   

# ENVC 24 : Energy and Environment


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Course Web : https://amitbny.github.io/akb.github.io/enerenv.html

Course timeline : Feb–June, '18

Evaluation : Weekly/monthly assignments followed by final examination

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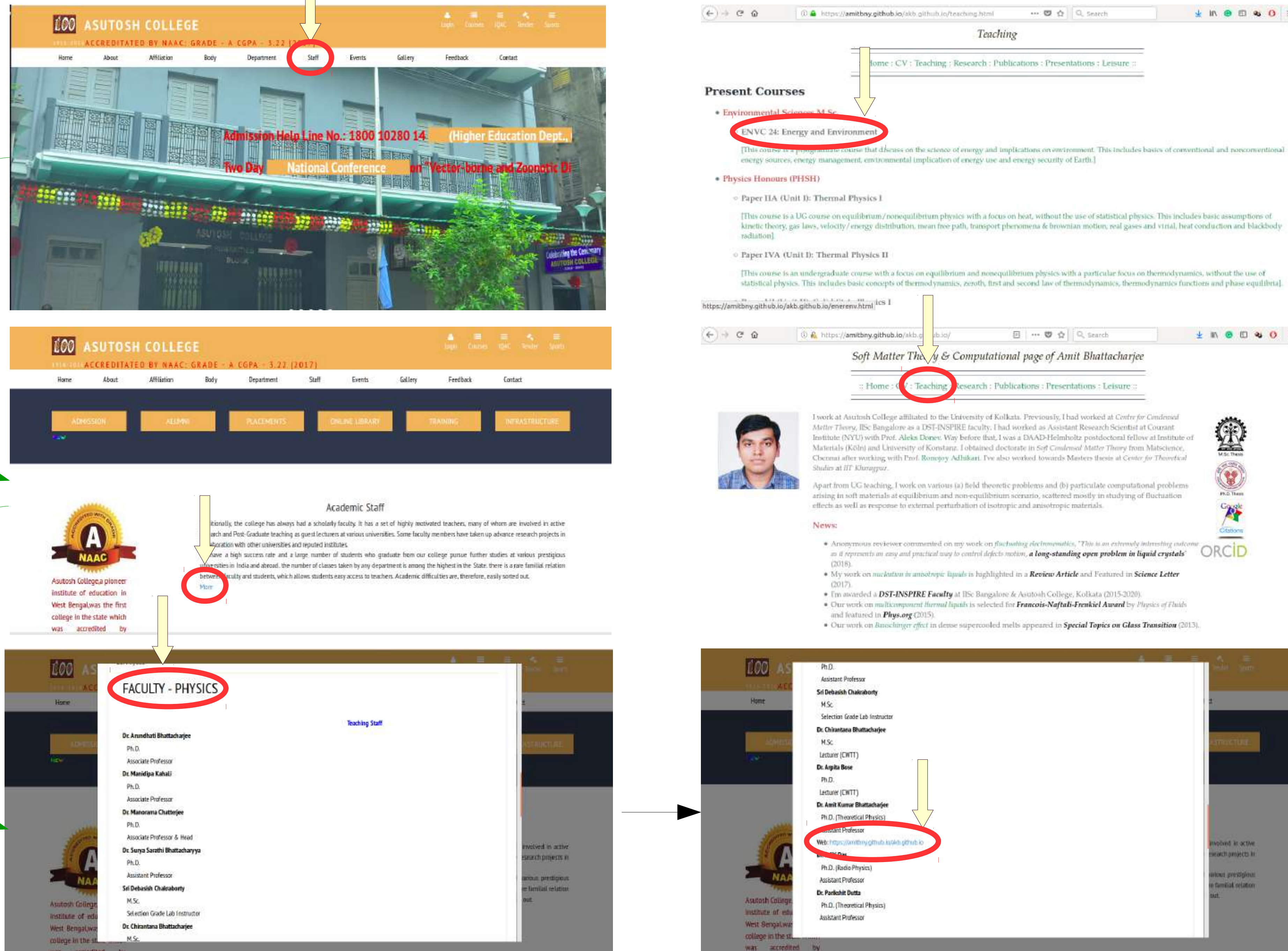
# Alternate way to access the webpage

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# Course: Marks - 25; Credit - 2

- General overview → Sun as a source of Energy, Solar Radiation & its Spectral Characteristics, Conventional & Nonconventional Energy Sources, Fossil Fuels – Classification, Composition, Physico-Chemical Characteristics & Energy Content of Coal, Petroleum and Natural Gas.
- Nuclear Energy → Fission & Fusion, Bioenergy – Energy from Biomass and Biogas, Anaerobic Digestion.
- Non-Conventional Energy → Principles of Generation of Solar, Hydropower, Wind, Geothermal & Ocean Energy, Solar Collectors, Solar Pond, Photo-voltaic, Energy Use Pattern in Different Parts of World and in India.
- Energy Measurement → Energy Consumption, Energy Conservation, Increased Efficiency & Cogeneration, Energy Policy, Management of Nuclear Energy Wastes, Research & Development on Renewable Energy, Energy Conservation Policy.
- Environmental Implication of Energy Use → Green-house Gas Emission, Global Warming.
- Energy Security & Energy Budget of the Earth.

# Energy and Environment

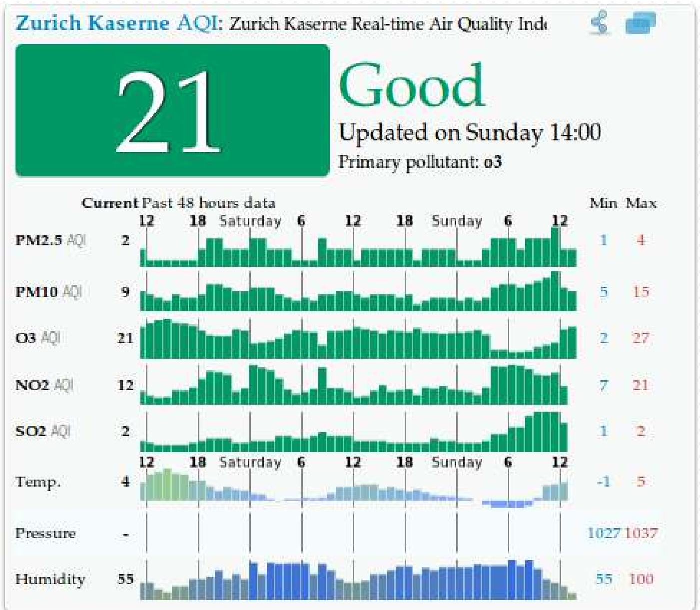
- Why should we study? If asked a few decades back, probably there were not so strong support.

Earth recordered from Apollo 17 crew in 1972 (NASA)

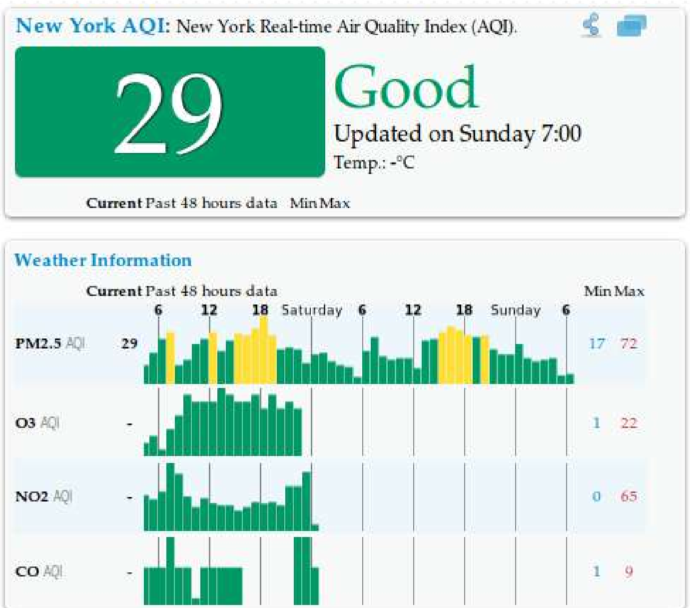
# Energy and Environment

- Why should we study? If asked a few decades back, probably there were not so strong support, **But** …..

