# FUEL and COMBUSTION

# Certain facts about energy we should know

The energy consumption in India is the fourth biggest after China, USA and Russia

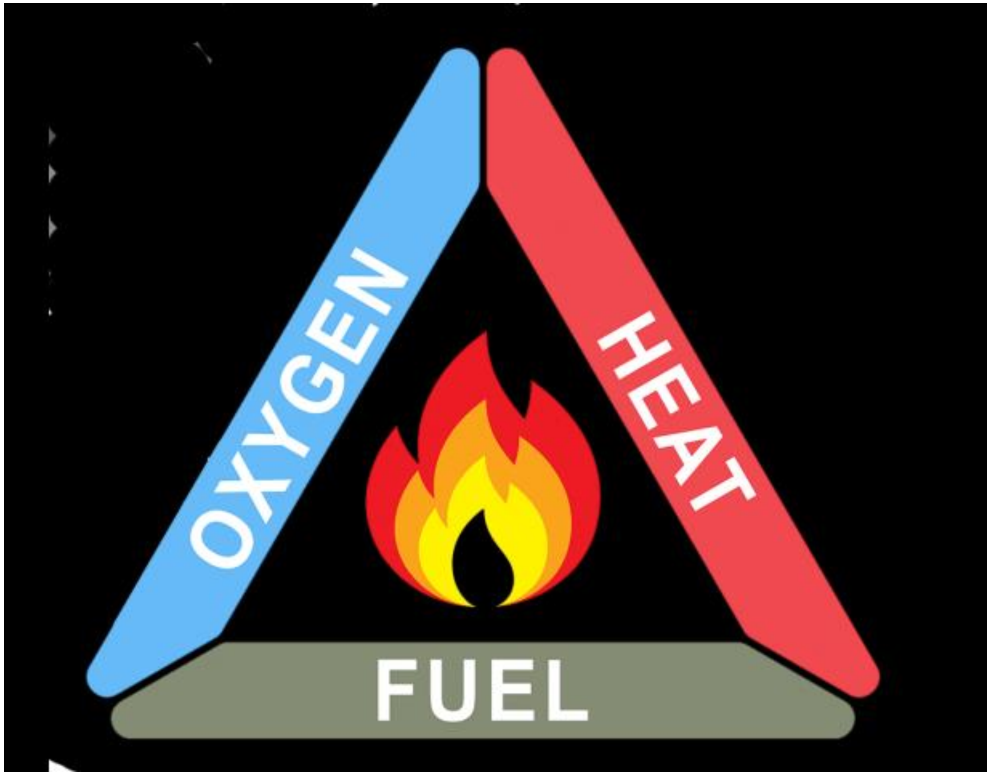
About 70% of India's electricity generation capacity is from fossil fuels

India is expected to account for 18% of the rise in global energy consumption by 2035.

To meet the energy demand, India has ambitious plans to expand
its renewable and most worked out nuclear power program.

India has the world's fifth largest wind power market

# Definition of FUEL




A fuel is a substance which on combustion gives heat energy to be utilized for various purposes.

# Classification of Fuels

**FUELS**

- Primary or NATURAL
  - Solid
    - wood
    - peat
    - lignite
  - Liquid
    - crude
    - petroleum
  - Gaseous
    - Natural
    - gas
- Secondary or DERIVED
  - Solid
    - Coke
    - Charcoal
    - briquette
    - coal
  - Liquid
    - Tar
    - Kerosene
    - Diesel
    - petrol
  - Gaseous
    - Coal gas
    - Watergas
    - Oil gas
    - Bio gas

# Characteristics of a good fuel

## Characteristics of Good Fuels:

- High Calorific Values
- Moderate Ignition Temperature
- Low Moisture Content
- Low Ash Content
- Moderate Velocity of Combustion
- Should not produce harmful products
- Low Cost
- Easy Storage & Transportation
- Easily Controllable

# Calorific Value

<u>Definition</u>

The total quantity of heat liberated when a unit mass of the fuel is burnt completely.

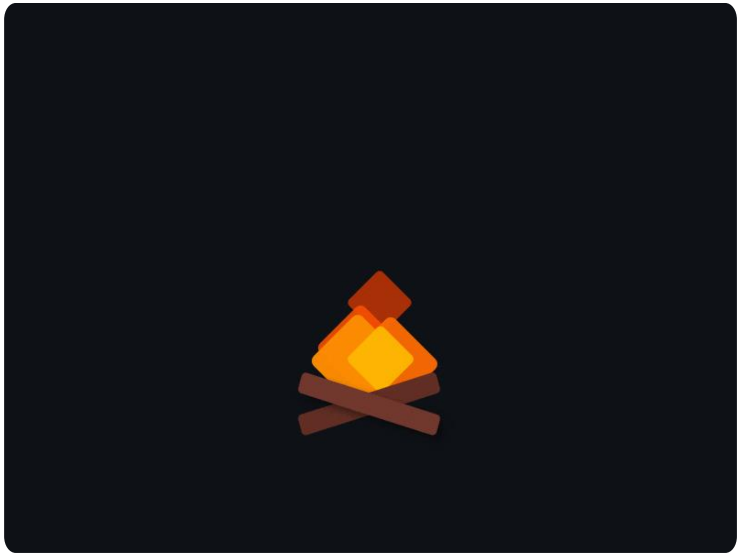
The calorific value is classified as---

(i) Higher or gross calorific value

(ii) Lower or net calorific value

# Gross Calorific Value (GCV or HCV)

The total amount of heat produced when a unit mass of fuel is burnt completely, and the products of combustion are cooled down to room temperature usually 60°F or 15°C.



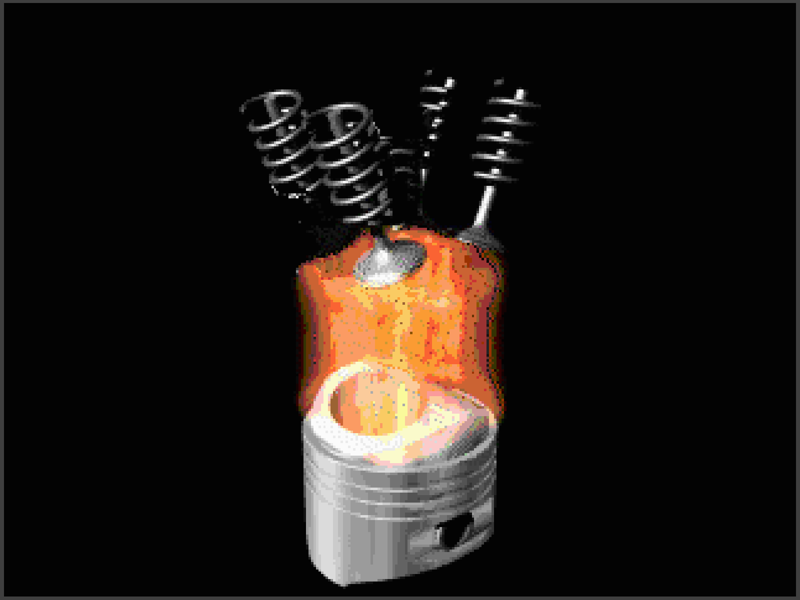
# GCV

**NET Calorific Value**

**Latent Heat of steam**


BOMB
of Calorific Value of

# Net calorific value (NCV or LCV )



The total amount of heat generated, when a unit mass of fuel is burnt completely, and the products of combustion are allowed to escape into the atmosphere.

# Net Calorific Value

- NCV = [GCV – latent heat of $H_2O$ vapor formed]
- [GCV– (wt. of H per unit wt. fuel × 9× latent heat of steam]
- NCV = GCV – 9 × H/100 × 587 kcal/kg

  (where, H = % of hydrogen in fuel)

$$\boxed{NCV = GCV - 0.09 \times H \times 587}$$

[*$2H_2 + O_2 \rightarrow 2H_2O$

4 g $H_2 \rightarrow$ 36 g of $H_2O$

1 g $H_2 \rightarrow$ 9 g $H_2O$]

# Dulong's Formula

- C = 8080 kcal/kg
- H = 34500 kcal/m3
- S = 2240 kcal/kg

**GCV= 1/100[ 8080 C + 34500(H-O/8) + 2240 S] kcal/kg**

# Dulong's Formula

$$GCV = 1/100[\,8080\,C + 34500(H - O/8) + 2240\,S]\ \text{kcal/kg}$$

$$NCV = GCV - 0.09 \times H \times 587\ \text{kcal/kg}$$

# Time to solve Problems

1. A coal has the following analysis, C=84%, S=1.5%, N=0.6%,H=5.5%,O=8.4%. Find GCV and NCV of this coal using Dulong's formula.
2. Calculate HCV and LCV for the coal having composition by ultimate analysis ; C=76%, H=7.5%, N=3%,S=4.5%, Ash=6.8%
3. Calculate the GCV and NCV of the fuel having composition; C=60%, O=16%, H= 18% and N= 6%
4. A coal has the following composition by weight, C=90%, O=3%,S=0.5% and NCV=8490.5 kcal/kg. Calculate the % of H and HCV.

# Practice Problems

1. A sample of coal has following composition; C=60 %, H=6%, N=0.3%,S=0.5%, Ash=0.2% and O=33%. Calculate HCV and NCV if latent heat of steam is 587 kcal/kg.

