Energy Conversion Technologies (Biomass and Coal)

Prof. Vaibhav V. Goud

Department of Chemical Engineering

Indian Institute of Technology, Guwahati

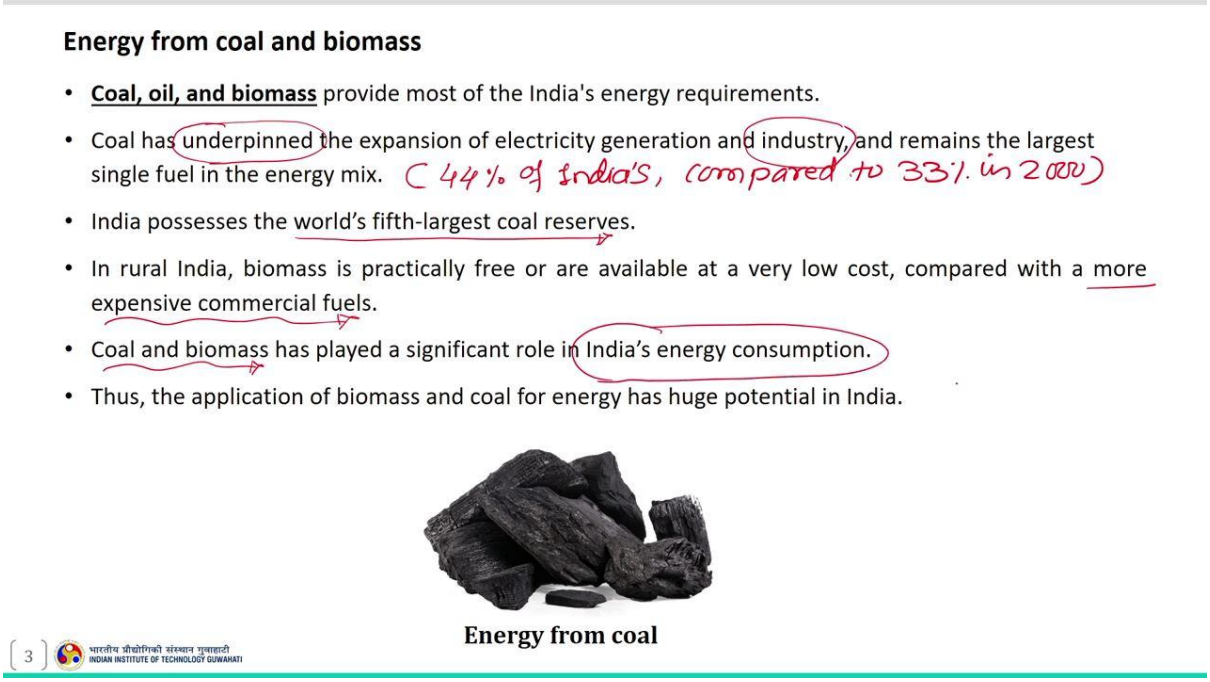
Lecture 4

Environmental aspects of energy

Good morning everyone.

Welcome to part one of lecture three under the module one. So, in this lecture we will discuss about energy from coal and biomass, environmental aspects of energy utilization that is conventional energy resources and their importance.

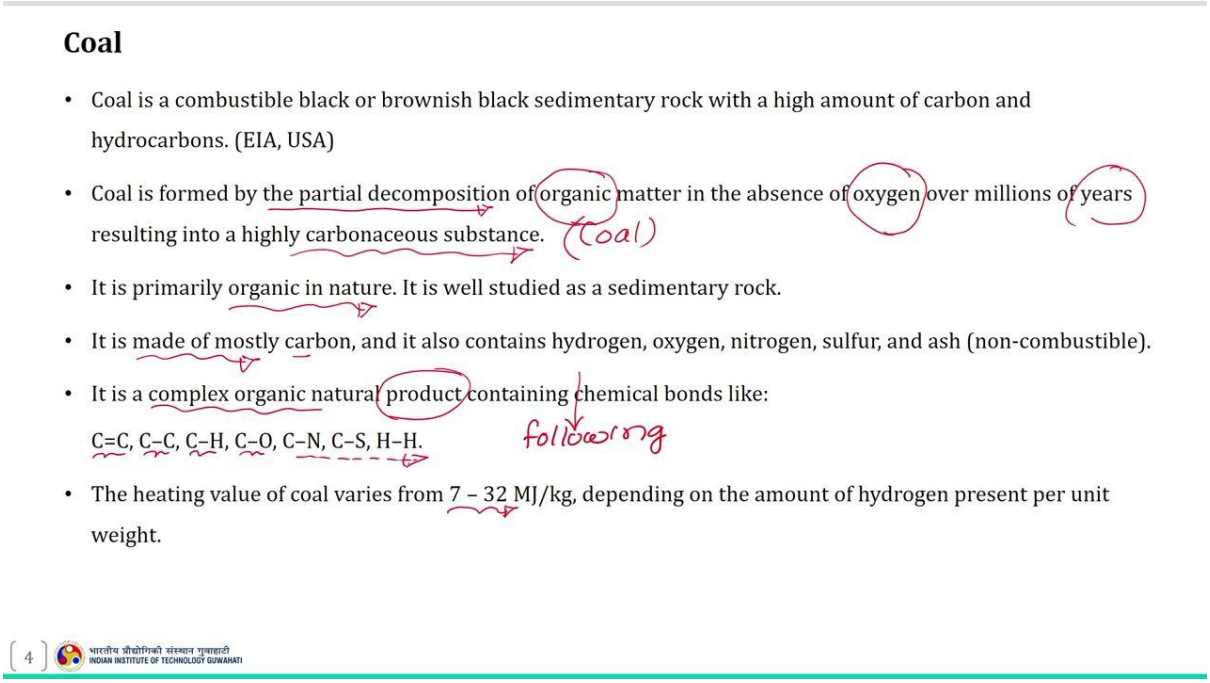
(Refer slide time: 00:50)



So, coal, oil and biomass provide most of the India's energy requirements. During last three decades these sources fulfilled over 80% of India's overall energy consumption. So, coal has underpinned the expansion of electricity generation and industry and remains the single largest fuel in the energy mix.