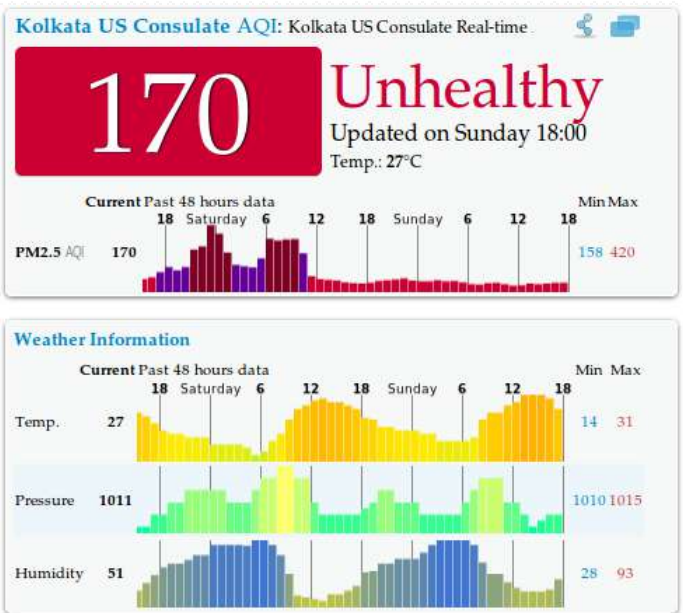
AQI (air quality index)  as on 04/02/2018




Zürich, CH




New York, USA




Kolkata, India

Zürich, CH

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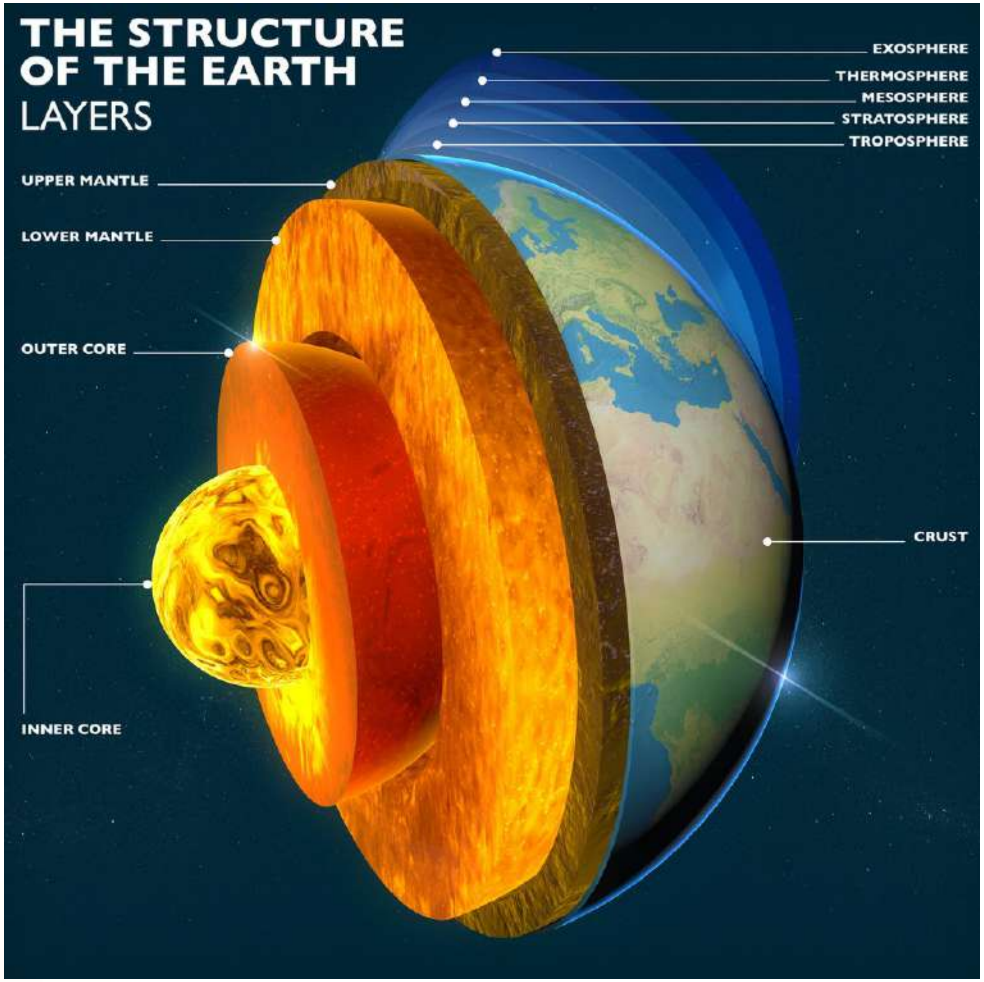
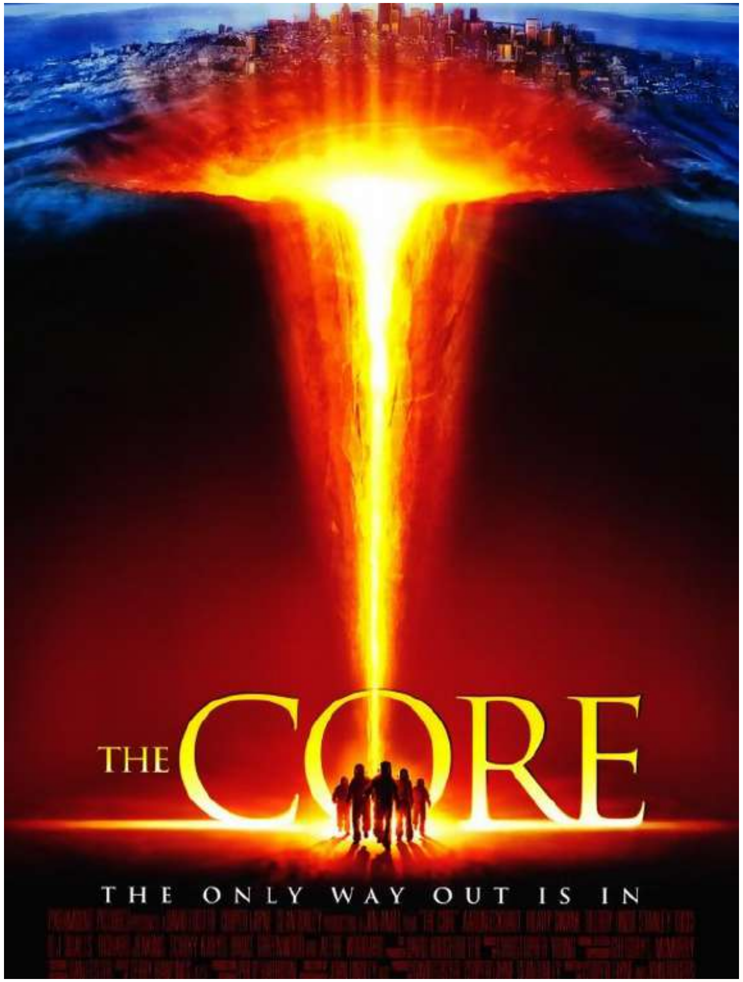
# Energy and Environment



# General Overview

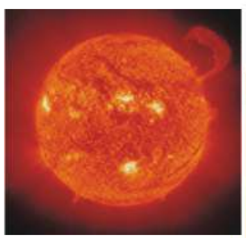
- **Energy** is a prime mover of economic growth and is vital to sustain the economy. Energy consumption is an indicator of economic growth of a nation. Future economic growth depends upon the long term availability of the energy resources which are affordable, accessible and environment friendly. Industrialization contributes to the growth of the economy and requires energy. Consumption of energy and industrialization go together. If the economy has to grow then energy consumption also has to grow. The growth of economy depends upon the growth of infrastructure, and the infrastructure demands the consumption of energy.

