Production of Electricity from Hydrocarbon Fuels

Block A represents a clockwise thermodynamic cycle. The fluid is normally water, and this cycle is then known as the Rankine cycle.

The process of taking in heat to produce electricity, as depicted, is known as the **heat engine.**

Fuel	Heating value (MJ/kg)
Liquefied petroleum gas (LPG)	46-51
Hard black coal	25
Petrol/gasoline	44-46
Firewood (dry)	16

- What kind of fuel can be used to provide heat by combustion?

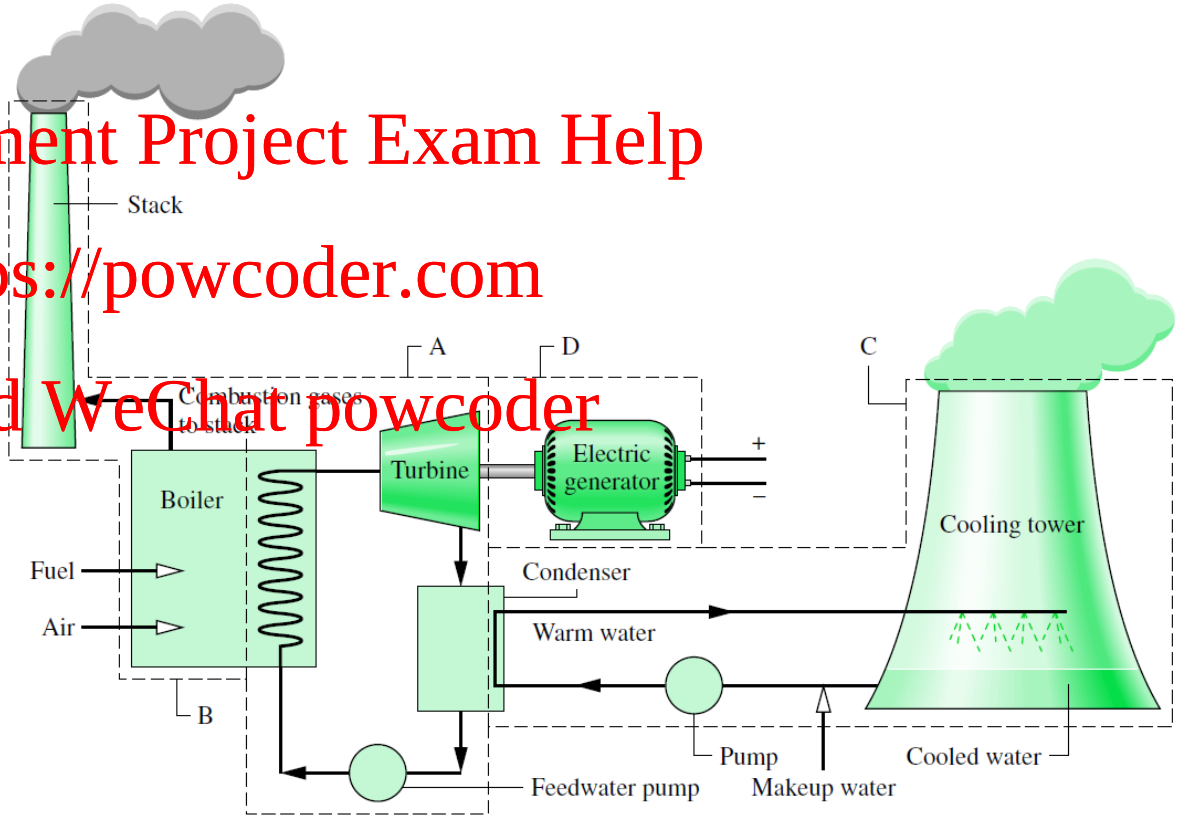


Figure: basic schematic of electricity production using hydrocarbon fuel combustion (from *Fundamentals of Engineering Thermodynamics* by Moran & Shapiro)