(Ans: GCV=5506.075 kcal/kg, NCV=5189.095 kcal/kg)

2. Calculate HCV and LCV by Dulong's formula if Anthracite coal has C=97%, H= 2.5%, S=0.5% and remaining is Oxygen.

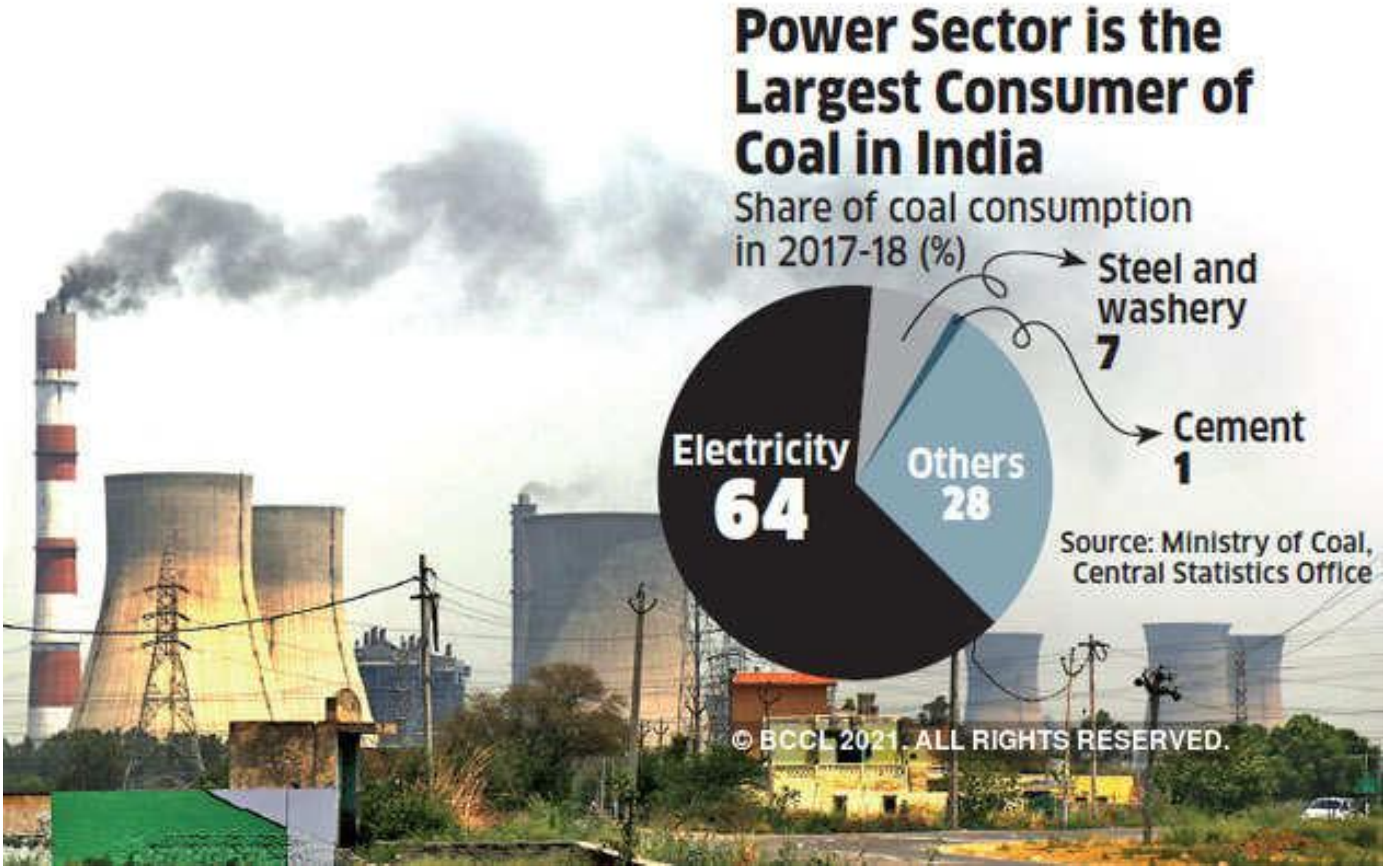
(Ans: GCV=8711.3 kcal/kg, NCV=8579.225 kcal/kg)

3. Calculate GCV and % of H if the coal has 80% C, 8% O and 5% S and NCV is 7984.02 kcal/kg.

(Ans:H=6%, GCV= 8301kcal/kg, )

# Coal

| Fuel | Moisture of air dried Sample at 40°C | C % | H % | N % | O % | Calorific value kcal / kg. |
|---|---|---|---|---|---|---|
| Wood | 25 | 50 | 6 | 0.5 | 43.5 | 4–4500 |
| Peat | 25 | 57 | 5.7 | 2 | 35.3 | 4125–5400 |
| Lignite | 20 | 67 | 5 | 1.5 | 26.5 | 65–7100 |
| Sub bitcoal | 11 | 77 | 5 | 1.8 | 16.2 | 7–7500 |
| Bit coal | 4 | 83 | 5 | 2 | 10 | 8–8500 |
| Semi–bitcoal | 1 | 90 | 4.5 | 1.5 | 4 | 8350–8500 |
| Anthracite | 1.5 | 93.3 | 3 | 0.7 | 3 | 8650–8700 |