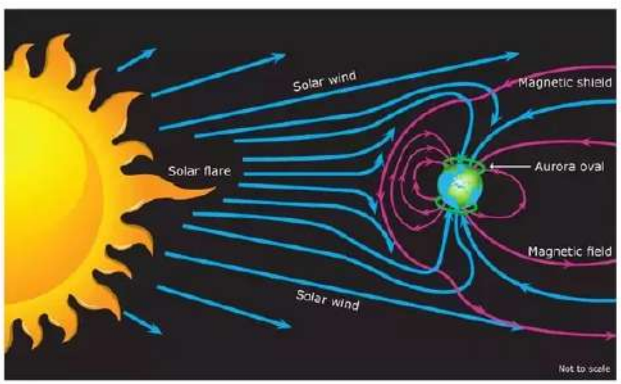
# General Overview

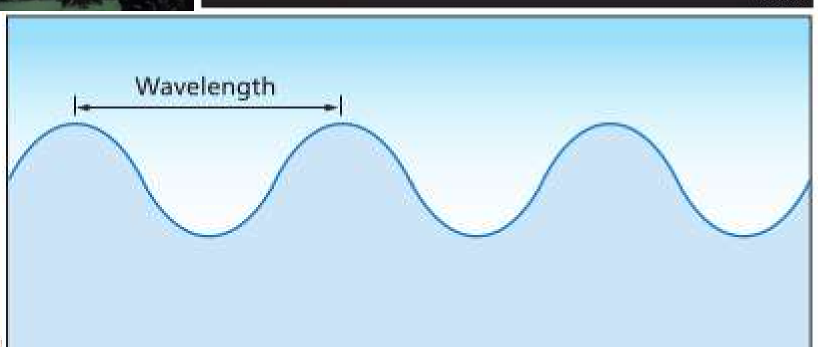
- Major energy intensive industries in 2005 required energy ~ **68%** of the total energy consumption, e.g., sectors that produced chemicals (Cement & others) took ~ **29%** of the total energy, Iron/Steel sector consumed ~ **20%** of the total energy. Steel and Cement are two main infrastructure materials. Non-metallic minerals have consumed ~ **10%** of the total energy, Paper/Pulp ~ **6%** of the total energy and Nonferrous metal ~ 3% energy. Though this data corresponds to 2005, but similar energy consumption is present in the subsequent years. India has setup ~ **7.6%** economic growth for **2019-20**. With this high economic rate of growth, the demands on infrastructure materials like Cement, Steel, non-ferrous material is bound to grow. In an estimate, India would be needing ~ **600 billion tons** of Cement and ~ **300 billion tons** of Steel by the end of the year 2030. This suggests that **industrialization**, **growth of economy**, and **energy consumption** are highly interrelated.

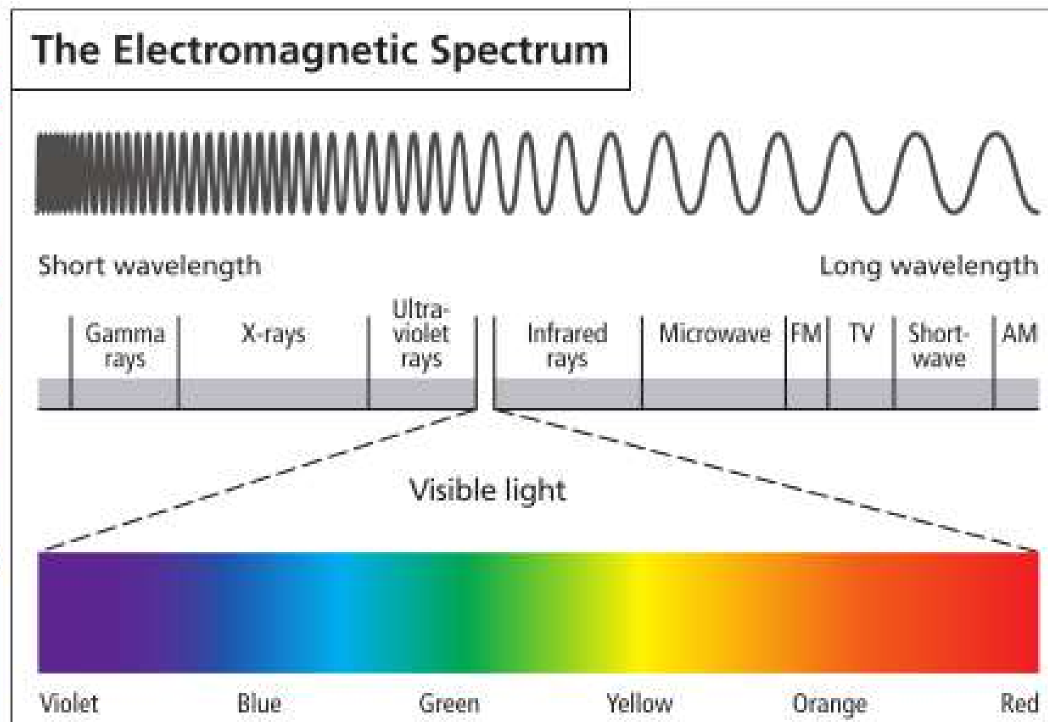
# General Overview

- In this perspective, we list what are the energy resources available because "*the long term sustenance of the economy will depend upon the availability of the energy resources which are affordable, accessible and environment friendly*". Ultimate energy resource is the **Sun**. It is the **solar power** that gives energy to life.
  Part of this energy is stored below the earth crust and part is available above the earth crust.





# General Overview

- In this perspective, we list what are the energy resources available because "*the long term sustenance of the economy will depend upon the availability of the energy resources which are affordable, accessible and environment friendly*". Ultimate energy resource is the **Sun**. It is the **solar power** that gives energy to life. Part of this energy is stored below the earth crust and part is available above the earth crust. As such, energy resources are divided in two parts, *(a)* Primary energy resources (Natural), *(b)* Secondary energy resources (Synthetically manufactured as demand from the industry). We first take the Primary energy resources, that can be further subdivided into the following,

  *(i)* **Non-renewable** energy resources.

  (*ii)* **Renewable** energy resources.

# General Overview

- **Non-renewable** means it takes several millions of years to form such resource. “Radiomatric dating” shows that Earth formed over 4 billion years ago. In this perspective, we have non-renewable and renewable – the renewable resources are available to us all the time. Example of non-renewable energy resources are ***fossil fuels*** and renewable energy resources are generated from natural resources.
- **Renewable** means they are constantly recyclable, they never exhaust as long as the solar power is. But non-renewable resources takes several millions of years to form below the earth-crust, that is in this time scale the fossil fuels are termed as non-renewable energy vis-a-vis renewable energy resources.

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- Fossil fuels are in fact *"plant origin"*. And among these fossil fuels, one have three different types of fuel, (a) Coal, (b) Petroleum, (c) Natural gas.

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- Fossil fuels are in fact *"plant origin"*. And among these fossil fuels, one have three different types of fuel, (a) Coal, (b) Petroleum, (c) Natural gas. Among the renewable energy resources, the most important one is (i) Solar power, (ii) Geothermal, (iii) Wind, (iv) Biomass, (v) Hydrothermal. Let's see how these non-renewable energy resources of plant origin are formed. There are special type of plants that give petroleum, natural gas and coal. **Coalification** or coal formation consist of two stages. First stage is the *Biochemical stage*. In this stage, the plant materials decay under the Earth crust, and they are degraded by the bacteria under moist condition. After this, there are several earth movement below the earth crust - there are several ecological forces also acting under the Earth crust to the deposit, which has been there at a particular time. It gets further buried into/below the earth crust and as a result of temperature and pressure, the process of coal formation begins.

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- The second stage is called **Metamorphism** or *dynamochemical stage*. In this stage, there is an effect of pressure because of the depth. Because of the movement of the earth crust, the deposit which has been occurred earlier gets buried further and as a result of this the effect of pressure begins as one go down the depth. Also, there is a tectonic pressure which is caused by the movement of the Earth and as a result, the deposit gets buried into some type of rocks below the Earth crust. Then there comes the effect of temperature because there is a rise of 3-5$^{o}$C for every 100 meter increase in depth. This is the most important stage in the formation of the coal deposit. And there is an effect of temperature and very high pressure and on account of it, several physico-chemical reactions take place during the life of the formation of the coal. So certain chemical reaction occur at dynamochemical stage.

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- They are, for example, dehydration (removal of water), decarbooxylation and dehydrogenation, and, on account of this three chemical reaction which are occurring because of the very large increase in pressure and temperature, and these results in removal of $H_2O$ , $CO_2$, $CH_4$ and $H_2S$. So on account of these physico-chemical reaction or dynamochemical reaction, the formation of coal occurs. The coal consists of organic mass (because it is from plant origin), and, this organic mass is a complex mixture of organic compounds of C, H, N, S and O. Then also coal contain inorganic substances like water and mineral. So as a result of these physico-chemical reaction which are a function of the pressure and temperature, the coal formation occur with these many stages.

- Stages of coal formation ➔ *Wood* followed by *Peat*. This is in the increasing order of the life of formation – meaning, if one stops at Wood, Peat is obtained. Then with further depth, one obtain *Lignite* followed by *Bituminous*, which is followed by *Anthracite* and then ultimately goes to *Graphite*. So as a result of the physico-chemical changes physical change is reflected in colour, strength, density and structure. To a user the chemical changes are important, for example, $O_2$ content on Dry Ash Free Basis (**DAF**) decreases from **40%** for Wood to **30%** for Peat and **20%** for Lignite, **5%** for Bituminus coal and **2%** for Anthracite. So the progressive action of the pressure and temperature brings the $O_2$ down the value to **2%**. As a result of this, the volatile matter (**VM**) decreases from ~ **70%** for Wood to < **5%** for Anthracite. So decrease in VM and $O_2$ content increases the available carbon from about **30%** for Wood/Peat to almost **100%** for Anthracite. ***Based on the extent of Coalification, Lignite is higher in rank than Peat and Anthracite is higher in rank than Bituminus coal.***

# General Overview

- **Petroleum is formed under the Earth crust by special type of plants which are gelatinous in nature. Near sea coast, such type of plants are present and with the same process as coal buried under the earth crust and over the time period of millions of years, the deposits of petroleum are formed below the earth crust. Liquid fuel oil, is derived from Crude petroleum and, is not a natural resource - it is obtained from Petroleum. Petroleum is a natural resource and it comes from – in greek** *Petra* **means rock and** *oleum* **means oil, so after drilling the rock beneath, petroleum is available for usage. Petroleum also contain elements e.g. C, H, N, O, S. From Crude Petroleum several types of bi-products are obtained, e.g. Gasolin, Lubricating oil, Fuel Oil and so on.**

- These are the non-renewable energy resources along with natural gas.