Learning Outcome Check

- What is the composition of the following: Raw natural gas, LNG, LPG, NGL, sales gas
- Why does raw natural gas need treatment, and what are these processes?
- What is "ROM coal", and what 3 types of processing does it need to obtain "clean coal" that is used as a fuel?
- What are the 7 broad categories of biomass? Give an example of each one.
- What are the 2 different types of components in any given biomass, and how does this impact its processing steps to produce a variety of fuels or energy?
- Hydrocarbons are used to generate electricity, usually by using the energy produced by combustion to produce high pressure steam that drives a turbine to generate electricity. What factors influence the suitability of a given hydrocarbon to produce electricity?

Energy Costs with Bulk Material Production

Looking at the Table below, some observations about different requirements for similar products can be made:

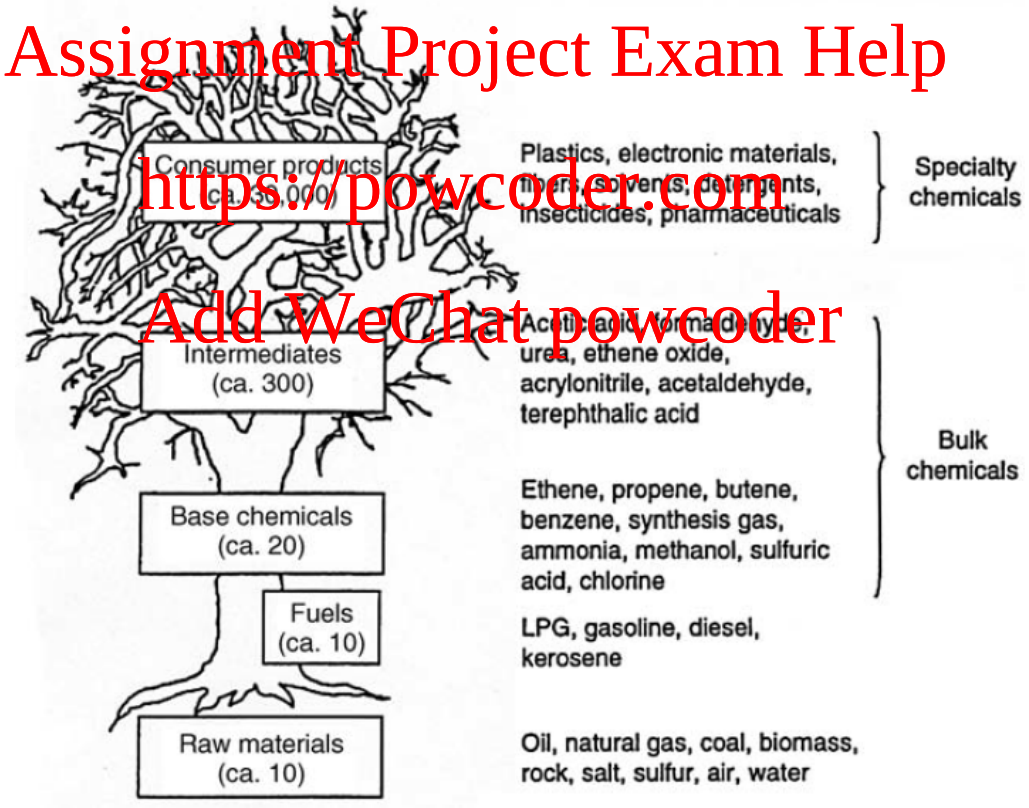
- Methanol from coal requires 1.5 times more steam/t than methanol from natural gas
- LDPE requires 4 times the electricity/t than HDPE
- Ammonia from coal needs 9 times the electricity/t than ammonia from either oil or natural gas

Table 5.5.4 Specific energy consumption (best practice performance) in primary energy terms for the production of key chemicals [primary energy was calculated assuming a steam production efficiency of 90% and power generation efficiency of 40% (IEA, 2009b)]. 1 toe (tonnes of oil equivalent) = 41.9 GJ. Current average energy requirements are about 20% higher than best practice. Negative values for steam indicate surplus of steam. This steam may be "exported" and used in other processes.

