Renewable Energy Engineering - Solar, Wind and Biomass Energy Systems
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Lecture - 16
Broad Classification and Compositional Analysis

Good morning everyone and welcome to part 2 of lecture 1 under the same module. So in the previous lecture, we discuss about the introductory part of the energy then we discussed the energy consumption pattern then we discuss about the classification of energy resources, in that we discuss about also the sub classification of energy resources. Further we discussed about the common forms of energy.

In the common forms of energy, we also discussed mechanical energy, thermal energy, electrical energy and chemical energy. While studying the chemical energy it is stated that during this module as well as in the subsequent module, we will be mostly focusing on the chemical form of energy because we will be mostly studying the biomass as a energy resource during this module as well as in the subsequent module. So, how to tap this particular energy resource and utilize it for the production of usable energy.

That is what we are going to study in this model as well as in the subsequent modules. At the end we will discuss about the importance of non conventional energy resources. Due to the growing concern about the depletion of fossil fuels, as well as the environmental concern about the utilization of these resources, it has become more important to explore and develop non conventional energy resources.

However, during the development of these non conventional energy resources, it appears that the process of development of non conventional energy resources is going to take some more time. As a result, this particular resource will serve as a supplement rather than substitute to a conventional energy resource. One such form of non conventional energy resource which we will be discussing in this particular class is biomass. Then the broad classification of biomass and at the end we will discuss the composition of biomass. So, let us discuss this topic one by one.

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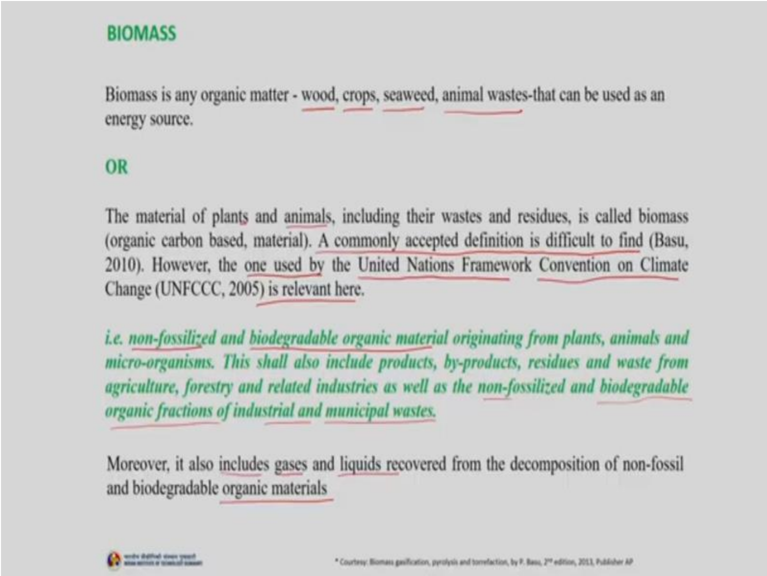

First of all, let us see what is mean by biomass. Biomass is an organic material that can be used as an energy resource. Now the example of the biomass we can say wood, crops, seaweed, animal waste we can consider all these materials as biomass or the material of plants and animals including their waste and residues is also called as biomass. It is very difficult to find a commonly accepted definition for biomass.

However, the one used by the United Nations Framework Convention on Climate Change is relevant here. What it says? Let us see. Non fossilized and biodegradable organic material originating from plants, animals and micro organisms, this is one way of defining the biomass. As well as these shall also include products, byproducts, residues and waste from agriculture, forestry and related industries as well as the non fossilized and biodegradable organic fractions of industrial and municipal waste.

So, this part of the materials can be termed as biomass. Moreover, it also includes gases and liquids recovered from the decomposition of non fossil and biodegradable organic materials. So, if you can see this entire slide, it only talks about how to define a biomass. So, I guess now it is clear that how to define a biomass. Biomass is considered to be a sustainable energy resource, because the growth of the biomass keep pace with its use that means it get replenished into the environment with a faster rate. As a result, we could term it as a renewable energy resource.