Coal now accounts for 44% of India's primary energy requirements compared to 33% in 2000. India possesses world's fifth largest coal reserve. And after coal conventional biomass predominantly firewood, charcoal, animal waste are rural India's primary energy source. Because in rural India biomass is practically free or are available at very low cost compared to more expensive commercial fuels. Coal and biomass has played a significant role in India's energy consumption and thus the application of biomass and coal for energy has a huge potential in India. So, here onwards in this module as well as the remaining modules we will be mostly discussing on biomass and coal as a source of energy.

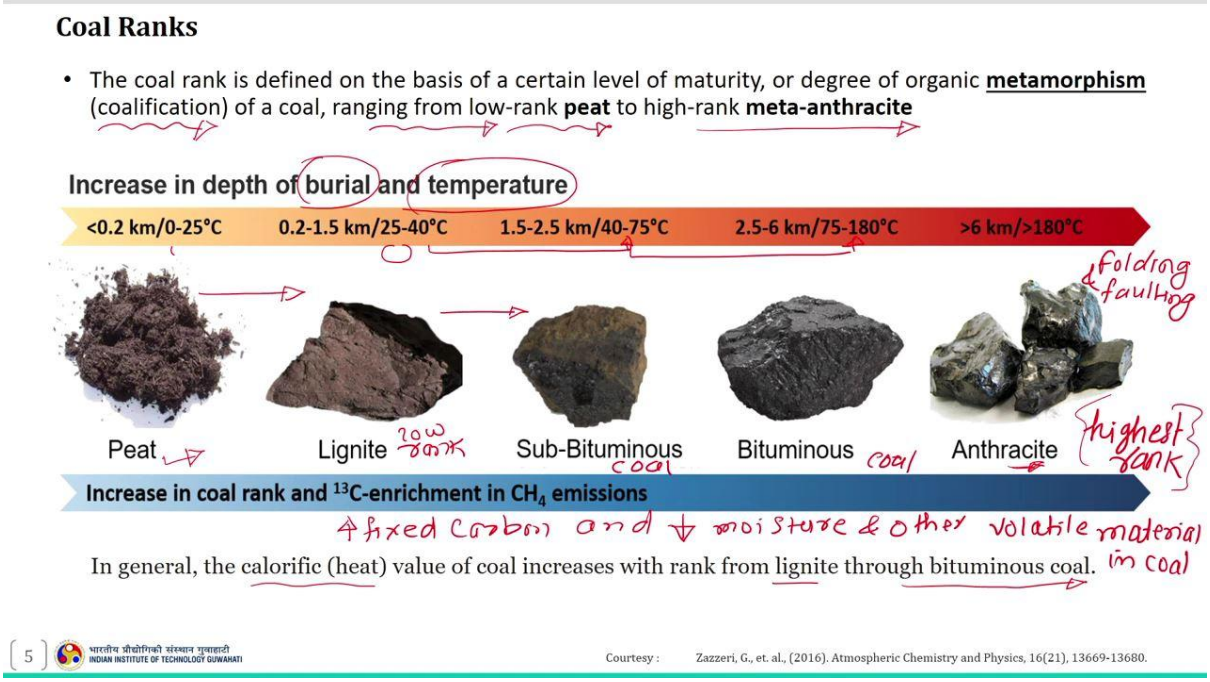
(Refer slide time: 03:03)



So, let us first discuss about the coal. Coal is a combustible black and brownish black sedimentary rock with high amount of carbon and hydrocarbons. So, if you see here the coal is formed by partial decomposition of organic matter in the absence of oxygen over millions of years resulting into a highly carbonaceous substance and which we name it as a coal. It is primarily organic in nature and it is well studied as a sedimentary rock. It is made of mostly carbon and it also contains hydrogen, oxygen, nitrogen, sulphur and ash. So, ash here is basically a non-combustible matter in the coal composition. It is a complex organic natural product containing following chemical bonds like C=C, C-C, C-H, C-O and likewise.

So, the heating value of the coal it varies from 7 to 32 MJ/kg. And it mainly depends on the amount of hydrogen present per unit weight and this is also one of the parameter to rank coal.

(Refer slide time: 05:05)



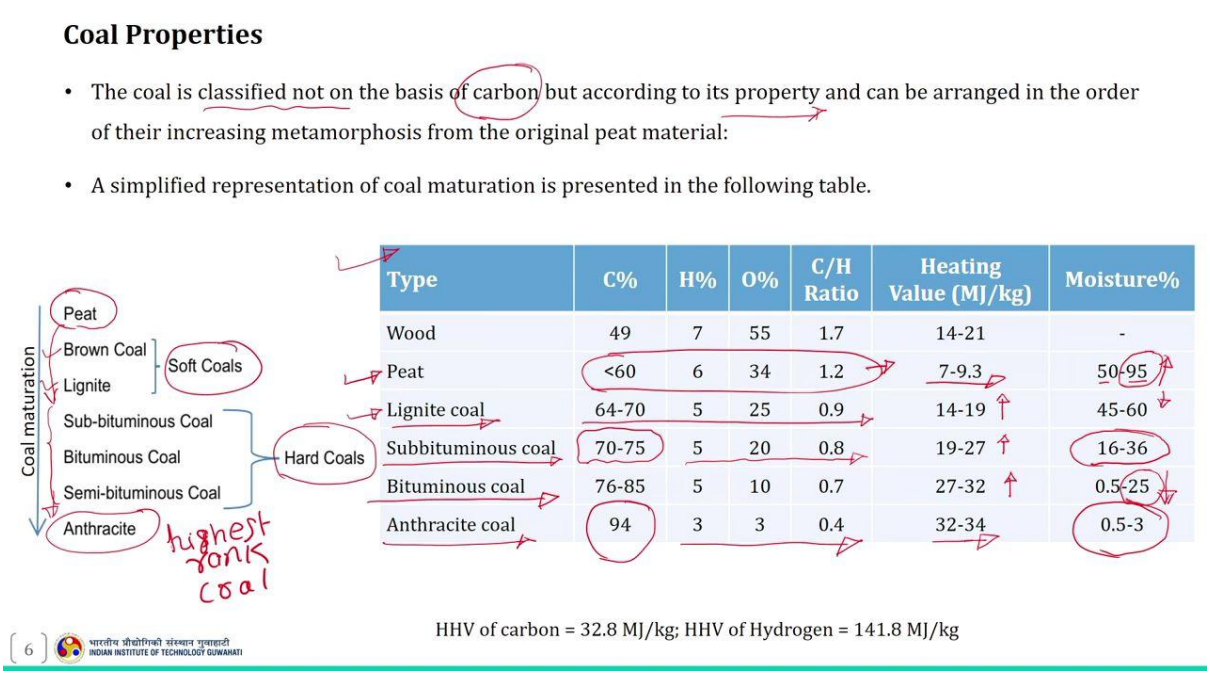
So, now let us discuss about coal ranks. The coal rank is defined on the basis of certain level of maturity or degree of metamorphism of coal and that is also called as Coalification, which basically use as a criteria to rank coal from low rank pit to high rank Meta anthracite. So, the rank of coal is determined primarily by the depth of deposition and the temperature to which coal was subjected over time.