# General Overview

- Among ***renewable*** energy resources, one is ***Geothermal*** that is, energy obtained by trapping the heat of Earth below its surface - *hot underground water* or *steam* is used to produce electricity because solar power is partly absorbed by the Earth to produce hot water.

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## General Overview

- Among *renewable* energy resources, one is *Geothermal* that is, energy obtained by trapping the heat of Earth below its surface - *hot underground water* or *steam* is used to produce electricity because solar power is partly absorbed by the Earth to produce hot water.
- Another important source is the ***Biomass*** energy and it consists of Biogas, that is produced from current waste streams like *paper* and sugar production, animal waste and so on, and $CH_4$ is the main product. Also there are **biofuel** like biodiesel, ethanol which are derived from plants. We also have solid Biomass - woodfuel, biogenic portion of municipal waste and certain plants.

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## General Overview

- *Hydrothermal* is water in the form of kinetic energy, temperature difference and as such we have hydrothermal powerstations for the conversion of kinetic energy of the water into the electrical energy.

*Maithan Dam*

$6\,x\,10^4\,kW$ *electric power*

# General Overview

- *Hydrothermal* is water in the form of kinetic energy, temperature difference and as such we have say hydrothermal powerstations for the conversion of kinetic energy of the water into the electrical energy.
- **Solar** energy or energy collected from sunlight. It can be used in many ways - for example - generation of electricity, photovoltaic cells (but with very low efficiency factor), generation of electricity using concentric solar power.

*Asutosh College*

*20 kW solar power*

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- **Solar** energy or energy collected from sunlight. It can be used in many ways - for example - generation of electricity, photovoltaic cells (but with very low efficiency factor), generation of electricity using concentric solar power.
- Another source of energy is ***windpower***. Wherever windpower is available (sea coasts, hilly region), it can be used for production of electricity.

*Muppandal , TN*

*15 K MW wind power*

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# Indian Context

- Lets try to realize in India, as our nation is $6^{th}$ in World in terms of total energy consumption and needs to accelerate the development of its energy sectors in order to sustain $8\text{-}9\%$ of growth by 2019-2020 – as $energy$, $infrastructure$, and $growth$ are interrelated. India, though rich in coal and abandantly endowed with the renewable energy, it has a very small hydrocarbon resource (fossil fuel) of the order of $4\%$ of the total World resource. India is a net importer of energy, more than $\mathbf{25\%}$ of the primary energy needs been met through the import of the *Crude Oil* and *Natural Gas*. This is important when we relate our economic growth with the energy, as we are also based on the import of the energy resources. This brings us to the *energy production sector* - coal and oil account for $54\%$ and $34\%$ respectively, and natural gas around $\mathbf{6\%}$.

# Indian Context

- India's total energy production is contributed by ***fossil fuel***, to the extent of **90%**, now rest say ***hydrothermal*** is around **6%**, ***nuclear*** is around ***1%*** & rest being ***geothermal, windpower*** and so on …
- India is a large consumer of the ***fossil fuel*** energy resources - not only India but the World, around **80-90%** of the energy is being produced by primary energy resources such as **coal**, **oil** and natural gas. Industrial sector in India consumes around **5.2%** of energy. When we relate energy with the economy, then it is also has a relation with the standard of living. And standard of living can be measured in terms of energy consumption - *oil equivalent per person*.

# Indian Context

- Consumption of primary energy in India is **530kg** of oil equivalent per person as in 2004, compared to **1240kg** oil equivalent per person in China and World average of **1770kg** of oil equivalent per person. So growth in economy is highly related with the energy consumption and so in terms of energy consumption, *we are at least 3-4 times lower than the World average*. If the primary energy consumption per person is an indicator of the economic growth, then it has to grow, because economy is a Country's index of prosperity. When this is the scenario,that **90%** of the derived energy is from the *fossil fuels*, we are also convinced that the economy has to grow as the country has to prosper, and then, energy consumption must increase. The question is how that can be met?

# Issue with fossil fuels

- Are there certain *issues* related to the fossil fuels? Why in the World there is a huge debate that **80-90%** of the Fossil fuel is used for the production of energy, India having more than 90%? What are the issues related with the Fossil fuel as the energy resource? The contribution from renewable energy sources is very very less, because of the economical considerations. In the years to come, the fossil fuel will remain to be a dominant source of energy not only in India, but the whole World.
- **Issue No.1** ➔ Fossil fuel contain *potential energy*. It means taken 1 Kg of coal, put that before industry - it has energy but industry can't use it. So the potential energy of the fuel is to be obtained by combustion in terms of sensible heat in *products of combustion* (**POC**).

# Issue with fossil fuels

- Heat transfer occurs between the ***source***, which is the product from the combustion and the ***sink*** which yields the required amount of energy. The source exits the system after imparting its energy. This means, the P.E. of fossil fuel is available by combustion and the products of the combustion (**POC**) is discharged in the atmosphere. So depending on the temperature of the sink, the product is discharged in the atmosphere. Higher is the temperature of the sink, higher amount of energy will be carried away by the products of the combustion. Here it calls for *recovery, recirculation* and *reuse* of the heat, which is being discharged with the product of the combustion -> **WASTE**.

# Issue with fossil fuels

- **Issue No.2** ➲ Fossil fuel are ***carbon*** fuels. If one combust 10Kgs of Coal, then 10Kg of Carbon will be output. Emissions can be categorized as Carbon emission $CO$, $CO_2$ and/or emissions in general ($NO_X$, $SO_2$, and $SO_3$). What is the issue here? To give an example, nature has its own Carbon cycle. If for a moment we are not using any of the Fossil fuel from the earth crust, then the Carbon which is emitted by the biological activity of the human beings in the Earth is absorbed by the plant, the $CO_2$ - net Carbon recycling is zero. So we are bringing extra Carbon from the Earth crust and thus disturbing the Carbon cycle → *environmental sustainability!!*

## Issue with fossil fuels

- **Issue No.3** ➲ Fossil fuel resources are limited and because we import a lot of oil, so energy security. So energy security and environment sustainability are the important issues and they can be achieved by applying the concept of "**switch, capture and reduce**".
- **Switch** means wherever someone is using Fossil fuel as the energy source, either for direct energy source, for example, generation of Carbon energy, or using for reduction purposes because its Carbon and Hydrogen, so it can do the reduction part of the source. If it is possible to replace a portion or the entire part of it with the fuel which is renewable that is called **switching**. *This means one has to identify the portion of the energy that doesn't contain Carbon.*

# Environment Sustainability

- **Capture** means it is in the inherent way of deriving thermal energy from the fossil fuel by the way of combustion, and the combustion products exits the furnace or wherever the thermal energy is derived at the temperature of the sink, the large amount of heat is going to waste. So, one has to invoke the possibility to capture the heat and recycle into whatever it demands. Capture brings the concept of ***energy recovery*** and ***reuse***.
- **Reduce** is, if someone can reduce it using 100Kg of Carbon by developing the technology or by optimal utilization, can someone reduce to 80kg or 70kg or so, and this reduction brings the concept of *energy efficiency.*

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# Example

- Indian Iron and Steel industry has produced **50 million tons** of steel in 2006-2007. **40%** of steel is produced by basic blast furnace and basic $O_2$ furnace ➔ **20 million tons**. **1 ton** (1000Kg) of hot metal yield ~ **750kg** of steel because loss of iron in slag. **20 million tons** of steel would require **27 million ton** of hot metal. 1 ton of hot metal require **600 kg** of coal and so, **1 ton** of coal will produce 1.25 ton of hot metals. So if **27 million ton** of hot metal is needed, then we will be consuming ~ **20-21 million tons** of coal. So we require technological innovation to cut down the consumption and it'll be beneficial not only from the *energy security* point of view but also from the *environment sustainability* point of view.
- Similarly, another carbon emission industry is cement. So here switching, for example as in cement industries, do by the use of tyres, as they contain a very large amount of energy.