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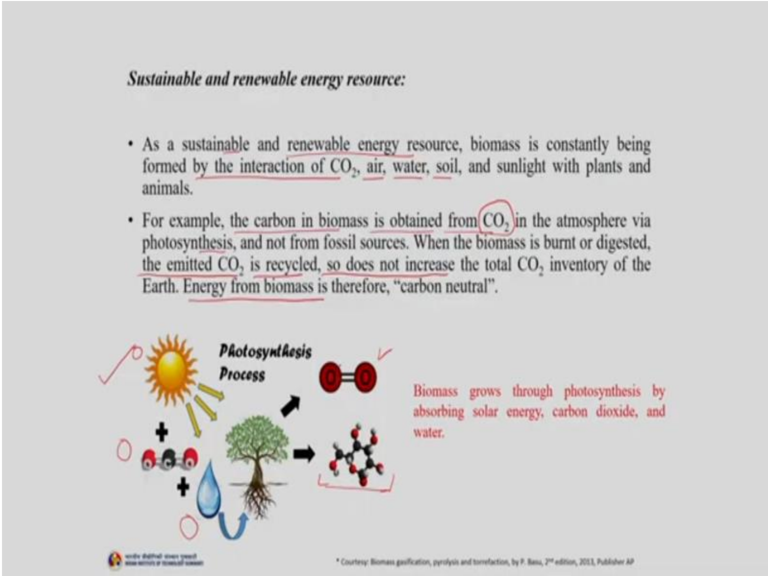

As a sustainable and renewable energy resource, biomass is constantly being formed by interaction of CO 2, air, water, soil and sunlight with plants and animals. If you just try to see one simple example for this, the carbon in biomass is obtained from CO 2 in the atmosphere via photosynthesis process and not from the fossil resources. This is very much clear here now, because the carbon in the biomass is mainly obtained from the CO 2 in the atmosphere via this photosynthesis process and it is not obtained from the fossil sources.

When the biomass is burnt or digested, the emitted CO 2 is recycled. So does not increase the total CO 2 inventory of the earth. And hence, the energy from the biomass is termed as carbon neutral. Let us see one small schematic which is shown here on this slide. Biomass grows through the photosynthesis by absorbing solar energy, carbon dioxide and water molecule.

So, while absorbing these 3 components, the photosynthesis process takes place as a result, it produces carbohydrate which is again here the representation of carbohydrate and oxygen as a molecule. So, during this photosynthesis process and during the growth of the biomass, the biomasses try to absorb solar radiation, CO 2 which is available into the atmosphere and the water from the moist soil. And by that way, the growth of the plant or you can say the biomass happens in the environment. As a result, it produces carbohydrate which is nothing but in the form of plant cell walls and releases oxygen into the environment.

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Now, biomass includes only living and recently dead biological species that can be used as fuel or in chemical production. So, another definition which is coming in place here is, biomass includes only living and recently dead biological species that can be used as a fuel or we can say for the production of fuel or production of chemical. Similarly, it is mentioned here, it does not include organic material that over many millions of years have been transformed by geological process into a substance of coal and petroleum.

So, this is also very much clear here, it does not include the organic materials which over millions of years have been transformed by geological processes into substances such as coal and petroleum. That is why these resources are regarded as conventional energy resource as well as the non-renewable energy resource. Biomass mainly comes from botanical and biological resources or from a combination of these 2. So, let us see about the formation of biomass.

So, incidence of solar radiation on green plants and other photosynthetic organism carry out 2 basic tasks, the first one proceeds the chemical reaction under controlled temperature and the second one is photosynthesis. Now let us see this particular step in more detail in the subsequent slide.