For example, with increasing temperature peat is converted to lignite, a very soft or you can say a low rank coal with further increase in temperature. Here you can see lignite is transformed to sub bituminous coal and then further to bituminous coal. So, if you see here the temperature difference also between these two classes of coal there is a significant difference between these two classes of coal as well. At even higher temperatures, usually accompanied by intense deformation generated by folding and faulting of the earth crust, anthracite the highest rank coal are produced.

So, this schematic it gives the visual representation of rank of coal starting from peat to anthracite which is the highest rank coal. The increase in coal rank is accompanied by

increase in amount of fixed carbon and decrease in the amount of amount of moisture and other volatile material in coal sample. In general, the calorific value of coal increases with rank mainly from lignite through bituminous coal. So, this gives information about the coal ranks. So, now after learning about this coal rank, let us discuss about the coal properties.

(Refer slide time: 08:42)



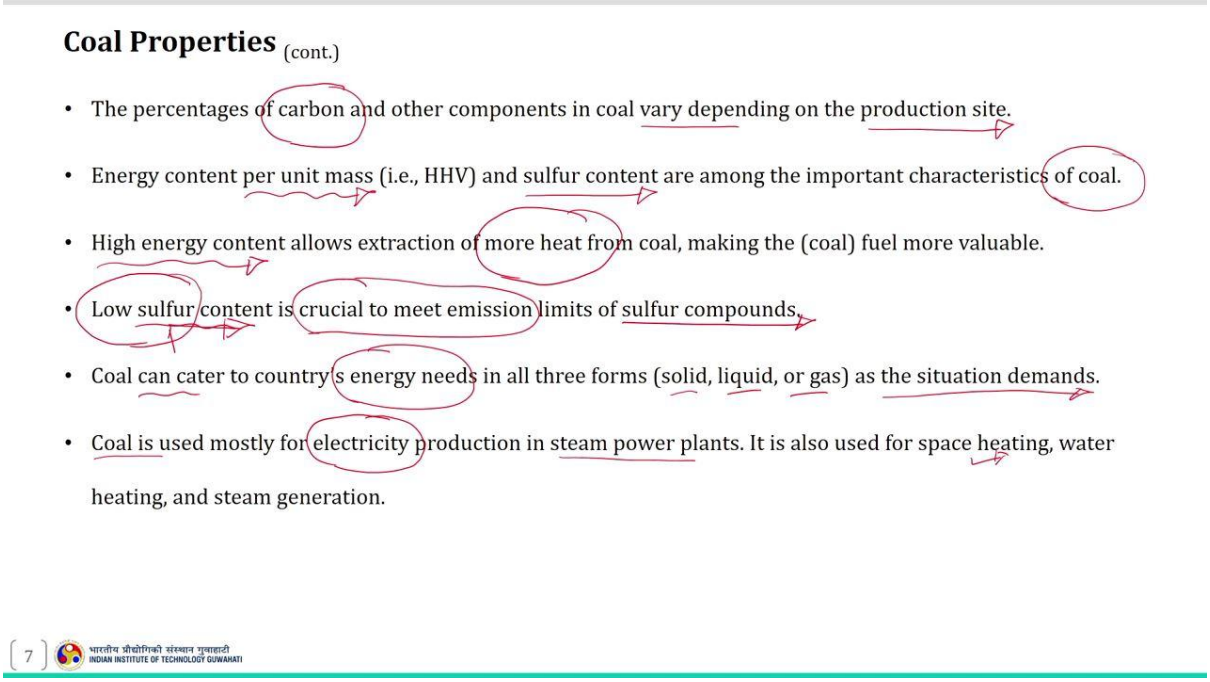
The coal is classified not on the basis of carbon but according to its property and can be arranged in the order of their increasing metamorphosis from the original peat material. A simplified representation of coal maturation is shown here in this table. So, if you see here that increasing metamorphosis from the original peat material, so the peat converted into a soft coal that is brown coal and lignite. Further this lignite convert into sub bituminous coal, bituminous coal and semi bituminous mainly a hard coals and this bituminous coal further converted into anthracite and anthracite is the highest rank. So, the original peat material contains the composition in this form which is shown here in this table and has the heating value in the range of 7 to 9.3, whereas the moisture content in the peat material is significantly high and it varies between 50 to 95 percent. The lignite coal has this particular composition and heating value of lignite material is relatively higher than that of peat material. Similarly, the moisture content is relatively less in case of lignite. Sub-bituminous coal contains carbon in the range of around 70 to 75 percent with remaining composition like

hydrogen, oxygen and C by H ratio in this form. And the heating value of sub bituminous coal is relatively higher than that of lignite and peat material.

Similarly, even the moisture contained in the sub bituminous coal is marginally less. Now, the bituminous coal and its composition, if you see here in this case the heating value is significantly higher. Similarly, the moisture percent is also relatively less in case of bituminous coal. Whereas, this indicates the highest limit of moisture content in the bituminous coal. And the last in the list is the anthracite coal which has highest carbon content of around 94% with remaining composition as shown here in the table.

And the heating value is in the range of 32 to 34 MJ/kg and the moisture content is significantly less in case of anthracite coal. So, the composition of coal sample which are shown here in this table does not remain constant and this composition varies from site to site.