**Source- The Economic Times**

**Sonaali Borkar**

# Analysis of Coal

## Proximate Analysis

## Ultimate Analysis

# Proximate Analysis

# Moisture content

% of Moisture Content

= loss in weight of coal*100/ weight of coal

# Volatile Matter

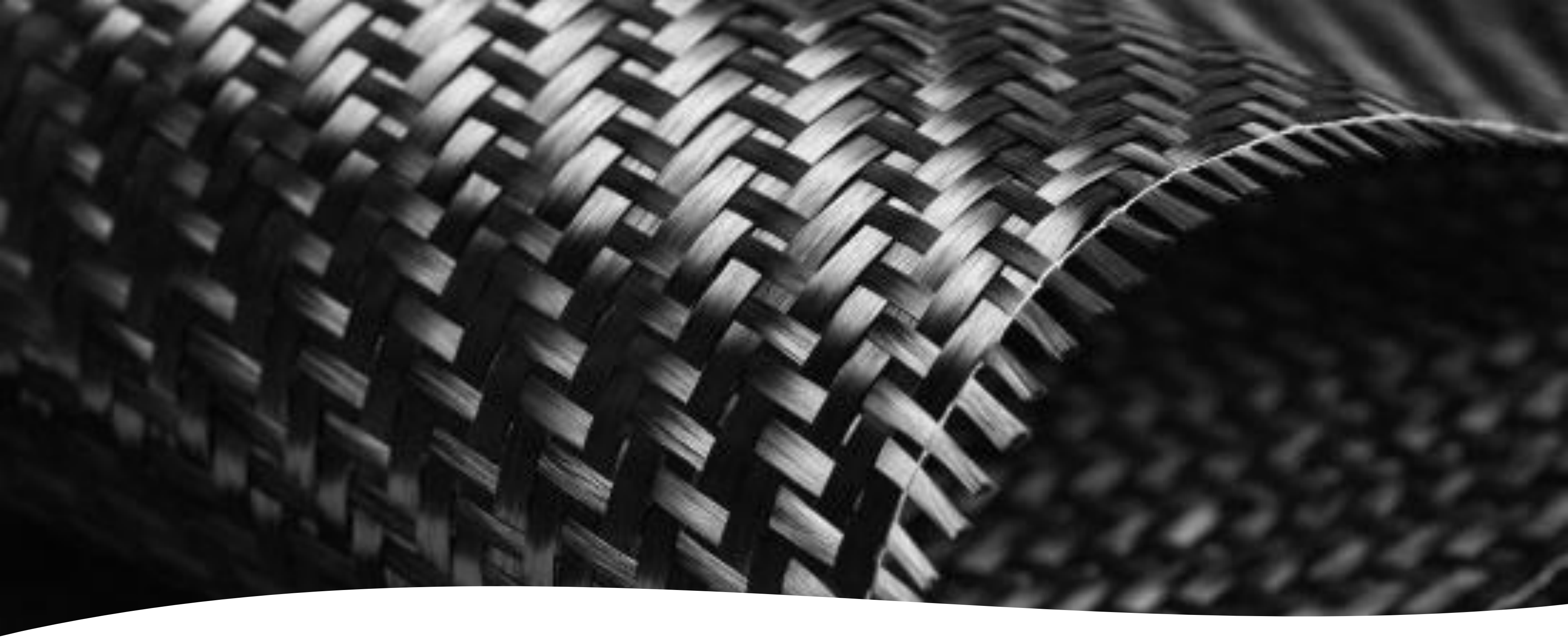
% of VM

= loss in weight of moisture free coal*100/ weight of coal

# Ash Content

% of Ash

= Weight of Residue*100/ Weight of coal



# Carbon Content

$$\% C = 100 - \% (\text{Moisture} + \text{Volatile Matter} + \text{Ash})$$

# Time to solve Problems

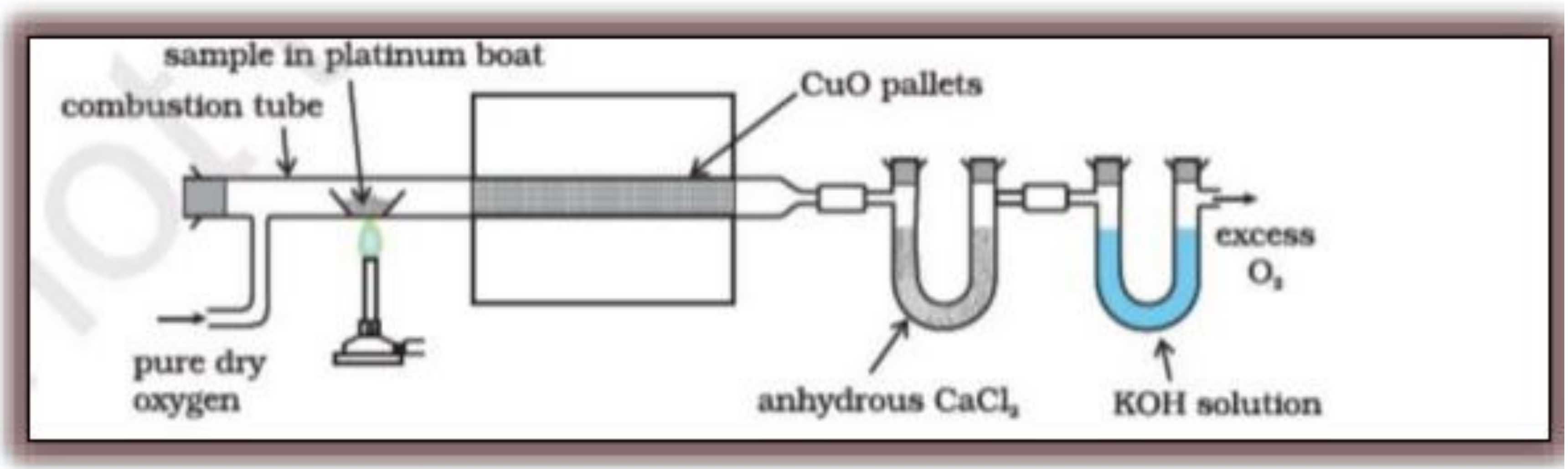
1. 2.9g of coal was heated in electric oven at 110 C. The weight of sample gets reduced to 2.75g. Further heating at 925 C for 7 min in muffle furnace with lid reduces the weight to 2.45g. After combustion at 750 c the residue obtained was 0.13g.Calculate %C in the coal.
2. In determination of proximate analysis, 3.6g of coal on heating for moisture got reduced to 3.4g. Further heating in muffle furnace for volatile matter reduces the weight to 3.2g. After complete combustion the residue obtained was 0.05g. Give the detailed analysis of coal.

# Ultimate Analysis

# Ultimate Analysis

- % of C
- % of H
- % of S
- % of N
- % of Ash
- % of O

# Determination of carbon & hydrogen



# Carbon and Hydrogen

1) % of C

= Increase in weight of KOH bulb*12*100/ weight of coal*44

2) % of H

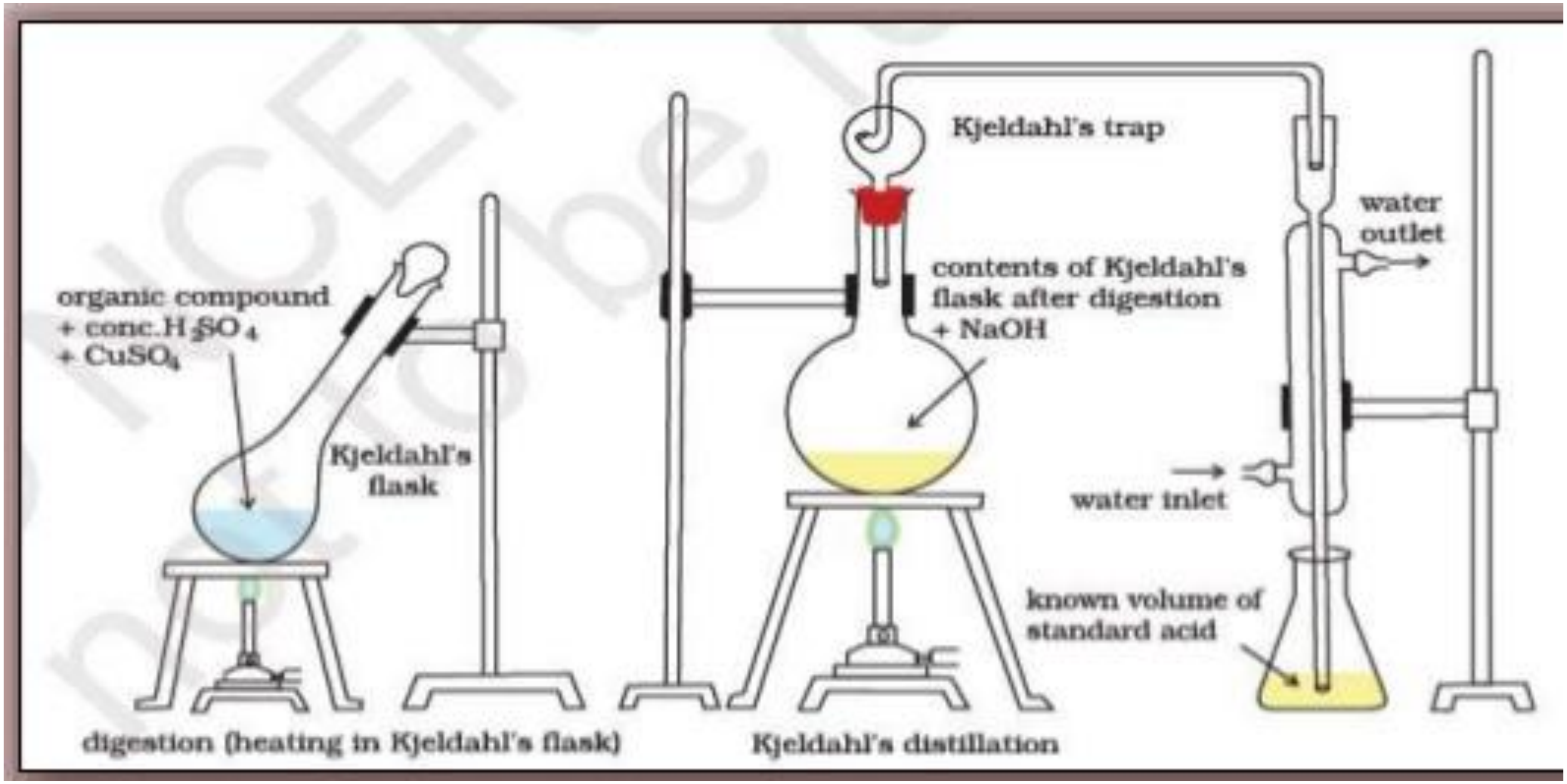
= Increase in the weight of $CaCl_2$ tube*2*100/ weight of coal*18

# Sulphur

% of S

= Weight of $BaSO_4$*32*100/ 233* weight of coal

# Estimation of N by Kjeldahl's Method



# Nitrogen

% of N

= Volume of $NH_3$* Normality of acid*1.4/ weight of coal

# Ash

% of Ash

= Weight of Residue*100/ Weight of coal

# Oxygen

$$\% O = 100 - \% (C + H + S + N + Ash)$$

# Time to solve problems

1. 0.2 gm of coal was burnt in a combustion apparatus and the products of combustion were absorbed in KOH bulb and CaCl2 tube which were previously weighed before the experiment. The increase in the weight of KOH bulb and CaCl2 tube were found to be 0.56 gm and 0.1 g respectively. Find %C and %H.
2. 0.8 g of sample of coal was used in bomb calorimeter. The residue in bomb was extracted and treated with acid and extract was treated with BaCl2 solution. The precipitate of BaSO4 was formed. The weight of ppt was 0.04 gm. Calculate % S.

# Time to solve problems

3. 0.7 gm of coal sample was used for N estimation by Kjeldahl's method. The ammonia evolved was collected in 50 ml of 0,02N HCl. 40 ml of 0.02N NaOH was required to neutralize the excess acid. Determine %N.

4. A coal sample on combustion gave following results.

i) 0.2 gm of coal sample on combustion gave 600 mg of $CO_2$ and 18 mg of $H_2O$.

ii) Kjeldal's estimation of 0.5 gm of coal gave reading as 2.3 ml $NH_3$ consumed of 0.02 N of Acid,

iii) For S estimation, 60 mg of $BaSO_4$ ppt was obtained from 0.6 gm of coal

iv) 1 gm of coal after combustion gave 0.005 gm of residue.

Calculate GCV and NCV of the above sample of coal

# Practice Problems

1. Find the ultimate analysis of a coal from following data.

I. 0.25 g of coal was burnt in combustion apparatus and gave increase in weights as 0.8 gm and 0.08 gm in KOH bulb and $CaCl_2$ Tube respectively.

II. Kjeldhal's estimation 1 gm of coal produced $NH_3$ which was passed into 50 ml of HCl and on titration with 0.15N NaOH it consumed 25.8 ml of NaOH.

III. Ash obtained was 0.3 gm after combustion.

IV. 2 g of coal on S estimation gave 0.5 g of $BaSO_4$ ppt.

( Ans: C= 87.27, H= 3.55%, N= 5.082%, S= 3.43%, O=0.368%)

# Practice Problems

2. A 3 gm of coal was heated in Kjeldahl's flask and $NH_3$ was absorbed in 40 ml of 0.5N $H_2SO_4$. Excess acid required 18.5 ml of 0.5 n KOH. Another 2.3 g of coal in quantitative analysis gave 0.35 g of $BaSO_4$. Calculate %N and %S.

(Ans : N= 5.016% and S= 2.089%)

3. 1.5 gm of coal was burnt in a combustion apparatus. The products were absorbed in KOH bulb and $CaCl_2$ tube, Increase in wt are found to be 3.92 gm and 1.25 gm respectively. Calculate %C and %H.