Chemical and process	Energy consumption in final energy terms (feedstocks not included)				
	Electricity (GJ t^{-1})	Fuel (GJ t^{-1})	Steam (GJ t^{-1})	Total	
				GJ t^{-1}	toe t^{-1}
Naphtha (refining of crude oil)					0.05
Ethylene, propylene, butane, butadiene, benzene (steam cracking of naphtha)	0.7	13.1	−1.5	12.3	0.29
Benzene (aromatic extraction)	0.1		2.2	2.3	0.05
Ethylbenzene	0.2		3.6	3.8	0.09
Ethylene oxide	2			4.5	0.11
Methanol from natural gas			9.4	9.4	0.22
Methanol from coal			16.1	16.1	0.38
Phenol	1.5		10.1	11.6	0.28
Phthalic anhydride	1.8	20		21.8	0.52
Propylene oxide	2.1		15.8	17.9	0.43
Polyethylene, high density (HDPE)	2.2		1.1	3.3	0.08
Polyethylene, low density (LDPE)	8.8		−2.4	6.4	0.15
Poly(ethylene terephthalate) (PET)	1.8	4.1		5.9	0.14
Polypropylene (PP)	2.2		0.1	2.3	0.05
Poly(vinyl chloride) (PVC)	1.6	0.5	1.4	3.5	0.08
Synthetic rubber	8.8		22.1	30.9	0.74
Ammonia from natural gas	0.7	10.9	−4.3	7.3	0.17
Ammonia from coal	9.3	17.3	−1.4	25.2	0.60
Ammonia from oil	0.7	16.1	−1.7	15.1	0.36
Oxygen	1.6			1.6	0.04
Chlorine (membrane process)	25		2.1	27.1	0.65

Case Study: Production of Ethylene from Crude Oil

Ethylene is one of the 20 or so bulk chemicals that are produced from raw material such as crude oil, biomass, natural gas and coal. It is produced through a variety of routes, mainly through steam-cracking processes of higher chain hydrocarbons and also catalytic dehydrogenation of ethane. Approximately 180 million metric tonnes will be produced this year, globally.