(Refer slide time: 12:35)

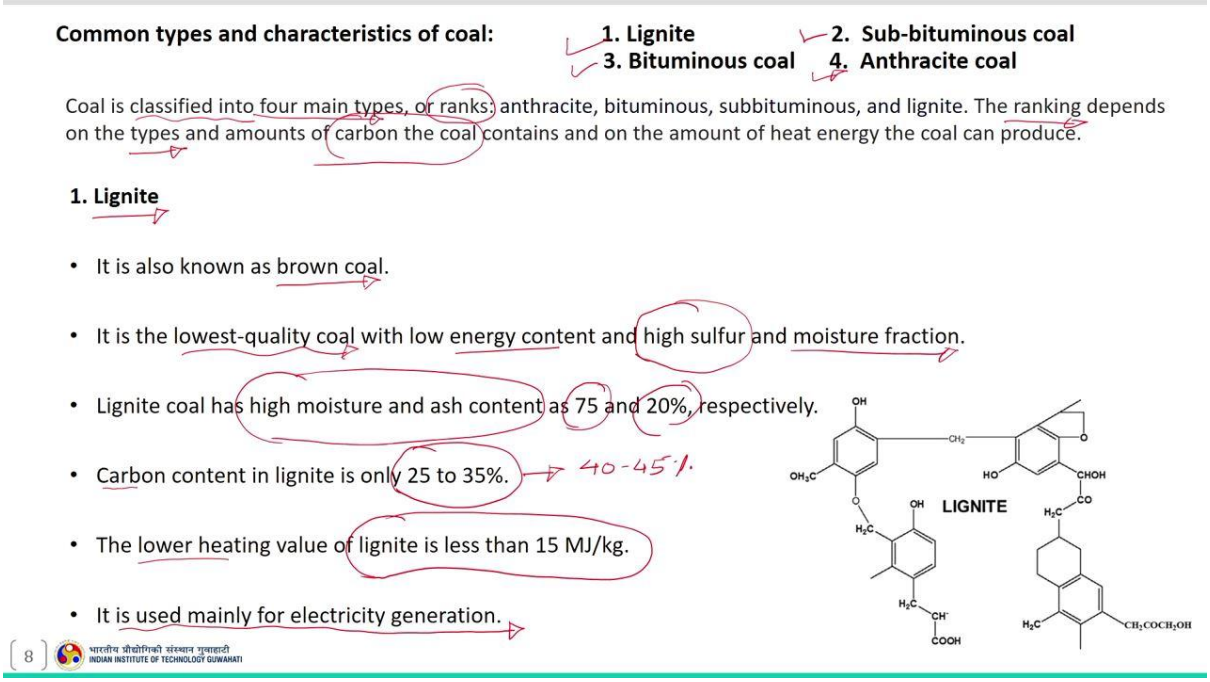


For example, the percentage of carbon and other component in coal vary depending on the production side and that is what as I mentioned in the previous slide. The composition of coal does not remain same and it varies from side to side. The energy contained per unit mass and the sulphur contents are among the important characteristics of coal sample.

In fact, the high energy content in the coal allows extraction of more heat from the coal making the coal or you can say a fuel more valuable. So, basically here as discussed in one of the slide previously, the coal ranks according to their calorific value as well. Low sulfur content is crucial to meet emission limits of sulfur compound. So, this is one of the important properties of coal where we always look for low sulfur content coal for the utilization purpose. Coal can cater to country's energy needs in all three forms that is solid, liquid or gas as the situation demands.

That means the solid coal can be converted into either liquid or gaseous fuel using a suitable and efficient conversion technology, so that the produced fuel either in the form of liquid or gas can be used for further utilization purpose and it mainly demand driven. Coal is used mostly for electricity production in steam power plants. It is also used for space heating water heating and steam generation. So, coal has significant application in the different ways.

(Refer slide time: 15:05)

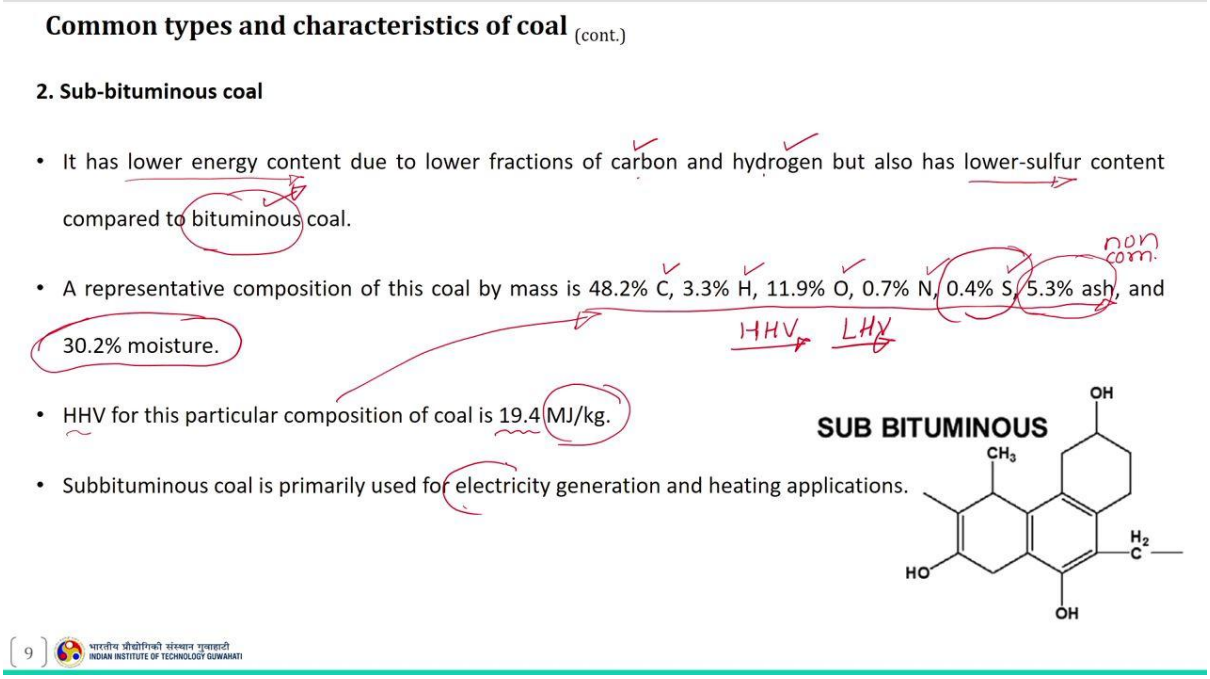


So, after learning about the coal properties, let us discuss about the common types and the characteristics of coal. Coal is classified into four main types or you can say the rank as well, that is lignite, sub bituminous, bituminous coal and the last in the list is the anthracite coal. And this particular classification and the ranking it depends on the types and amount the coal

contains and the amount of heat energy the coal can produce. So, basically the coal and its classification and ranking it mainly depends on the amount of carbon the coal contains as well as the amount of heat coal can produce during combustion process. So, let us discuss about these four main classification or we can say the four main types of coal. So, first let us begin with the lignite.