# Energy and Environment

We posed importance of energy and the contribution of fossil fuels for the energy production, energy consumption and energy utilization. In this context, we can also term that fuel is energy.


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# Characterization of Fuel

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# Characterization of Fuel

- Fuel characterization ➲ (a) *Analysis* : As we want to do calculations – how much amount of fuel is required for a particular objective, then knowledge of analysis of the fuel, (b) Calorific value of the fuel is required.
- Analysis ➲ By fuel we mean solid fuel (e.g. coal), liquid fuel (fuel oil which is derived from petroleum), and natural gas. Two types of analysis are done for solid fuel - (i) **Proximate analysis ($\mathcal{PA}$)**, (ii) **Ultimate analysis ($\mathbb{UA}$)**.
- In the proximate analysis, the following are determined: **Moisture** (M) in the fuel is determined by taking 1gm of sample and heated on a furnace for 1 hour at $105 \pm 5$°C, then the weight loss is expressed in terms of percentage moisture. Another important constituent is **Ash** (A) which is the residue after complete combustion in the furnace. Third constituent determine **Volatile Matter** (VM) which is loss in weight of **1gm** of sample heated for **7minutes** at 950°C in the absence of air. *VM does not contain Moisture.*

$$\textbf{Fixed Carbon (FC)} = 100 - \left(\%M + \%A + \%VM\right).$$

# Characterization of Fuel

- ***Proximate analysis (PA)*** of the fuel can be reported in several ways. Basis of report ➡ (a) As received : $\%M + \%A + \%VM + \%FC$.

  (b) Dry Basis (Moist free basis) : $\%A + \%VM + \%FC$.

$$\%A \text{ (dry basis)} = \frac{100 * \%A}{100 - \%M}. \qquad \%VM \text{ (dry basis)} = \frac{100 * \%VM}{100 - \%M}.$$

$$\%FC \text{ (dry basis)} = \frac{100 * \%FC}{100 - \%M}.$$

  (c) Dry Ash Free (DAF) Basis : consist of $\%VM \,\&\, \%FC$.

$$\%VM \text{ (DAF basis)} = \frac{100 * \%VM}{100 - (\%M + \%A)}.$$

$$\%FC \text{ (DAF basis)} = \frac{100 * \%FC}{100 - (\%M + \%A)}.$$

- Whole idea of reporting the proximate analysis on different basis depends upon what is the ultimate use or the objective.

# Illustrative Example

- **Proximate analysis (*PA*)** of sub-Bituminous coal.

| | As Received | Dry Basis | DAF Basis |
|---|---|---|---|
| %M | 6.8 | - | - |
| %A | 12.3 | 13.2 | - |
| %VM | 36.7 | 39.4 | 45.4 |
| %FC | 44.2 | 47.4 | 54.6 |
| Total | 100 | 100 | 100 |

# Illustrative Example

- Ash and VM ➡ Coal contains *Mineral Matter* (MM) and ash is residue after complete incineration of coal, MM is greater than Ash and MM in coal are of two types -

  (i) **Inherent inorganic material** of original vegetable substances (*as coal is of plant origin and plant contains organic as well as inorganic matter*),

  (ii) **Extraneous in nature** - (a) Rock & Dirt, (b) Associated with decaying vegetables. Extraneous matter can be removed by coal washing.

$$\mathbf{MM = 1.1 * \%A + 0.55 * \%S.}$$

- Ash is a very important constituent of coal as whatever ash is present in the coal will be available in the furnace when coal is combusted for deriving thermal energy. Ash contains $SiO_2$, $Al_2O_3$, **Ferric Oxide**, $CaO$, $MgO$, $Na_2O$.

# Illustrative Example

- For example, coal is used to convert *coke* and coke is used in the blast furnace for iron making, so Ash content of coal is transfered to Ash content of *coke*. In blast furnace, Ash is removed in the form of slag, so higher amount of ash in the *coke* due to higher amount of ash in the coal demands larger volume of blast furnace. Melting point of Ash is greater than blast furnace temperature, so that it remains solid. If its low, then highly viscous molten Ash will choke the passage of air.
- *VM does not contain Moisture*, VM contains volatiles of the Mineral Matter. MM can be $CaCO_3$, $MgCO_3$ or ***Hydroxides***. So as such when a coal is subjected to VM determination, then the volatile constituents of these Mineral Matter $CO_2$ or $H_2O$ will also be counted. Actual VM can be obtained by subtracting VM with the volatile of Mineral Matter. Accordingly, the actual VM can be obtained by calculating the proximate analysis on *Dry Mineral Matter Free Basis* (**DMMF**).

# Calculations of Element

$$\%VM \text{ (DMMF basis)} = \frac{100*(\%VM - 0.1*\%A)}{100-(1.1*\%A + 0.55*\%S + \%M)}.$$

[0.1%A is estimated to be contribution of volatiles from MM]

$$\%FC \text{ (DMMF basis)} = \frac{100*\%FC}{100-(1.1*\%A + 0.55*\%S + \%M)}.$$

- In that previous example, %S=0, so

$$\%VM \text{ (DMMF basis)} = \frac{100*(36.7 - 0.1*12.3)}{100-(1.1*12.3 + 6.8)} = 44.52\,\%.$$

| | As Received | Dry Basis | DAF Basis |
|---|---|---|---|
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| Total | 100 | 100 | 100 |

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# Calculations of Element

$$\%VM\ (\text{DMMF basis}) = \frac{100 * (\%VM - 0.1 * \%A)}{100 - (1.1 * \%A + 0.55 * \%S + \%M)}.$$

[0.1%A is estimated to be contribution of volatiles from MM]

$$\%FC\ (\text{DMMF basis}) = \frac{100 * \%FC}{100 - (1.1 * \%A + 0.55 * \%S + \%M)}.$$

- In that previous example, %S=0, so

$$\%VM\ (\text{DMMF basis}) = \frac{100 * (36.7 - 0.1 * 12.3)}{100 - (1.1 * 12.3 + 6.8)} = 44.52\,\%.$$

$$\%FC\ (\text{DMMF basis}) = \frac{100 * 44.2}{100 - (1.1 * 12.3 + 6.8)} = 55.48\,\%.$$

- %VM on DAF basis > %VM on DMMF basis. In DAF basis, the contribution of volatile from Mineral Matter is also present, also because in DMMF basis, we are reducing the amount of volatiles which are coming from Mineral Matter.

# Calculations of Element

- Similarly, %FC on DMMF basis > %FC on DAF basis, because FC does not include the Ash content. This is all about the proximate analysis.
- **Ultimate analysis (UA)** ➡ required for all combustion calculation. Based on the proximate analysis, if required to calculate the quantity of air for a given composition of coal, one cannot calculate. In order to calculate the amount of air or the amount of energy that the coal has, one have to know the elemental analysis of the coal & this is termed as *Ultimate Analysis*. **C, H, N, S** are determined & reported in dry basis, %A, %M are determined from the proximate analysis (PA).

$$\%O = 100 - [\%C + \%H + \%N + \%S + \%A].$$

[*Carbon(C), Hydrogen(H), Nitrogen(N), Sulphur(S), Oxygen(O), Ash(A), Moisture(M)*].

# Calculations of Element

- **Carbon** is determined by completely combusting the coal, collecting the amount of $CO_2$ and it is absorbed in $KOH$ solution. **Hydrogen** is determined together with Carbon by complete combustion and from amount of water produced from that, hydrogen in coal is determined. Of course, one has to subtract the correction for moisture of coal and water of dehydration of mineral.
- Carbon content determines the **rank** of the coal. Pitt to Anthracite, carbon content increases, means rank increases. Hydrogen content is not dependent on the rank, as we know, beyond Bituminous stage, hydrogen content drastically decreases from **5%** to as low as **1.2%** in the Anthracite. ***Sulfur*** in the coal is present as (i) Pyritic $FeS_2$, (ii) Sulphates, (iii) Organic. *Ultimate Analysis* (UA) reports Organic Sulfur in the Bomb method. Total Sulfur is converted in the Sulphate form, then Pyritic and Sulphate are determined by analytical method.

**Organic sulfur = Total Sulfur - Inorganic Sulfur**

# Sulfur in Coal

- ***Sulfur*** content in coal is very important because it will also determine on complete combustion the amount of $SO_{2,} SO_3$ production. **Sulfur content has no relation with the rank of the coal.**
- Procedure to calculate ⮊ Moisture contains $H_2O$.