(Ans : C=71.27% and H=9.25%)

# Significance of Proximate and Ultimate Analysis

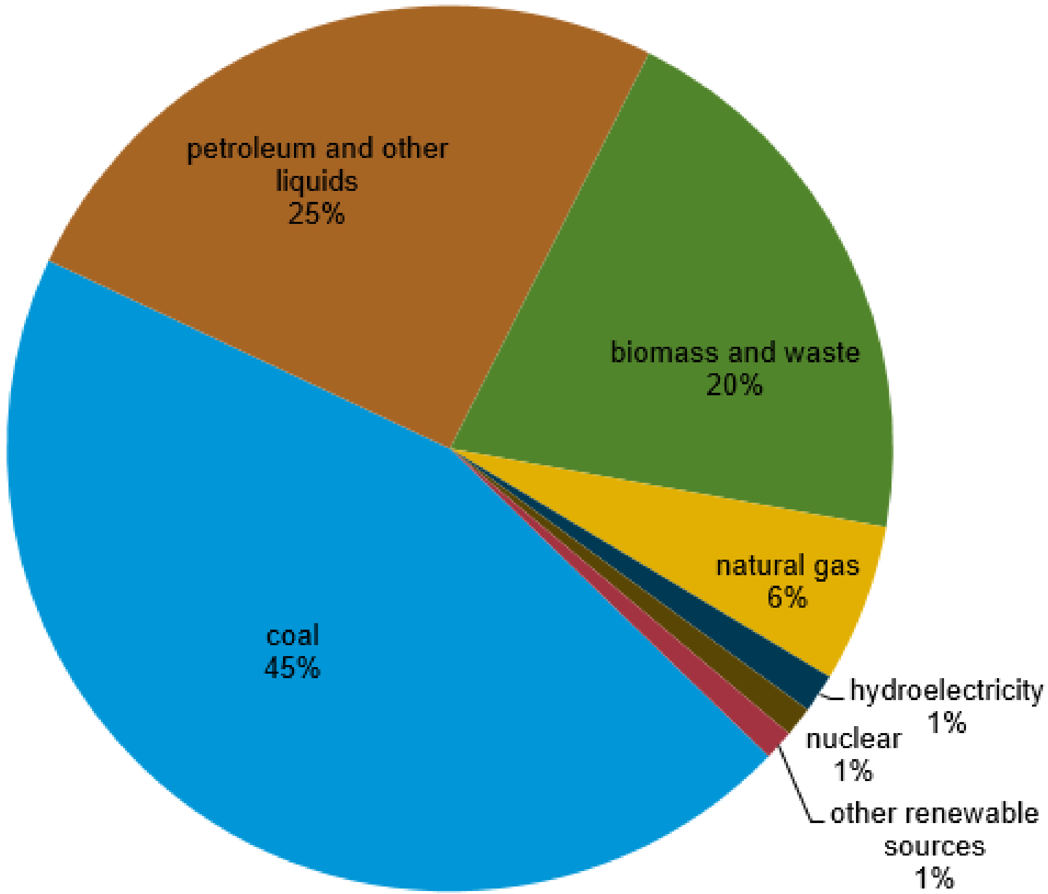
## Proximate

- Simple, cost effective
- Moisture, Volatile Matter and Ash should be less as they will add to weight, Increase cost and lowers calorific value.
- More the C, better as it increases the calorific value and decides the furnace design as C burns in solid state.

## Ultimate

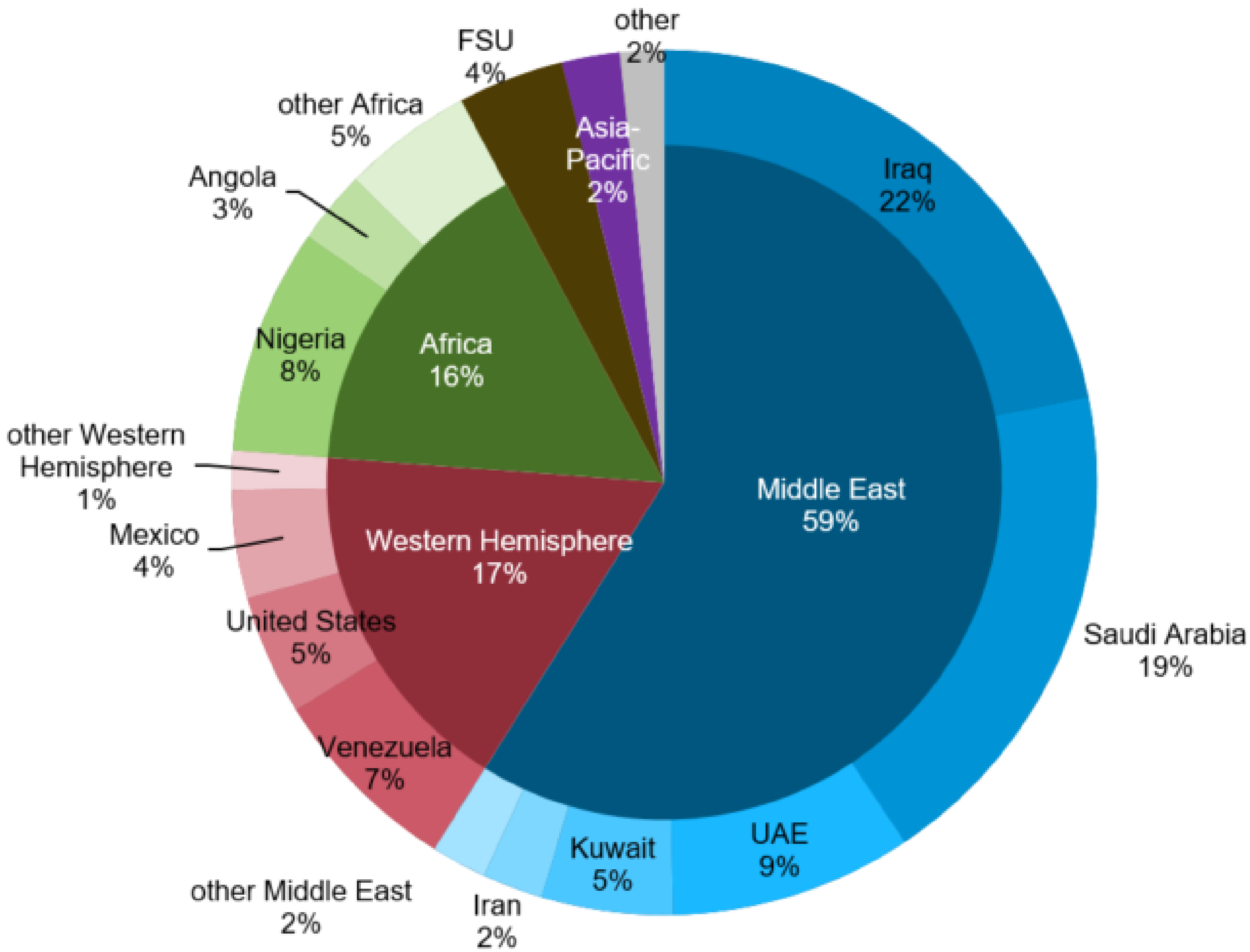
- Detailed, specific and costly.
- C and H should be more as they contribute to major calorific value.
- S and N are undesirable as they create pollution.
- Ash should be low or nil.
- O should be minimum as it contributes to moisture and brings down the calorific value.

Figure 1. India total primary energy consumption by fuel type, 2019

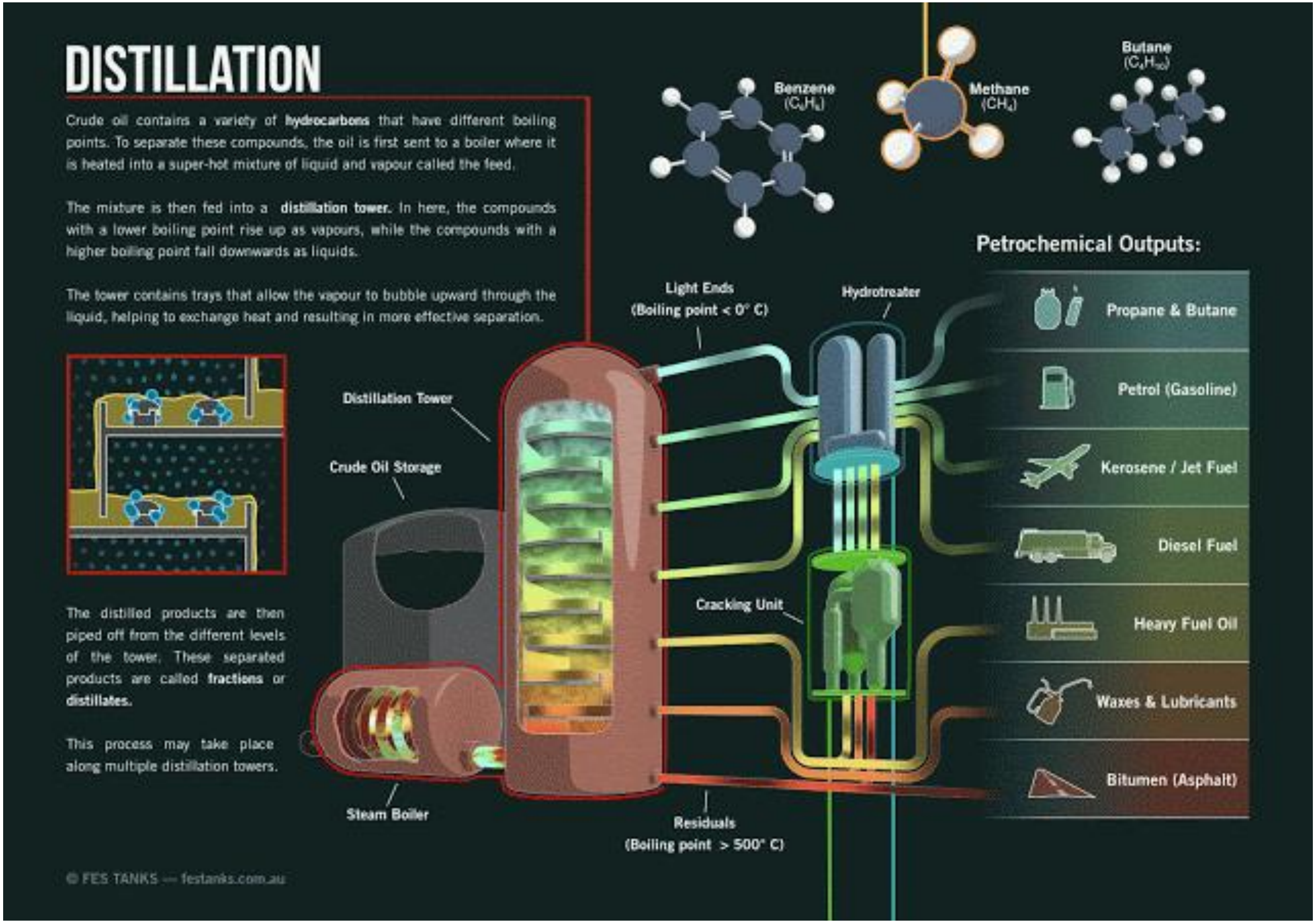



Source: International Energy Agency, World Energy Outlook 2019
Note: Total may not equal 100% because of independent rounding.