Lignite is also known as brown coal. It is the lowest quality coal with low energy content and high sulfur and moisture fraction in its composition. Lignite coal has high moisture and ash content as 75 and 20% respectively. Similarly, carbon contained in lignite is only 25 to 30 percent and in some cases we may find it is in the range of around 40 to 45 percent. The lower heating value of lignite is less than 15 MJ/kg and this type of used mainly for electricity generation.

(Refer slide time: 17:40)

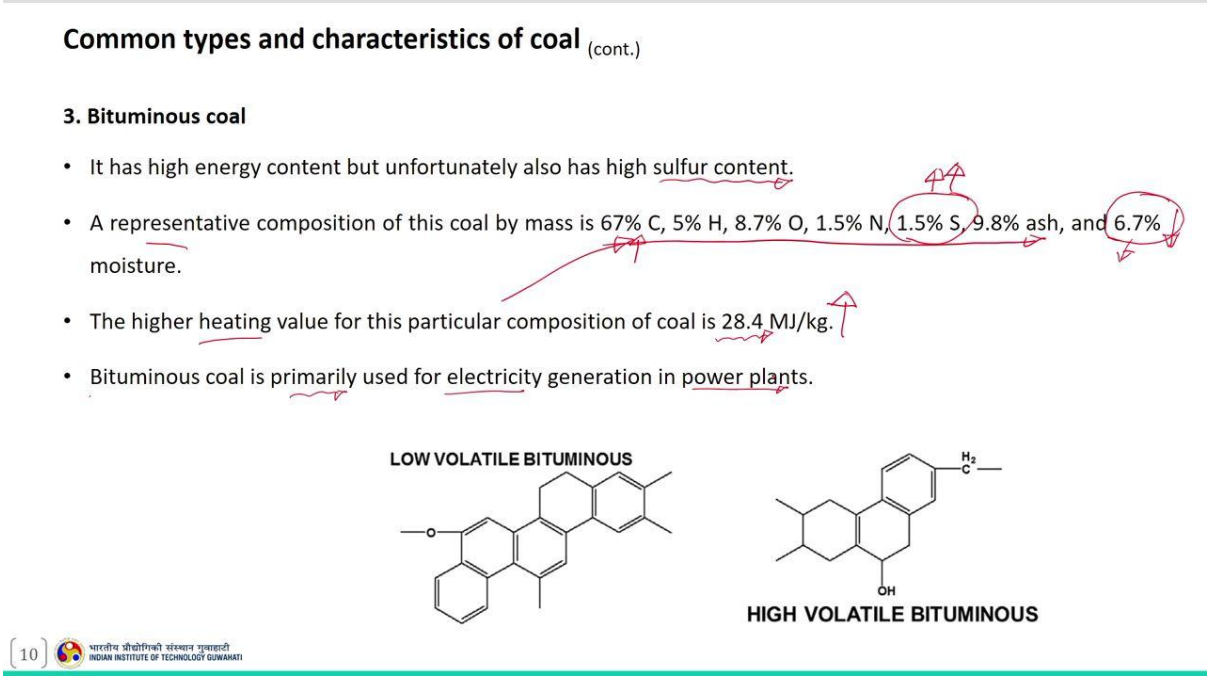


So, the next in the list is sub-bituminous coal. So, it has low energy content due to lower fraction of carbon and hydrogen, but also has lower sulphur content compared to that of the bituminous coal. So, if you see the composition of sub bituminous coal here, so it has lower fraction of carbon and hydrogen but also has lower sulphur content in its composition. So, if you see here the sulphur content in its composition is relatively less compared to that of the bituminous coal. Here if you can see here, a representative composition of this type of coal is

shown here which is in the form of carbon, hydrogen, oxygen, nitrogen, sulphur and ash, which is basically a non combustible material in the composition of coal and it has moisture content of around 30.2%.

So, if you see the higher heating value for this particular composition of coal, it is around 19.4 MJ/kg. So, here I want to just brief you that once we know the composition of the coal, so with the help of certain empirical equation, we can easily calculate the higher heating value of coal sample as well as the lower heating value of coal samples. Sub bituminous coal is primarily used for electricity purpose and heating applications.

(Refer slide time: 19:48)