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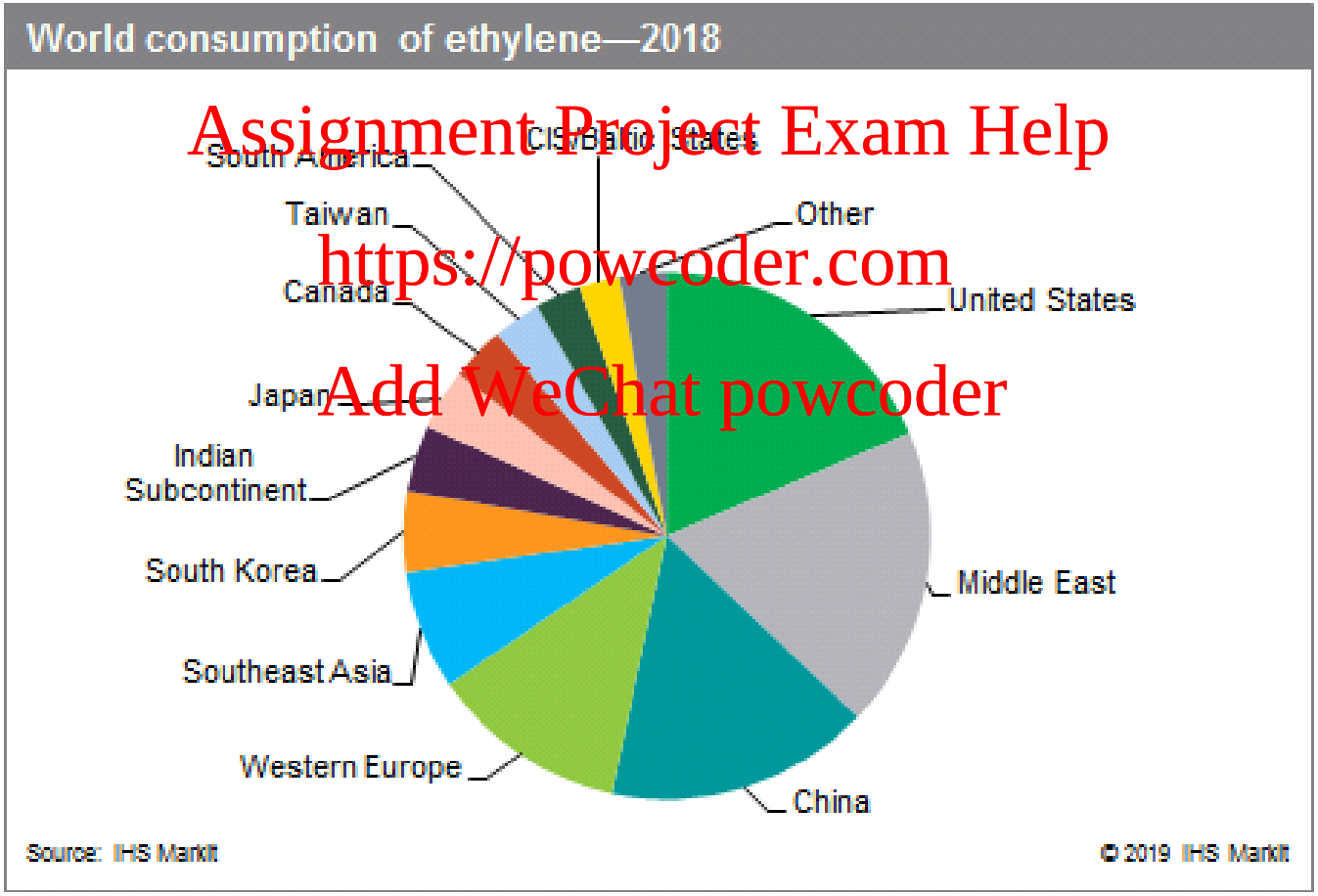
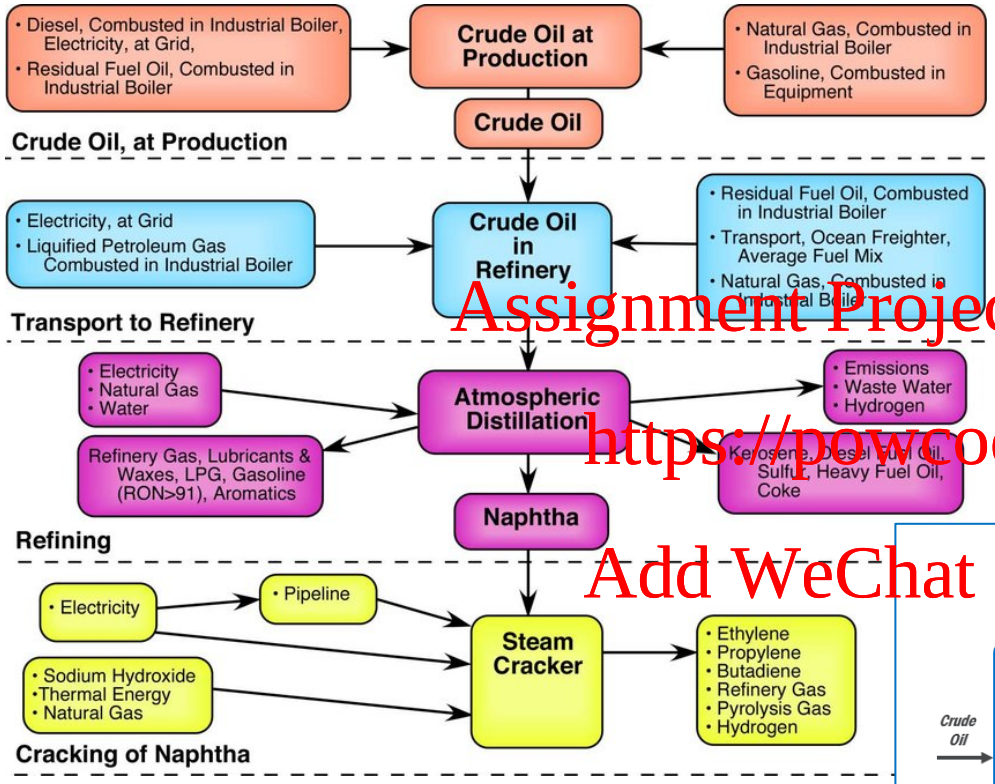
Case Study: Production of Ethylene from Crude Oil