  So,

$$\%\mathrm{H\ in}\ H_2O = \%\mathrm{M} * \frac{2}{18}, \quad \%\mathrm{O\ in}\ H_2O = \%\mathrm{M} * \frac{16}{18}.$$

$$\%\text{element on Dry Basis} = \frac{100 * \%\text{element on Moist Basis}}{100 - \%\mathrm{M}}.$$

# Sulfur in Coal

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| % | Moist Basis | Moist Basis(A) | Dry Basis |
|---|---|---|---|
| C | 69.8 | 69.8 | 73.1 |
| H | 4.6 | 4.6+(4.5*2/18)=5.1 | 4.8 |
| O | 8.5 | 8.5+(4.5*16/18)=12.5 | 8.9 |
| N | 1.4 | 1.4 | 1.5 |
| S | 2.5 | 2.5 | 2.6 |
| A | 8.7 | 8.7 | 9.1 |
| M | 4.5 | --- | --- |
| Total | 100 | 100 | 100 |

# Calorific Value Of coal

- It is the amount of heat liberated on complete combustion at the reference state of products of combustion (**POC)**. In coal, there are *combustible* and *incombustible* components. Combustible are C,H,S, whereas incombustible are O,N,A,M. For a hydrocarbon fuel containing C,H,S, combustible determine the Calorific Value (CV).
- Product of complete combustion (**POC**), $C = CO_{2,} H = H_2O, S = SO_2$. Reference State of POC at 25$^o$C, $CO_2$ (gas), $SO_2$ (gas), $H_2O$ (liquid) state ➲ *Gross Calorific Value* (GCV) or *Higher Heating Value* (HHV).
- Reference state chosen, $CO_2(g), SO_2(g), H_2O(v)$ ➲ *Net Calorific Value* (NCV) or *Lower Heating Value* (LHV). While using calorific value of coal, one has to be clear, about what is the state of combustion. Accordingly, the calorific value will differ by an amount = latent heat of condensation.

**GCV/HHV > NCV/LHV**

# Calorific Value Of coal

- Calorific Value (CV) can be expressed as Cal/gm, kCal/kg, kJ/kg, B.Th.U./Lb, Cal/gm-mole, kCal/kg-mole, kJ/kg-mole, Btu/Lb-mole and can be calculated both theoretically and experimentally.
- Conversion factors:

  $1 \text{ Cubic Ft} = 0.02832\, m^3$, $1\text{kCal} = 3.968\, Btu = 4186\, Joules = 0.0016 \text{ kiloWatt-hour}$,

  $1 \text{ kW-hour} = 1.34 \text{ horsepower-hour} = 3.6\, x\, 10^8 \text{ J} = 860\, kCal = 3412.14\, Btu$.

  Also, 1 horsepower hour = 0.746 kWh.
- Atomic weights of H = 1, N = 14, O = 16, S = 32.
- Composition of dry air = $79\%\, N_2 + 21\%\, O_2$ (Volume Basis),

  $77\%\, N_2 + 23\%\, O_2$ (Weight Basis).
- Experimentally in a Bomb Calorimeter, a unit mass of Coal is completely combusted at *constant volume* and from the rise in temperature, the Calorific Value of coal is calculated.

# Calorific Value Of coal

- **POC**

$CO_2(g) \Rightarrow -\delta H_f^o = 97.20\,x\,10^3$ kCal/kg-mol at 25°C, 1atm, C in amorphous state.

$H_2O(l) \Rightarrow -\delta H_f^o = 68.32\,x\,10^3$ kCal/kg-mol at 25°C, 1atm, C in amorphous state.

$H_2O(v) \Rightarrow -\delta H_f^o = 57.80\,x\,10^3$ kCal/kg-mol at 25°C, 1atm, C in amorphous state.

$SO_2(g) \Rightarrow -\delta H_f^o = 70.96\,x\,10^3$ kCal/kg-mol at 25°C, 1atm, C in amorphous state.

- 1kg of C on complete combustion will yield $8.10\,x\,10^3$ kCal.

  1kg of H on complete combustion will yield $34.16\,x\,10^3$ kCal.

  1kg of S on complete combustion will yield $2.24\,x\,10^3$ kCal.

- If we want to express these values as %element and we say that Caloric Value of the coal is a sum of combustible component of the coal, then Dulong formula gives,

**GCV = 81%C + 341[%H - %O/8] + 22%S** kCal/kg

NCV = GCV - 5.84(9%H + %M) kCal/kg

Similarly, **GCV = 339%C + 1427 [%H - %O/8] + 92%S** kJ/kg

**NCV = GCV - 24.44(9%H + %M) kJ/kg**

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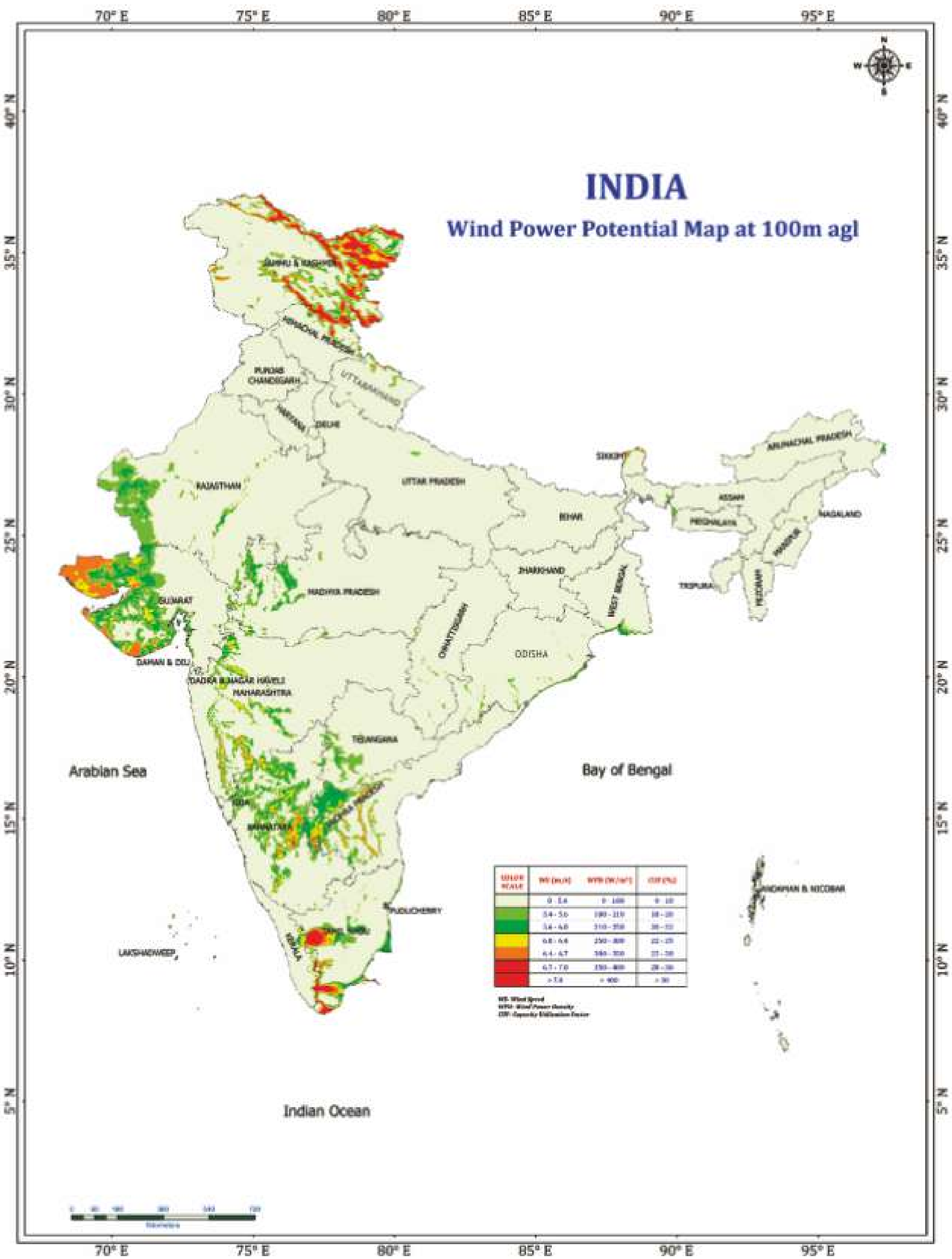
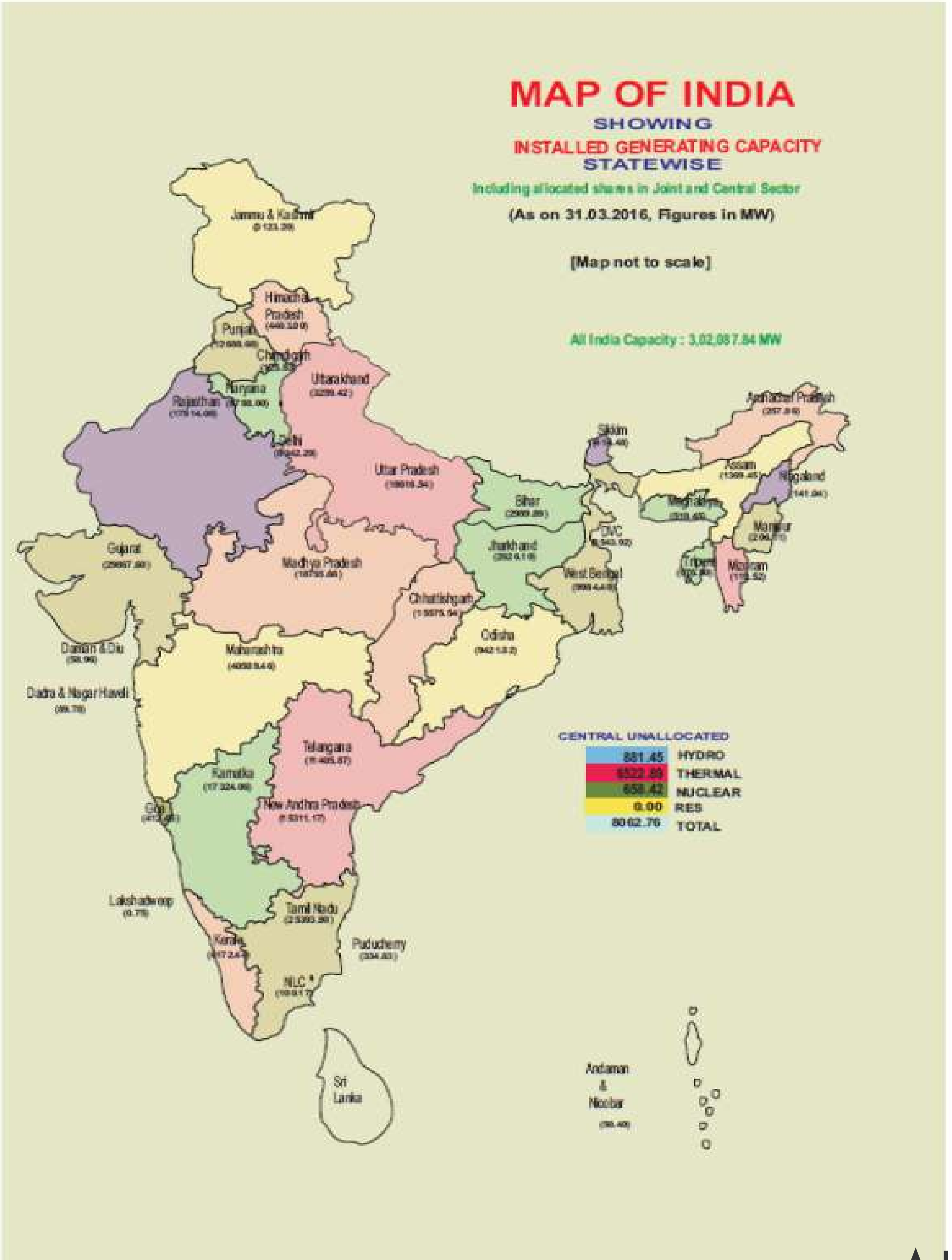
# Assumptions made in formula