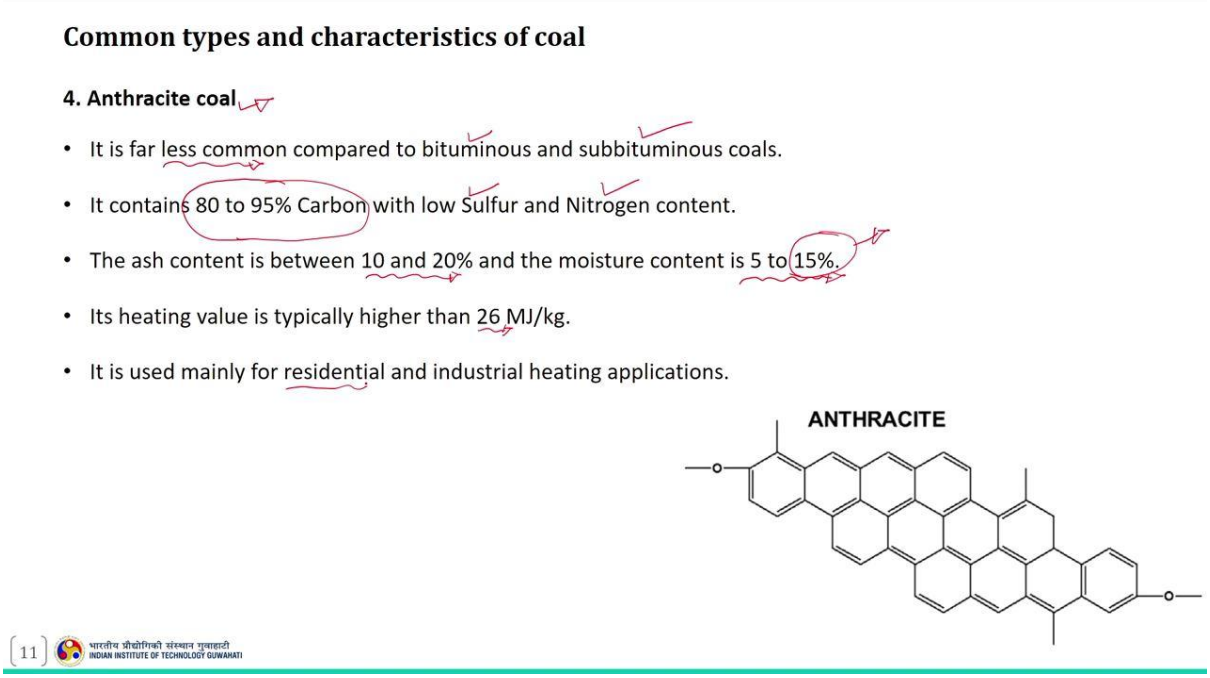


So, next classification is bituminous coal. This type of coal has high energy content and unfortunately also has high S content. So, that is the limitation of this kind of coal materials. A representative composition of this coal biomass is also shown here.

In this case if you see, so the sulphur content in this composition is relatively higher. However, if you look at the moisture content, so the moisture content in this coal is relatively less and the higher heating value of this particular composition of the coal if you can see here it is around 28.4 MJ/kg. So, now if you see particularly this composition, because of low moisture content as well as relatively higher carbon content, the higher heating value of this

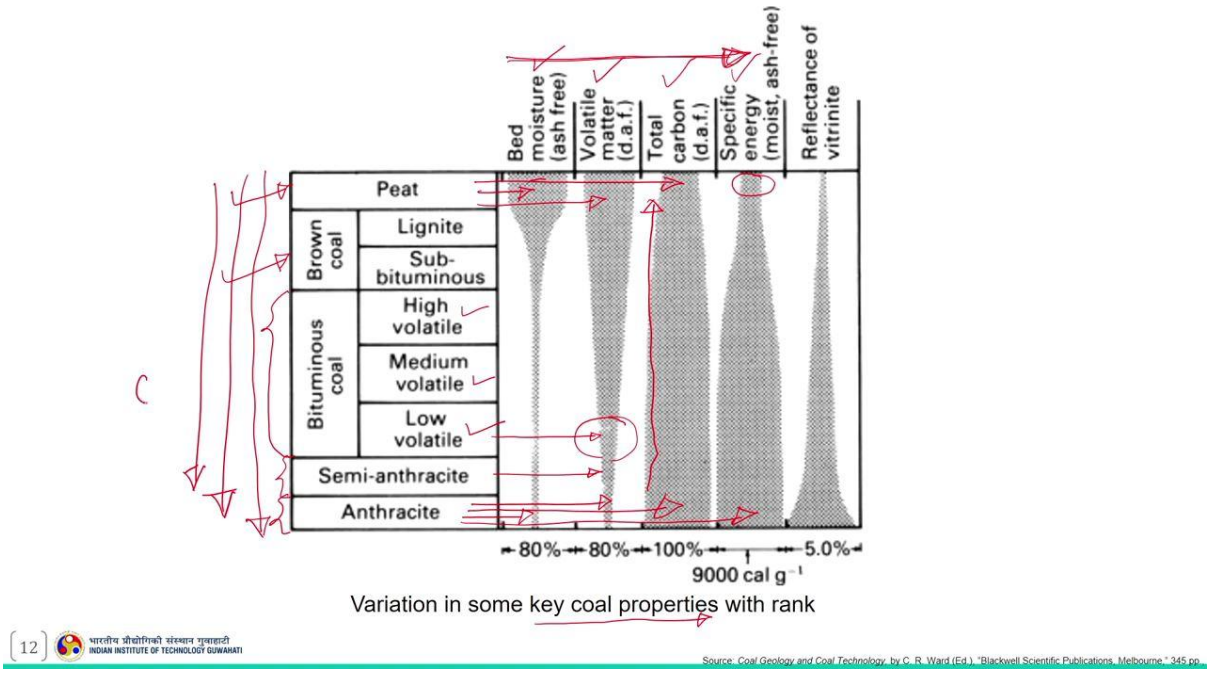
particular composition of coal is relatively high. Bituminous coal is primarily used for electricity generation in power plant.

(Refer slide time: 21:06)



So, the last classification in the list is anthracite coal it is far less common compared to bituminous and sub bituminous coals. It contains around 80 to 95 percent carbon with low sulfur and nitrogen content in its composition. Now, if you look at the ash content, it is between 10 to 20% and the moisture content is marginally less in case of anthracite coal. This particular number here it indicates the highest limit of moisture content in the anthracite. However, in case of anthracite the moisture content varies between around 0.5 to 5% or 6%. Its heating value is typically higher than 26 MJ/kg and it is mainly used for residential and industrial heating application. So, this is about the anthracite coal.

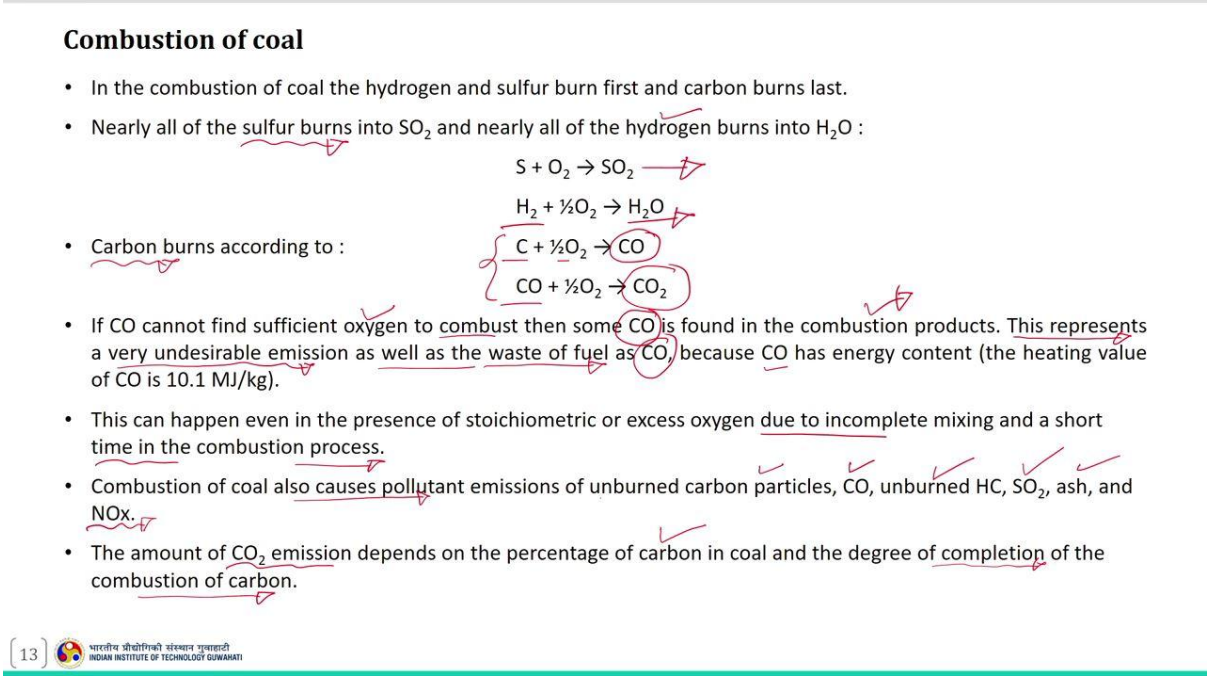
(Refer slide time: 22:20)