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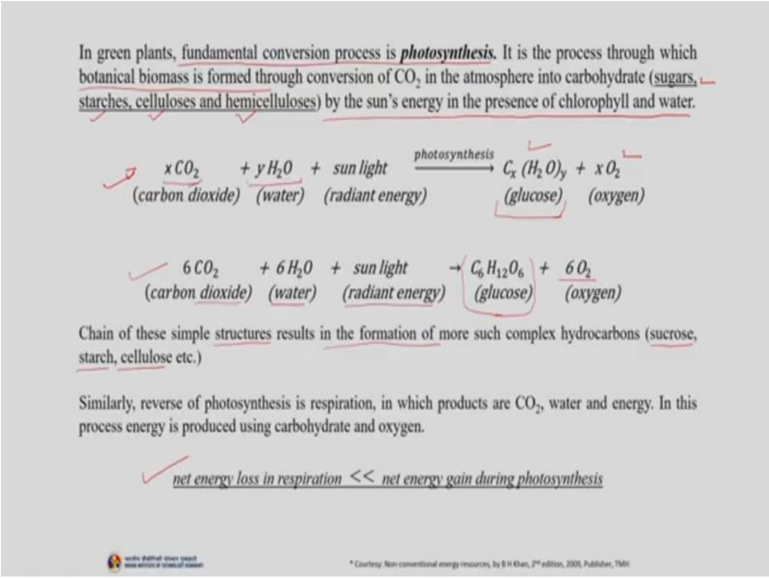

In green plants, if you see the fundamental conversion process is photosynthesis. It is the process through which botanical biomass is formed through conversion of CO 2 in the atmosphere into carbohydrate. Now the example of carbohydrate here you can see sugars, starches, celluloses, hemicelluloses by suns energy in presence of chlorophyll and water. So, this gives clear idea about the photosynthesis process and how it utilizes CO 2 in the atmosphere and converts into carbohydrate.

General representative scheme of photosynthesis process is shown here which shows x component or you can say molecule of CO 2 reacts with y molecule of water in presence of sunlight that is called as a or we can say which is a photosynthesis process converts into again here a carbohydrate representation which we have shown in the form of glucose plus oxygen as a molecule.

Now if you try to see this equation with the help of carbohydrate molecule and in the stoichiometric form, it shows 6 CO 2 that is the 6 carbon dioxide molecules react with 6 water molecules in presence of radiant energy of sun and use carbohydrate, again which we are mentioning here carbohydrate we have represented in terms of glucose plus oxygen, chain of these simple structure results in the formation of more such complex hydrocarbon such as sucrose, starch, cellulose, etcetera.

Similarly, if you try to see the reverse of this photosynthesis process that is called as a respiration, it produced CO 2, water and some amount of energy. Now if you try to see this respiration process, so in this process energy is produced using carbohydrate and oxygen. So, this is as simple as that. So that is why it is mentioned here. The net rate of energy loss in respiration is much less compared to the rate of energy gain during the photosynthesis process. Let us discuss this small concept in more detail in the next slide.

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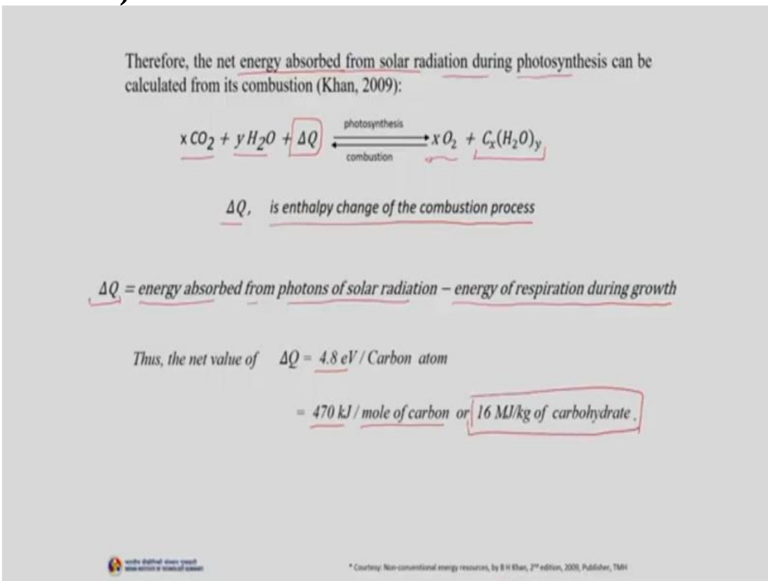