Ethylene is a key bulk chemical that forms the base for production of several other chemicals such as polyethylene, polyester, PVC and others.

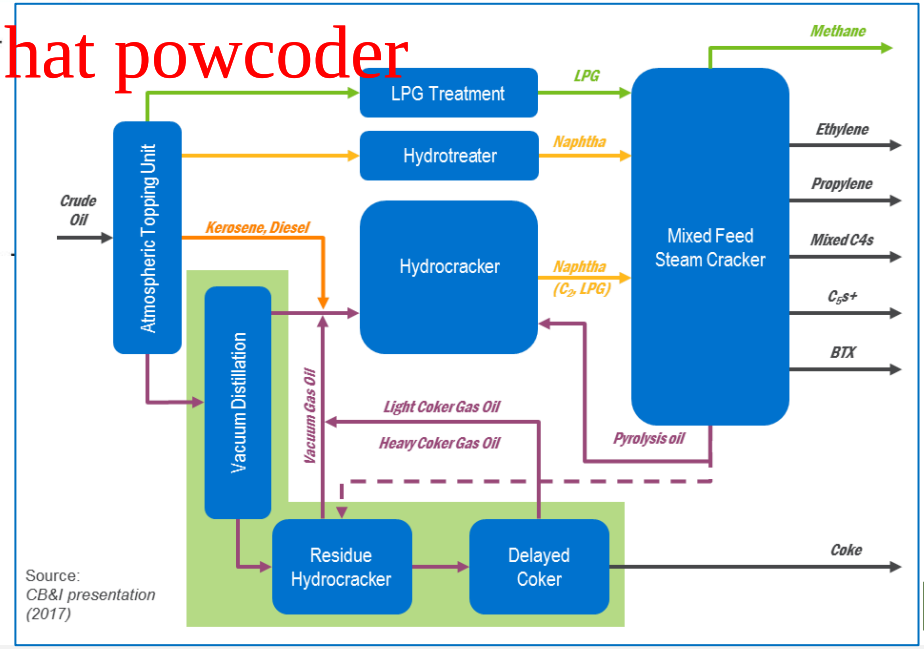


Case Study: Production of Ethylene from Crude Oil



Ethylene is primarily produced by the steam cracking of natural gas processing products or crude oil fractions (see schematic on left).