Figure 3. India's crude oil imports by source, 2019




Source: U.S. Energy Information Administration; ClipperData (accessed May 2020)
Note: Total may not equal 100% because of independent rounding.


DISTILLATION
Crude oil contains a variety of hydrocarbons that have different boiling points. To separate these compounds, the oil is first sent to a boiler where it is heated into a super-hot mixture of liquid and vapour called the feed.
The mixture is then fed into a distillation tower. In here, the compounds with a lower boiling point rise up as vapours, while the compounds with a higher boiling point fall downwards as liquids.
The tower contains trays that allow the vapour to bubble upward through the liquid, helping to exchange heat and resulting in more effective separation.
The distilled products are then piped off from the different levels of the tower. These separated products are called fractions or distillates.
This process may take place along multiple distillation towers.
Benzene ($C_6H_6$)
Methane ($CH_4$)
Butane ($C_4H_{10}$)
Petrochemical Outputs:
Propane & Butane
Petrol (Gasoline)
Kerosene / Jet Fuel
Diesel Fuel
Heavy Fuel Oil
Waxes & Lubricants
Bitumen (Asphalt)
Light Ends
(Boiling point < 0° C)
Hydrotreater
Distillation Tower
Crude Oil Storage
Cracking Unit
Steam Boiler
Residuals
(Boiling point > 500° C)
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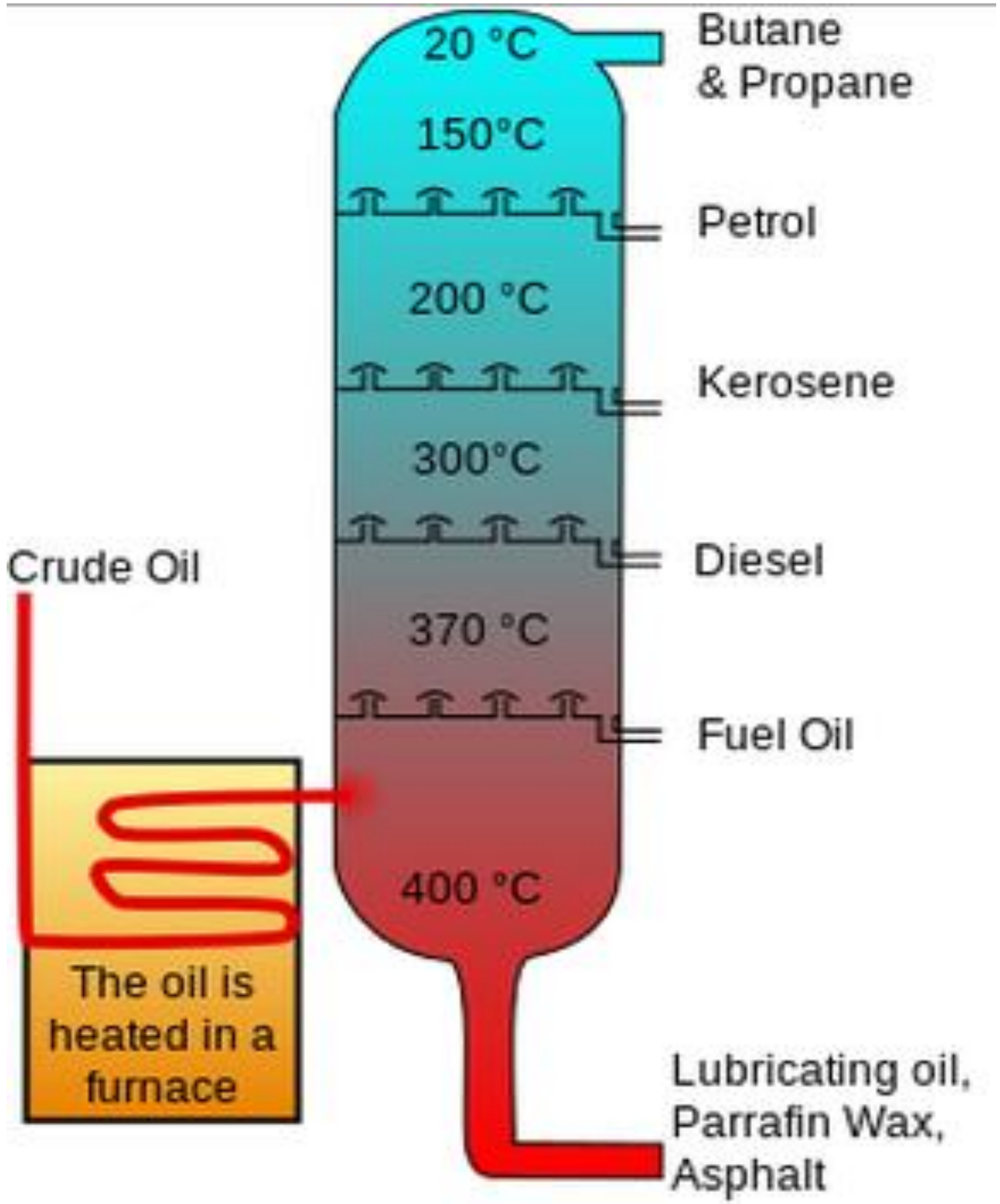
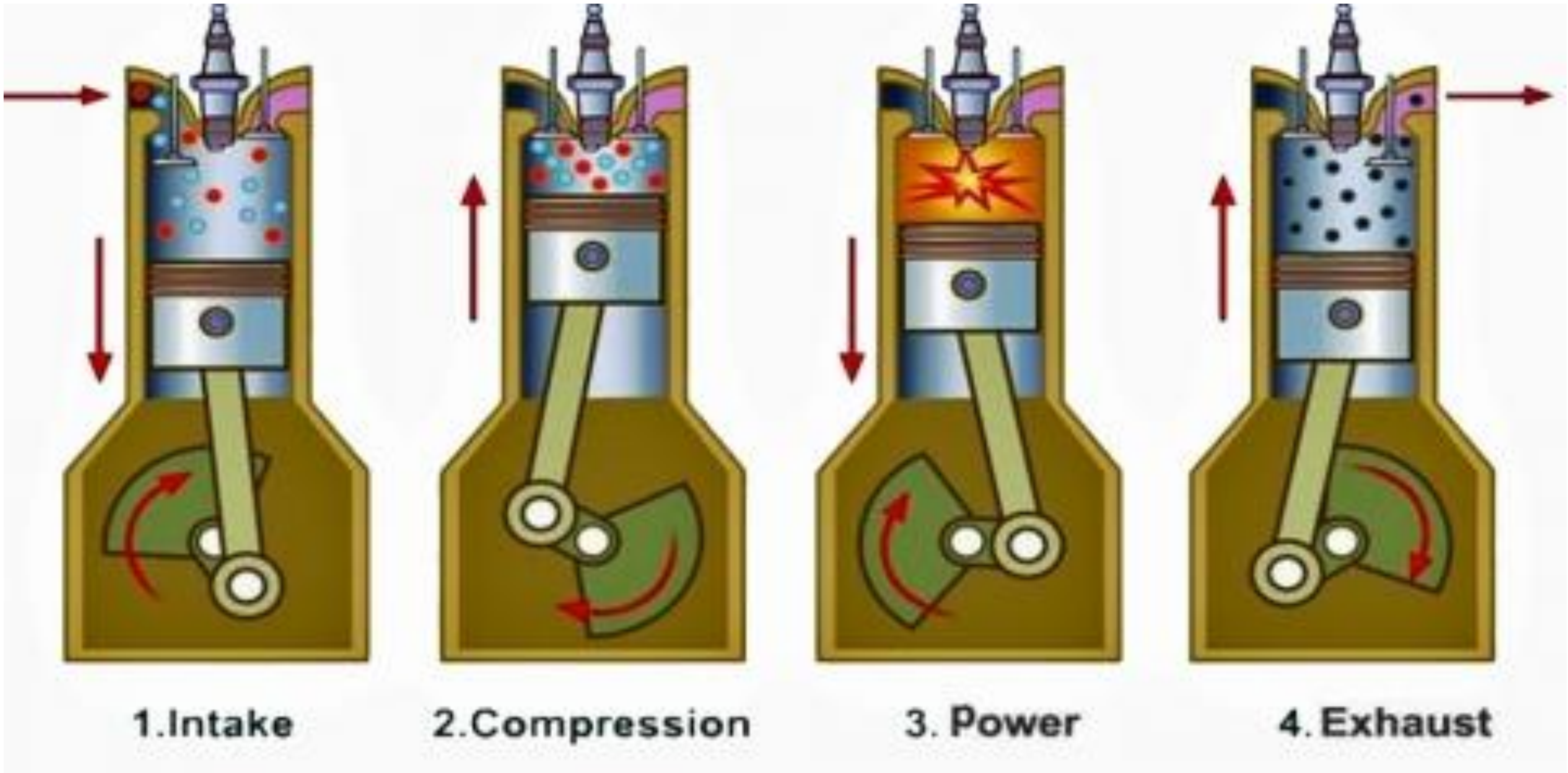
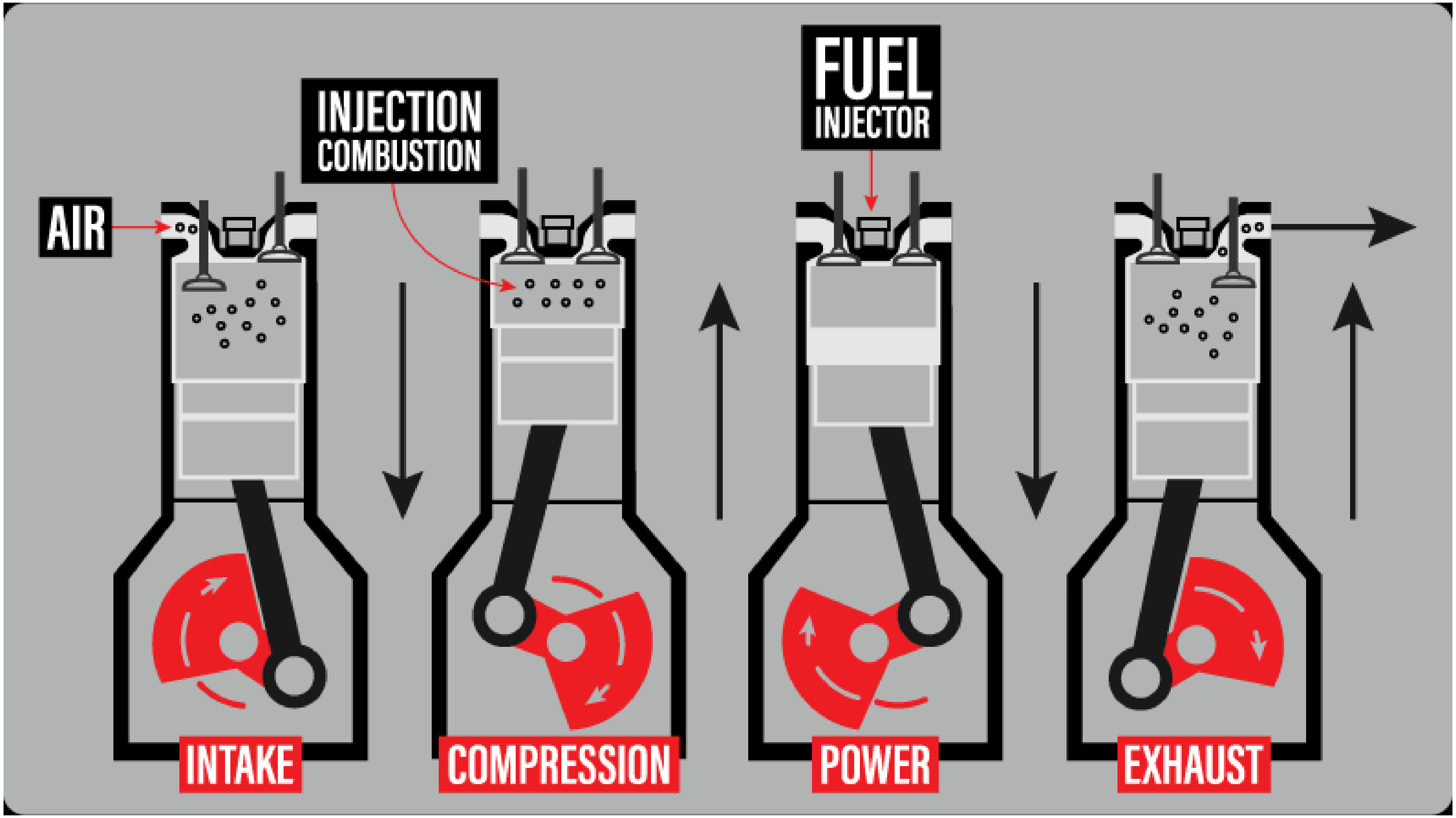