This schematic here provides the visual representation of variation in some key properties of coal sample. For example, the original peat material, then you can see here the lignite and sub bituminous coal, then the bituminous coal which is sub classified into high volatile coal, medium volatile coal and low volatile coal followed by semi anthracite coal and anthracite coal. And this side it represent some key properties of coal for example moisture, volatile matter, carbon content and specific energy content of coal. So, now if you look at the schematic, so from this schematic it indicates that the pit has highest moisture content, whereas anthracite has the least moisture content in its composition.

Similarly, the volatile matter content is highest in pit and lowest in anthracite. Similarly, the semi anthracite and low volatile bituminous coal has relatively less volatile matter in its composition. While the total carbon content, we can see here the reverse trend that the total carbon content is highest in anthracite and minimal in peat material and it is decreasing from anthracite to peat material. Similarly, if you see the specific energy content, the specific energy contained in the anthracite coal is highest and lowest in the peat material. So, this particular schematic, it also gives the visual representation of variation in some of the key properties of coal even as per coal rank.

(Refer slide time: 24:55)

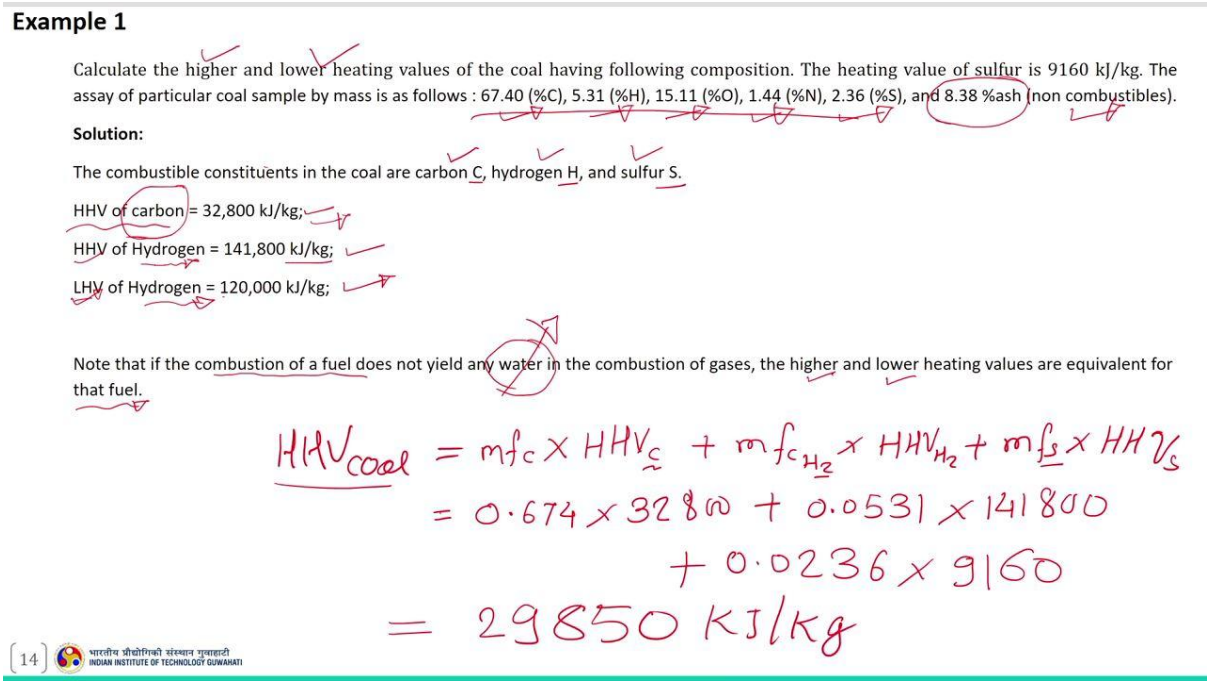


So, after understanding about the different properties of the coal, let us discuss about the combustion of coal. During the coal combustion process, sulfur and hydrogen burns first and carbon burns last. Nearly all sulfur burns into SO_2 and nearly all hydrogen burns into H_2O. And carbon burns according to these two reactions where carbon first get oxidized to form CO and then CO further get oxidized to form CO_2. So, if CO cannot find sufficient oxygen to combust then some CO is found in the combustion product.

That means if the CO does not find sufficient oxygen during the combustion process then it comes out as it is along with the combustion product without further getting reacted in the process. This represents a very undesirable emission as well as the waste of fuel as CO, because CO also has energy content and the heating value of CO is around 10 MJ/kg. So, if CO comes out as it is without further getting combusted in the combustion process, so that also represent as a loss of heat. And this is not only because of the limited supply of oxygen, this can also happen in presence of stoichiometric amount of oxygen as well as excess oxygen during the combustion process because due to incomplete mixing and a short time in the combustion process. Combustion of coal also causes pollutant emission of unburnt carbon particle, carbon monoxide that is CO, unburnt hydrocarbon, SO_2, ash and NOx.