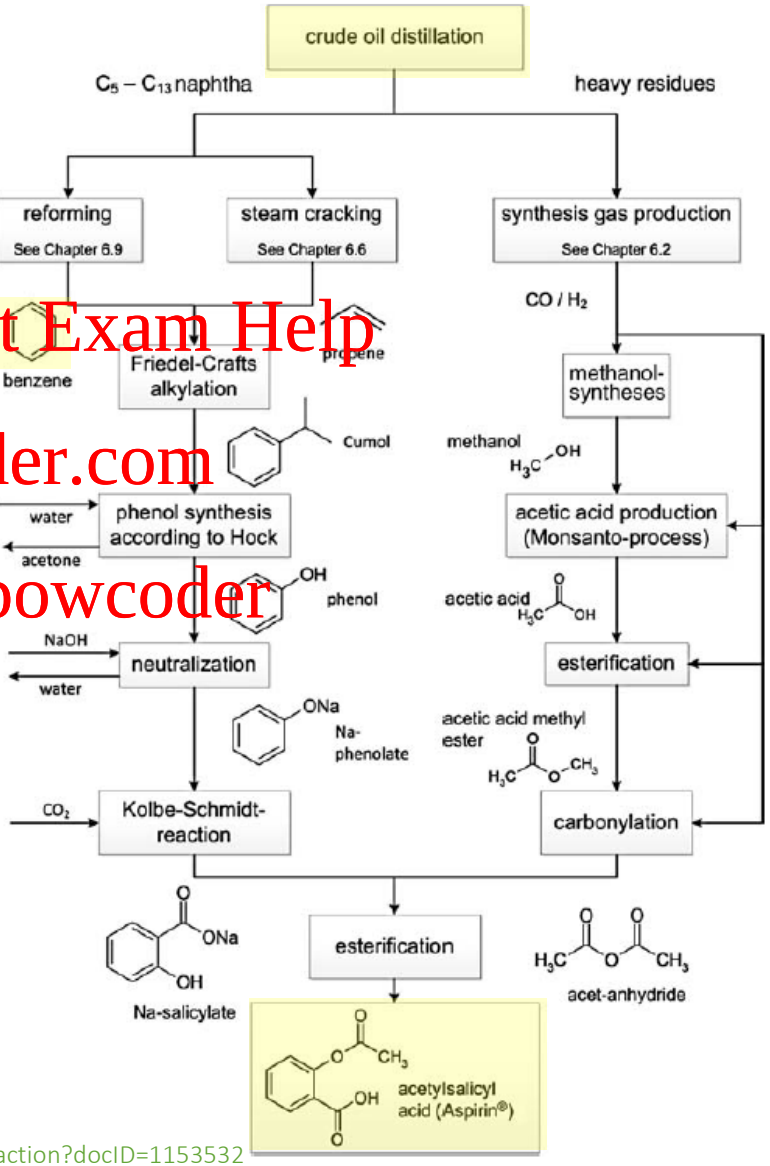
In 2014, Exxon Mobil commissioned a world-scale facility in Singapore—the first of its kind—that produces 1 million tonnes per annum of ethylene directly from crude oil, thus skipping the refining step (see schematic below).



Case Study: Production of Pharmaceuticals

Aspirin is a common pharmaceutical drug (end product) formulated from crude oil (raw material) via benzene (bulk material). It is on the WHO's list of Essential Drugs, and it is estimated that the global demand is about 40,000 tonnes each year. The active ingredient in Aspirin is acetyl salicylic acid, which is formed by esterification of Na-salicylate and acetic anhydride.

- What are the material residues, and energy costs involved in each step of the process?
- What other pathways are available to meet the global demand, and what are the material and energy costs in the alternatives?



https://ebookcentral.proquest.com/lib/curtin/reader.action?docID=1153532

Case Study: Production of Pharmaceuticals

https://www.youtube.com/watch?v=daGFjQPizK8

Learning Outcome Check

- What are “bulk” or “key” materials, as depicted in the lifecycle of materials (see page 3)? List 10 examples of bulk/key materials.

- On page 22, the steam, fuel and electricity requirements for producing several bulk chemicals have been tabulated.
  - What factors cause these differences, for the same chemical from different raw materials?
  - How can we use this information to create a more sustainable future?

- Ethylene is an important Bulk Material used to produce several End Products. Describe 2 different routes to form ethylene from crude oil.

- Identify the Resources, Raw Material, Bulk Material(s) in the production of Aspirin

Lecture Summary

✓Hydrocarbon raw materials and identification of bulk materials

✓Hydrocarbon Processing

- production of electricity from hydrocarbons
- production of key bulk chemicals: ethylene
- production of speciality chemicals: Aspirin