20 °C
Butane
& Propane
150°C
Petrol
200 °C
Kerosene
300°C
Diesel
Crude Oil
370 °C
Fuel Oil
400 °C
The oil is heated in a furnace
Lubricating oil,
Parrafin Wax,
Asphalt

# Spark ignition type

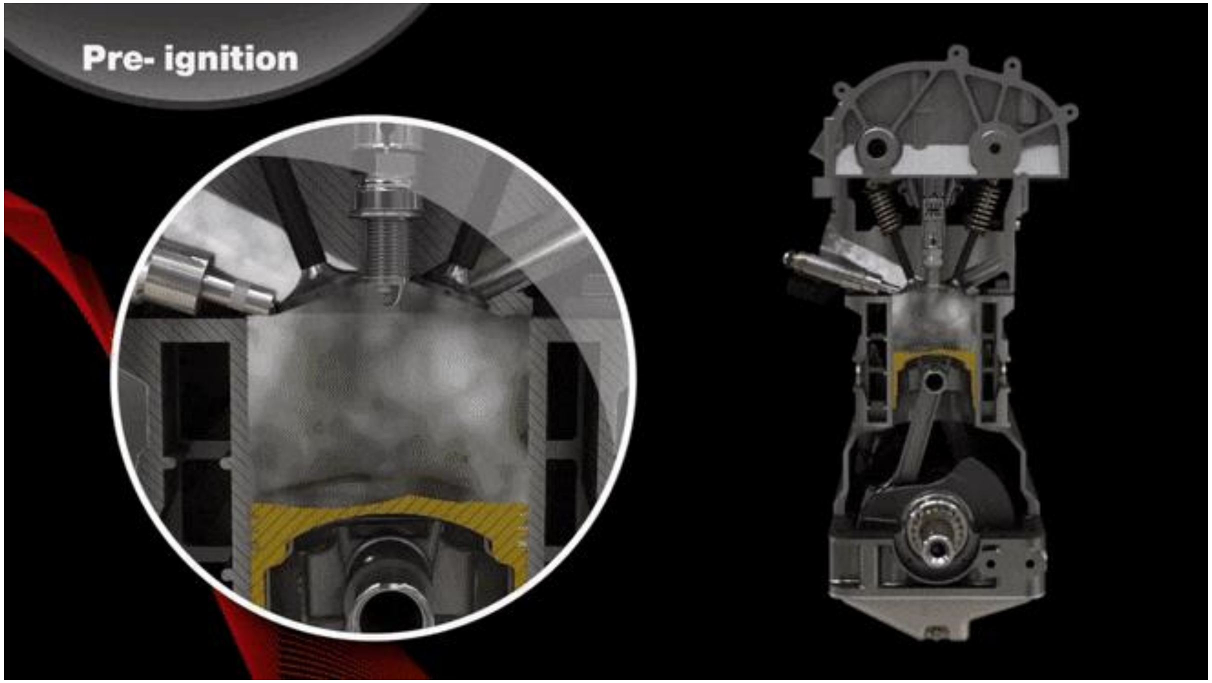


# Compression Ignition Engine



# Knocking

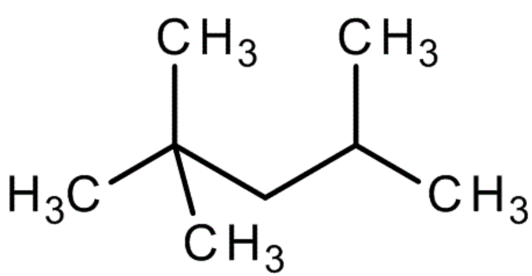
A sharp metallic sound produced in the internal combustion engine and results into a loss of energy.

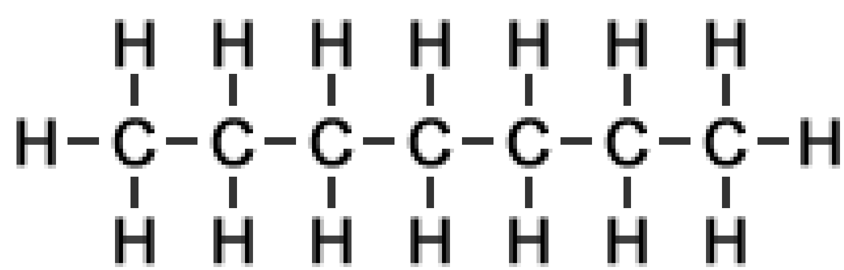


# Octane number

**Definition :**

Percentage by volume of iso–octane in a mixture of iso–octane and n–heptane which just matches the knocking characteristics of a fuel under test.