- Heat of formation of Coal is zero, meaning calorific value to break the bonds and the required amount of heat is neglected, and they are in free state.
- Coal contains H & O. Calorific value determines what part of H has reacted with gaseous O. Accordingly, there will be reaction between H and O of the coal internally & $H_2O$ will form. So one has to subtract the O equivalent of H, i.e. available gaseous H for reacting with gaseous $O_2$ of air (combustion) = %H - %O/8.
- CV of coal is sum total of combustible elements.
- Heat of vaporization of water at 100°C = 542 kCal/Kg = 975 Btu/Lb.
  At 25°C, 584 kCal/kg or 1050 Btu/Lb.

# Indian Context



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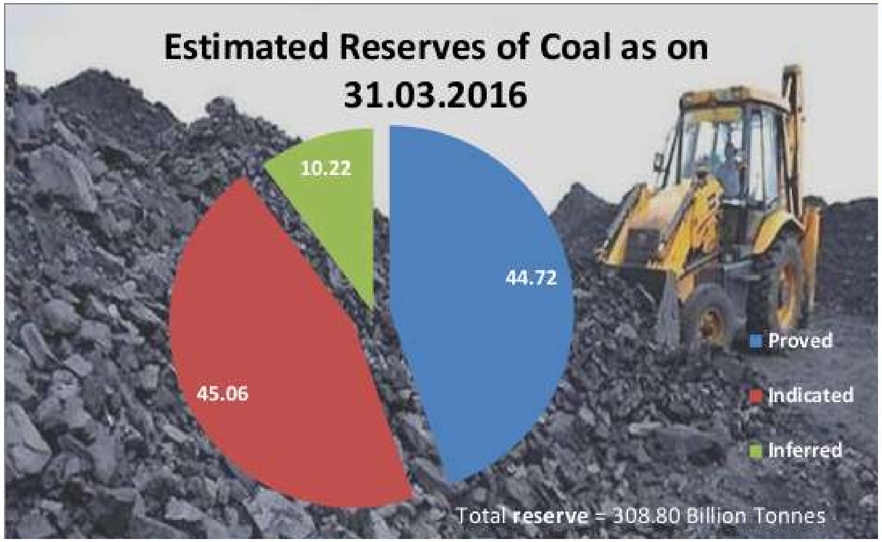