The amount of CO_2 emission, it mainly depends on the percentage of carbon in the coal and the degree of completion of the combustion of carbon. So, that is what I mentioned earlier. If CO comes out as it is in the form of combustion product without taking part further into the combustion process that also causes pollution. So, after discussing on the coal and biomass sources, coal ranks, common types and characteristics of coal, combustion of coal, let us try to solve one simple example with the help of this coal composition.

(Refer slide time: 28:04)



As I mentioned earlier the coal composition can also be used to calculate the HHV as well as the LHV of the given coal sample. So, let us try to solve one simple example considering the following coal composition. So, in this example here we need to calculate the higher heating value as well as the lower heating value of the coal which has following composition. So the composition of coal is given as carbon 67.4%, hydrogen 5.31%, oxygen 15.11%, nitrogen 1.44%, sulfur is given as 2.36% and ash is around 8.38%. But as I mentioned earlier, this is basically a non-combustible material. So with the help of this given data, we need to calculate the higher heating as well as the lower heating value of the given coal sample.

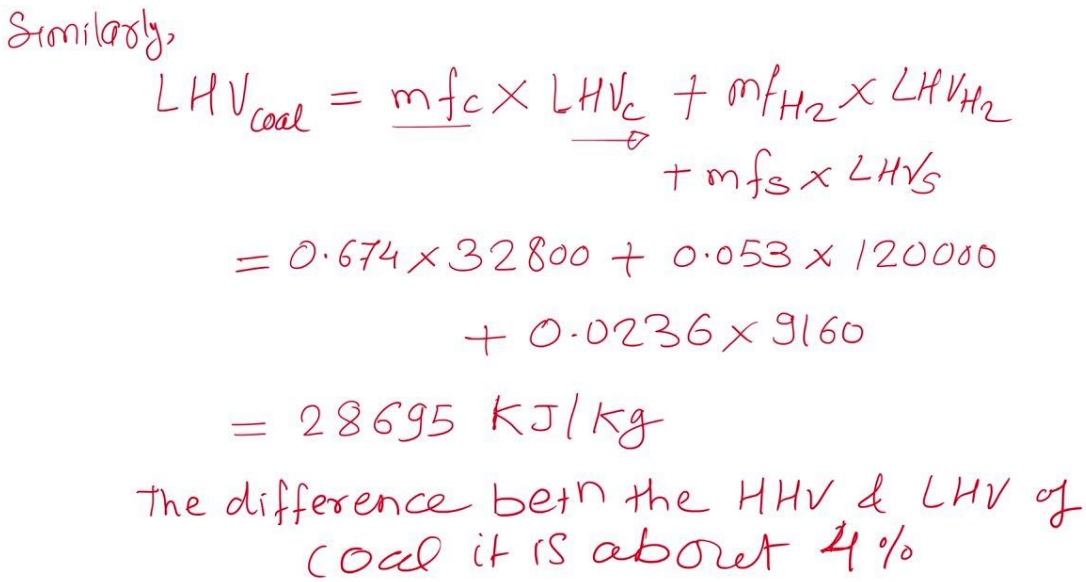
So, the combustible constituents in the coal are mainly carbon, hydrogen and sulphur, which we already discussed just now, that the combustible constituents in the coal are carbon, hydrogen and sulphur. And the higher heating value of carbon is given as 32,800 kilo joule

per kg, HHV of hydrogen is given as 141800 kilo joule per kg and lower reading value of hydrogen is given as 1200 kilo joule per kg. So, in this example we have to note that if the combustion of fuel does not yield any water in the combustion of gases, then the higher and the lower heating value are equivalent for that particular fuel. For example, in case of pure carbon, if the pure carbon is undergoing the combustion process, so it will not yield any water and because of that the higher heating value as well as the lower heating value of carbon is equivalent. Similarly, in case of hydrogen here, we can see that higher heating values as well as the lower heating value are given.

Because the combustion of these fuels may yield water in the combustion product and because of that the higher heating value and the lower heating value of this particular fuel are different. So, now let us try to solve this small example here. So, for the calculation of higher heating value as well as the lower heating value of this coal sample we have to use this following equation. With the help of this equation we can calculate the higher heating value as well as the lower heating value of the coal sample of given composition. So, higher heating value of coal is equal to mass fraction of carbon into higher heating value of carbon plus mass fraction of hydrogen into higher heating value of hydrogen plus mass fraction of sulphur into higher heating value of sulphur.

Because these three are the major combustible constituents in the coal. So, the mass fraction of the carbon is known that is 0.674 as well as the high reading value of the carbon is given here in this example that is 32,800 plus mass fraction of the hydrogen is 0.0531 into higher heating value of hydrogen as 141.800 plus mass fraction of sulphur 0.0236 into the higher heating value of sulphur and its value is already given in the example as 9160. So, now if you just, if you multiply this value and take the summation of those values we will get the answer in the form of 29850 kJ/kg.

(Refer slide time: 33:10)



So, in the similar line we can also calculate lower heating value of coal. So, similarly now we can calculate mass fraction of carbon. Now instead of using the higher heating value of carbon we will use the lower heating value of carbon for the calculation purpose.

Plus mass fraction of hydrogen into lower heating value of hydrogen plus mass fraction of sulphur into lower heating value of sulphur. Now, mass fraction of carbon is known. So, now here the lower heating value is given as because since in case of carbon the lower heating value and the higher heating value are equivalent. So, we are using the same value of higher heating value of carbon here that is 32800 plus mass fraction of hydrogen is given as 0.0531 into so the lower heating value of hydrogen is 1200. Clear? And now we will just use the mass fraction of sulphur 0.0236. So, in this case as well we will be using the same value, so after multiplication and taking the summation of this number here we will get the value in the form of 28695 kJ/kg.

So, now if you take the difference between the higher heating value and lower heating value of coal here of coal it is about this. So, this is basically a very simple example. So, we can solve the example of similar type by just varying the composition of the coal. So, we will give some more examples for practice purpose in the assignment. And I hope you will be able

to solve this example easily because these are very simple calculation. We have to just use the high rating value and the mass fraction of the specific component in that composition.

So, with this we will end our lecture here. Regarding this lecture, if you have any doubts feel free to contact me at vvgoud@iitg.ac.in. So, in the next lecture that is part 2 of lecture 3, in that we will discuss about the biomass resources and biomass structure.

Thank you.