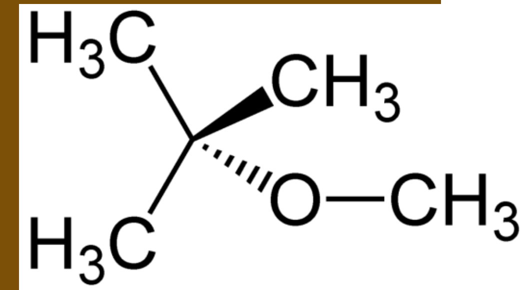




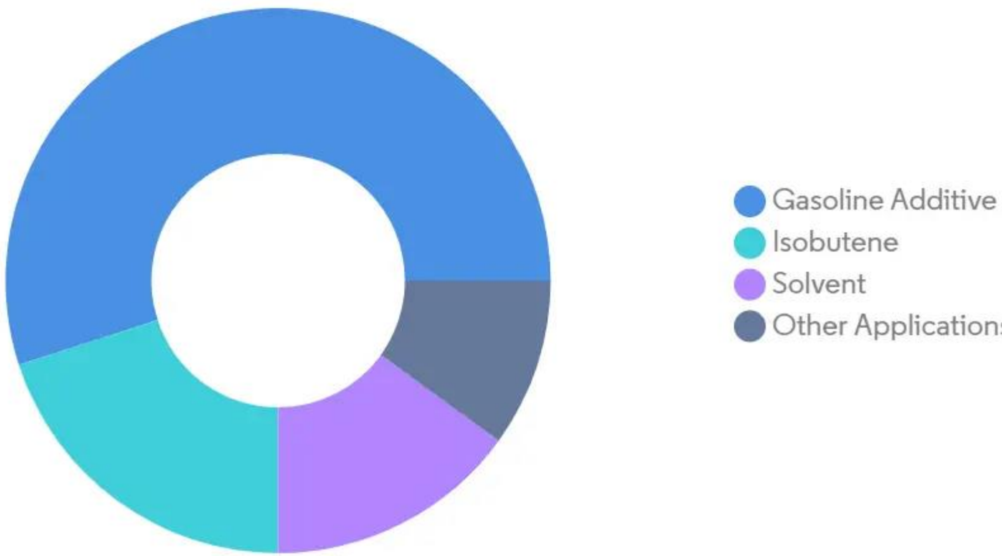
# Antiknocking Agents

- TEL and TML
- Toluene
- MTBE
- ETBE
- Iron carbonyl

# MTBE
# (Methyl Tertiary Butyl Ether)



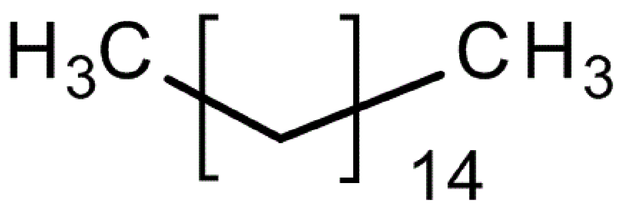

Methyl Tertiary Butyl Ether (MTBE) Market, Volume Share (%), by Application, Global, 2021

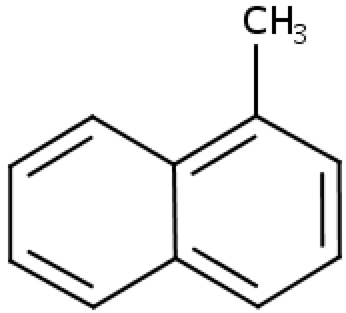



**Source:** Mordor Intelligence

# Cetane Number

The percentage by volume of Cetane in a mixture of Cetane and α–methyl naphthalene which just matches the knocking characteristics of diesel oil under test.



Why is Petrol a bad diesel & vice versa

Diesel → high HC (C16–C18), 250–320°C BF, knock → Ig delay, CI engine, Cetane No.

Cetane = 100

Diesel preferred

α methyl naphthalene = 0

Straight chain>Branched chain>olefins>cycloparaffins>aromatics

Preferred petrol

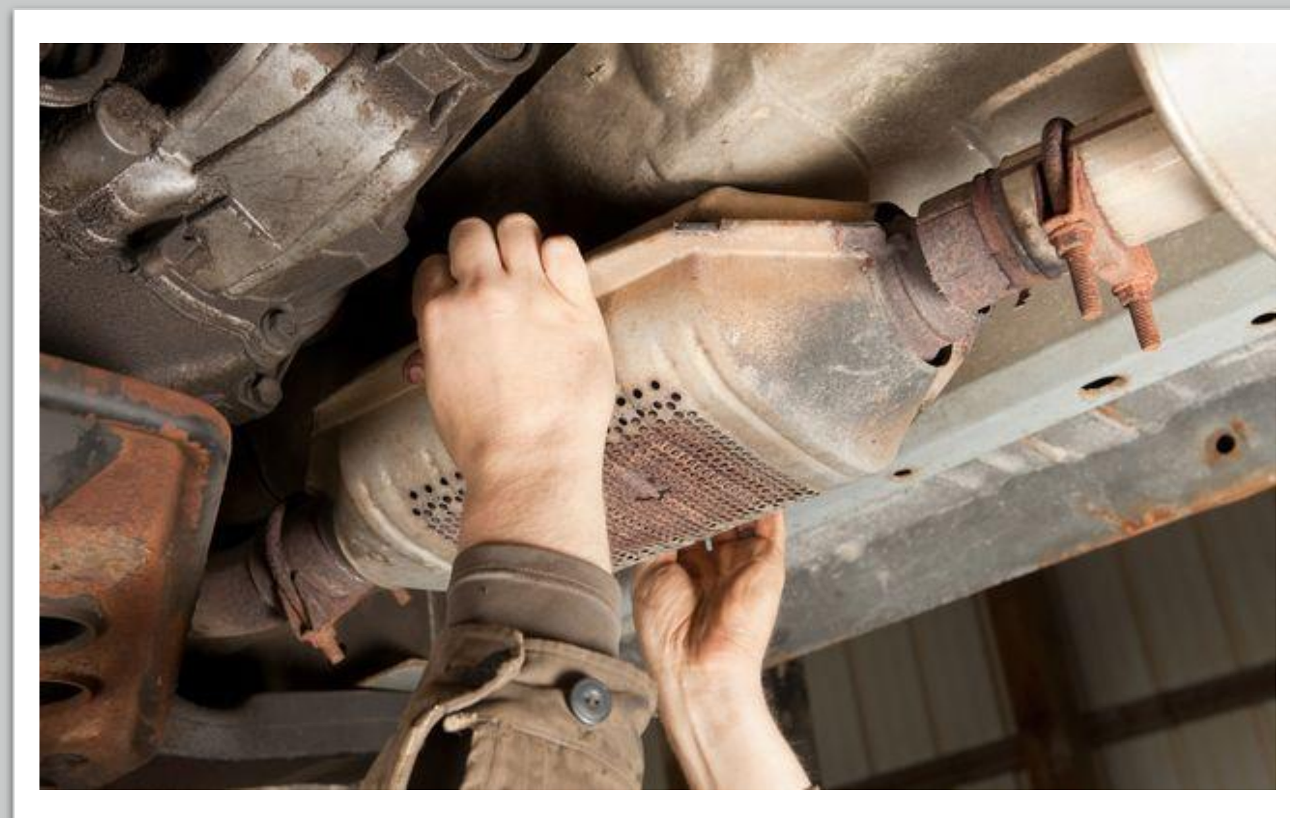
Petrol

n heptane = 100

Isooctane = 100

low HC (C5–C8), 40–120°C BF, knock – Preignit, SP type, octane no.

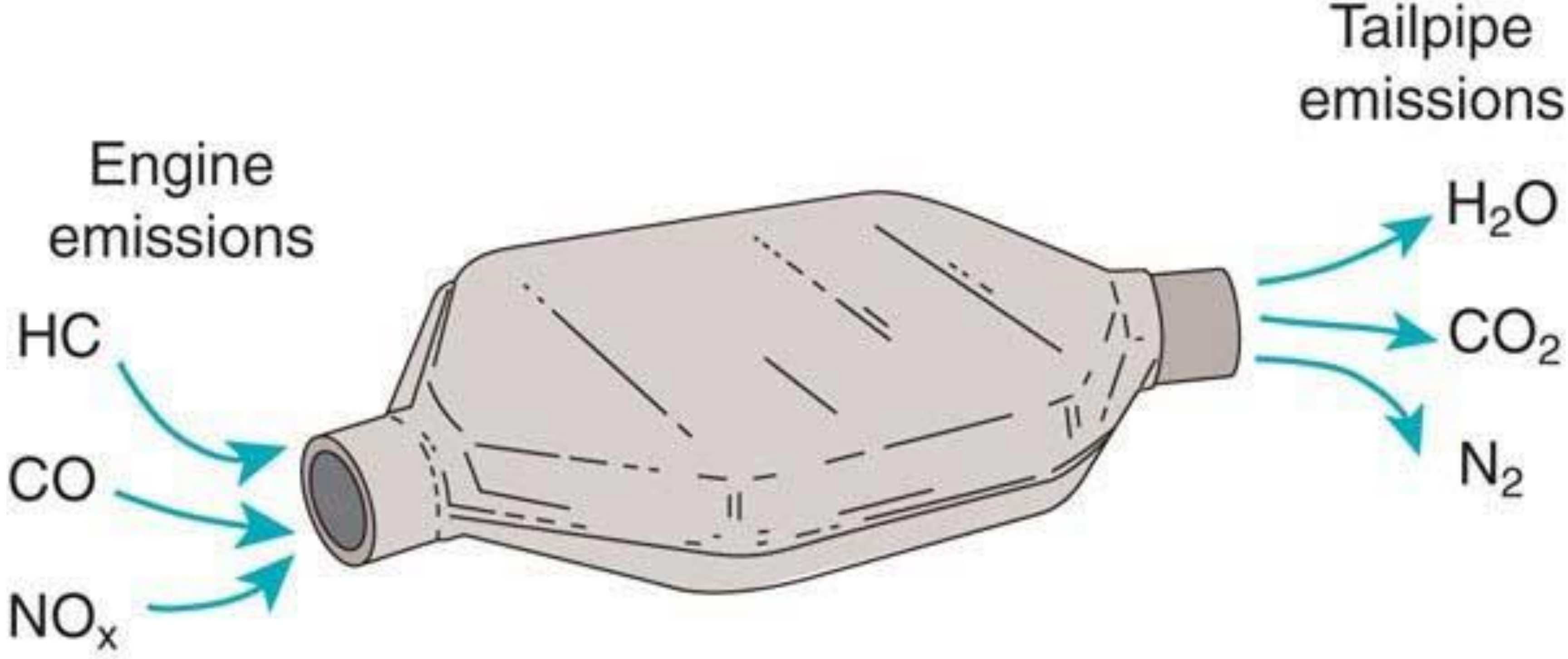
| Petrol Engines | Diesel Engines |
|---|---|
| Follows Otto cycle | Follows diesel cycle |
| Air and petrol are mixed into the carburetor before they enter into the cylinder | Fuel is mixed with air inside the cylinder |
| Ignition is done by an electric spark | Ignition is done by heat of compression |
| Lower compression ratio | Higher compression ratio |
| Less power output | More power output |
| Contains spark plug | Contains fuel injector |
| Burns highly volatile fuel | Burns less volatile fuel |
| Used in light vehicles | Used in heavy vehicles |
| More fuel consumption | Less fuel consumption |
| Lighter | Heavier |
| Frequent maintenance is required | Less frequently maintained |
| Lower maintenance cost | Higher maintenance cost |
| Less initial cost | More initial cost |
| Thermal efficiency is about 26% | Thermal efficiency is about 40% |
| The starting of petrol engine is easy due to low compression ratio | The starting of the diesel engine is slightly difficult due to higher compression ratio compared to a petrol engine |
| High speed engines | Low speed engines |



# Catalytic Converter

Invented by Eugene Houdry, a French mechanical engineer, in the mid-1950s.