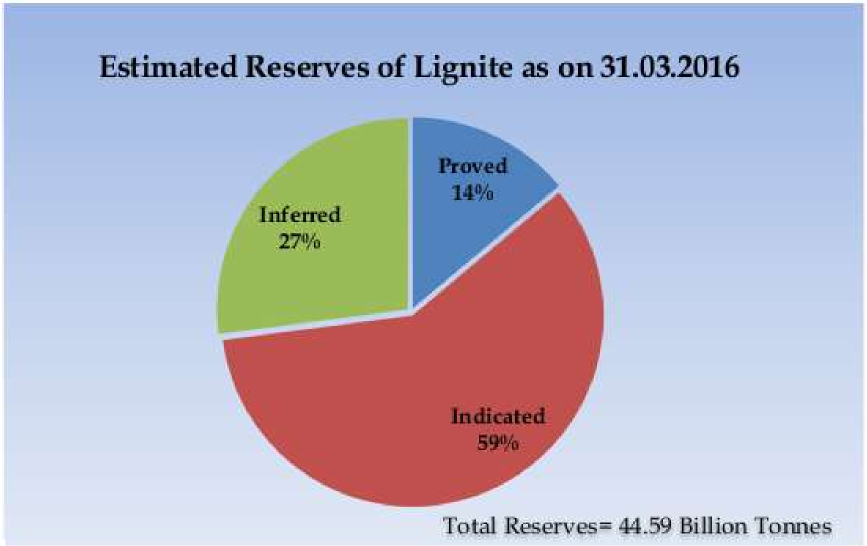


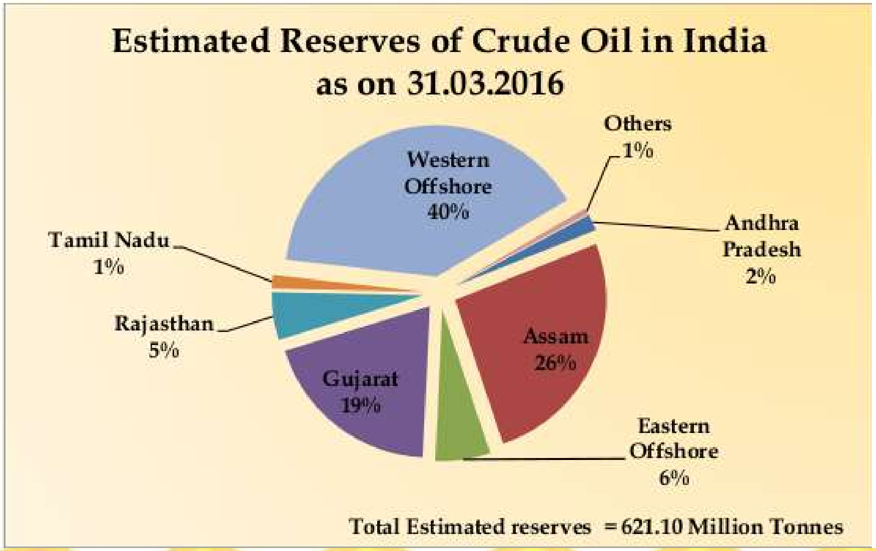


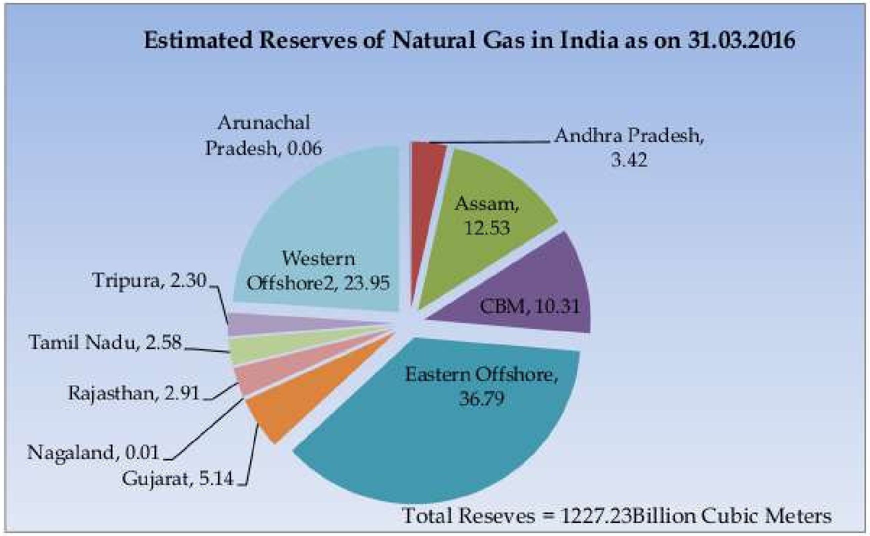


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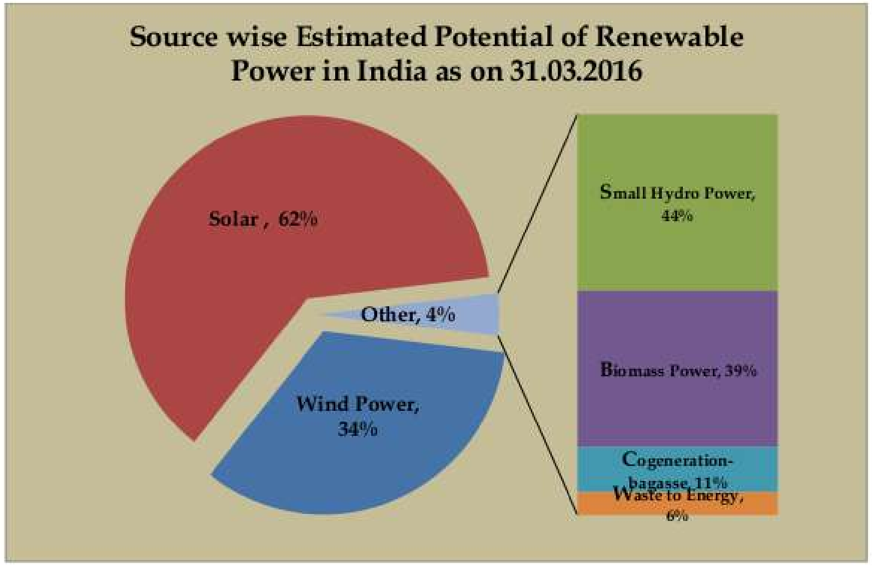


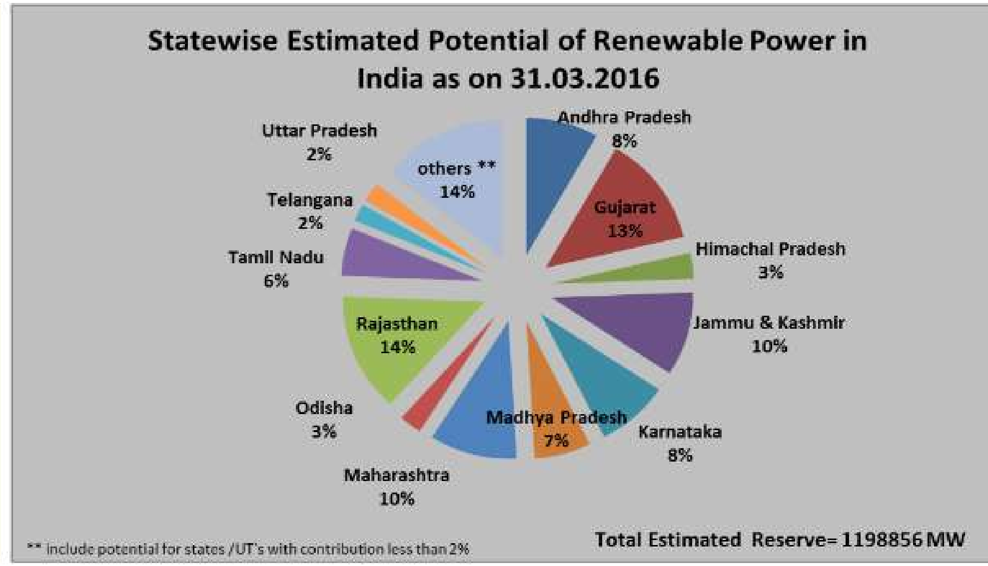


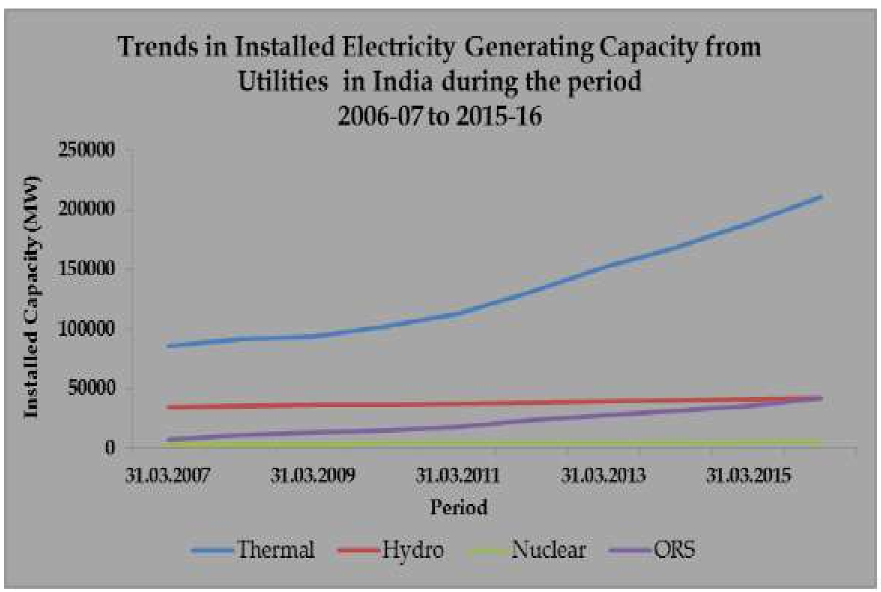


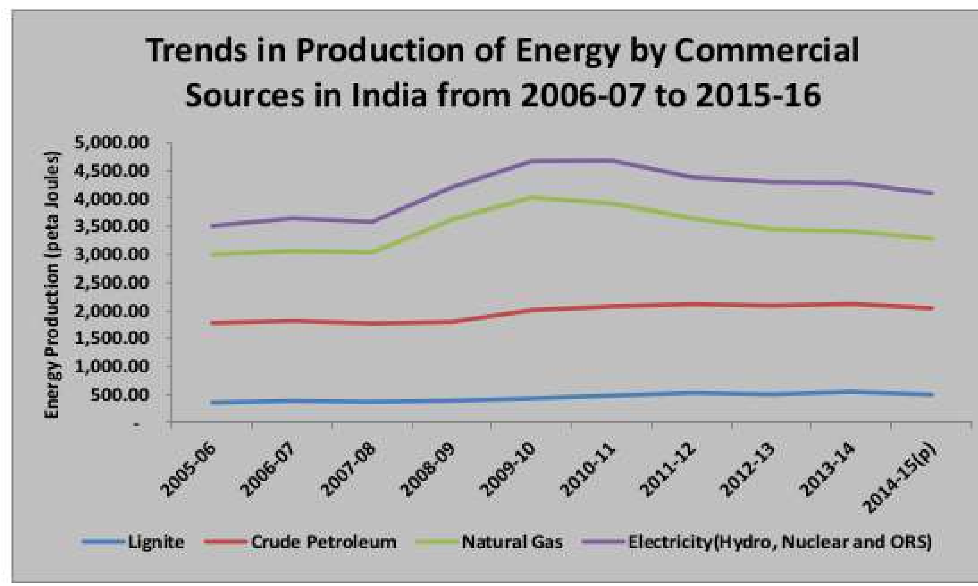


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