# Function of Catalytic Converter



- A converter consists of a ceramic honeycomb structure which is lined with metals such as rhodium or palladium.
- **Reduction catalysts:** Help reduce nitrogen oxide pollution by removing oxygen.

| | |
|---|---|
| Nitric acid | $2NO \rightarrow N_2 + O_2$ |
| Nitrogen dioxide | $2NO_2 \rightarrow N_2 + 2O_2$ |

- **Oxidation catalysts:** Used to change carbon monoxide into carbon dioxide through an opposite process of adding oxygen.

| | |
|---|---|
| Reaction #1 | $2CO + O_2 \rightarrow 2CO_2$ |
| Reaction #2 | $HC + O_2 \rightarrow CO_2 + H_2O$ |

# Numerical Problems on Combustion

## Tips For Combustion problems

- Air contains 23% O2 by weight and 21% O2 by volume.
- At NTP, 273K and 760 mm pressure,

22.4 litres of any gas will weigh 1 gm molecule

- Average molecular weight of air is 28.94

# Numerical Problems on Combustion

1. A coal has following analysis; C=80%,S=2.6%,$H_2$=10%,N=0.6%, Ash=4.4% and rest is $O_2$. Calculate the minimum quantity of air needed for complete combustion of 1 kg of above coal.
2. Calculate the weight of air needed for complete combustion of 1 kg of coal containing C=72%, H=10%, O=9%, N=3% and remaining ash.
3. Calculate the volume of air required for complete combustion of $1m^3$ of gaseous fuel having following composition by volume: $CH_4$=40% $H_2$=40%, $N_2$=5%,CO=10%,O=5%.

# Numerical Problems on Combustion

4. Calculate the volume of air required for complete combustion of 1 m3 of gaseous fuel having following composition by volume: $H_2$=10%, $CH_4$=40%,$C_2H_6$=6% and CO=15%, $N_2$=2%.

5. Calculate weight and volume of air required for complete combustion of 1 kg of coal with analysis; C=75%, $H_2$=12%, S=3%, $N_2$=5%,rest is Oxygen.

6. Calculate weight and volume of air required for complete combustion of 1m3 of gaseous fuel containing $H_2$=33%,$C_2H_6$=18 %,$C_3H_8$=26 %,CO=13 %,$N_2$=4% and rest is Oxygen.

# Numerical Problems on Combustion

7.The fuel is having composition; $CH_4$=70%, $C_2H_6$=15%, $H_2$=13% and 2% $O_2$. Calculate the weight and volume of air required for complete combustion of 1 $m^3$ of gaseous fuel assuming 50% excess of that theoretically required air was used.

8. A gas has following composition by volume;$H_2$=20%,$CH_4$=6%,CO=22%,$CO_2$=4%,$O_2$=4%,$N_2$= 44%.If 20% excess air is used, find the weight actually supplied per $m^3$ of the gas.

# Practice Problems on Combustion

1. Calculate volume of air required for the complete combustion of 5m3 fuel having composition by volume: $CH_4$=45%,$C_2H_4$=24%, CO=5.5%,$C_3H_6$=19.5%, $N_2$=6%.
2. Calculate weight and volume of air required for complete combustion of 1 kg of fuel having C=67.7%, $H_2$=12.3%,S=6.4%, O=8.9% and 4.7% $N_2$.
3. The composition of a gas was found to be $H_2$=10%, $CH_4$=16%, $C_2H_6$=20%, $N_2$=6%, CO= 22%, $CO_2$= 18%, $O_2$= rest. Calculate the weight and volume of air required for complete combustion of 1m3 of this gas.

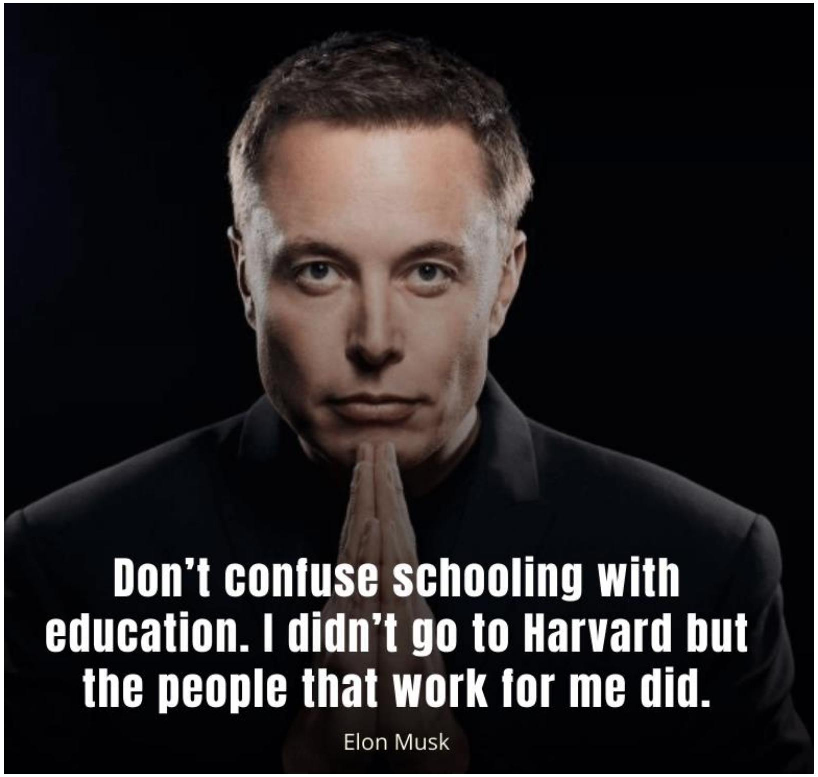
# Practice Problems on Combustion

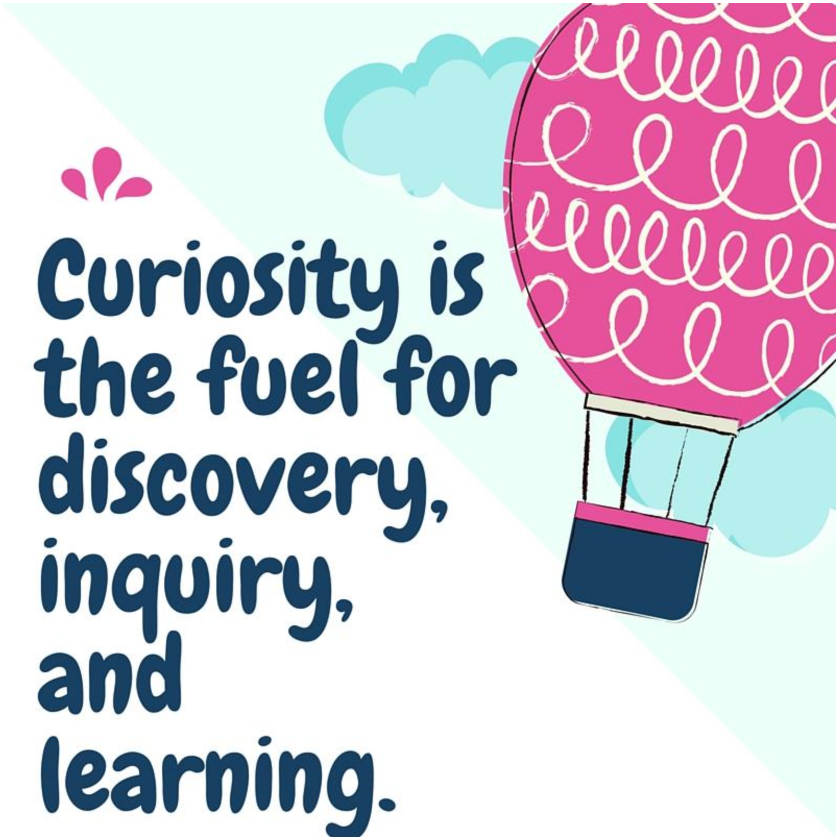
4. A coal sample has the following composition by weights: C=82%, H=3%, O=8%, S=2%, N=2% and Ash=3%. Calculate the minimum amount of air required both by weight and volume for complete combustion of 2 kg of coal. (mol-wt. of air = 28.949 gm).

5. 1 m3 of gaseous fuel having $C_2H_6$=35%, $C_3H_8$=24%,$C_5H_{10}$=16%,$C_4H_{10}$=22% and rest is $O_2$. If 33% excess air is used, find the weight actually supplied per m3 of the gas.

6. A fuel has 60% $C_2H_6$,20%$C_2H_4$,10%$C_3H_6$ and 10%$O_2$

If 70% excess air was supplied, then find weight of air supplied actually per m3 of the fuel.


Don’t confuse schooling with
education. I didn’t go to Harvard but
the people that work for me did.
Elon Musk


Curiosity is
the fuel for
discovery,
inquiry,
and
learning.