The net energy absorbed from solar radiation during photosynthesis can be calculated from its combustion process. Why we are saying here it is combustion, because the carbohydrate molecule is reacting with oxygen and then producing CO 2 water and energy. Although we mentioned here the combustion which is a respiration process, but conventionally if you try to see the combustion process which carries out at very high temperatures, say around like 400 degrees C.

But here as this reaction is taking place under the catalytic enzyme condition, here the temperature may be around 20 to 22 degree Celsius. So here the delta Q is nothing but the enthalpy change, of the combustion process. Now if you try to find out this delta Q from this equation, it is energy absorbed from photons of solar radiation minus the energy of respiration during growth of biomass and the net value of this delta Q is 4.8 electron volt per carbon atom.

If you just try to convert this value in terms of mole of carbon, it comes out to be 470 kilo Joules per mole of carbon or 16 Mega Joules per kilogram of carbohydrate. So, this value here, it represents the energy content of biomass which we normally use to measure this value using calorie meter and we term it as a calorific value. So now, let us see in detail about the types of biomass.

So up till this point, we discuss about how the formation of biomass is taking place in the environment by absorbing solar radiation as well as the CO 2 available in the atmosphere with some water molecule. So now, once these biomasses are formed, so this kind of biomass are available in various kinds of types as well as you can say in the categories.

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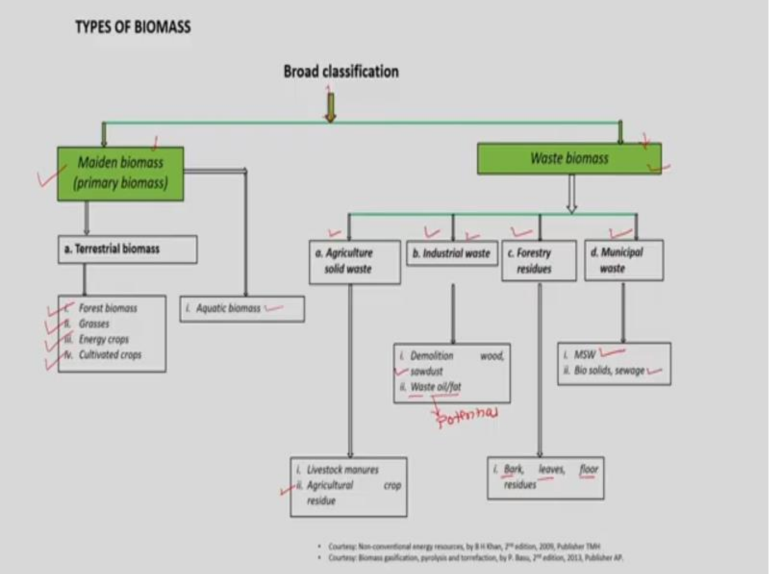

The types of biomass are classified in the following ways. The first one is maiden biomass and waste biomass. Let us discuss first of all with the maiden biomass. The maiden biomass is also termed as a virgin biomass or the primary biomass. It is further sub classified into terrestrial biomass and example of the terrestrial biomass or forest biomass, grasses, energy crops, cultivated crops as well as under this maiden biomass, there is one more classification which is shown here on the slide that is termed as aquatic biomass.

And the examples of the aquatic biomass are you can say seaweed, water hyacinth and algae. Now if we just talk about the waste biomass, it is further sub classified into 4 divisions. First, agriculture solid waste, so in that livestock manures, agriculture crop residue comes under the agriculture of solid waste. If you talk about the industrial waste, demolition of wood then sawdust, waste oil or fat comes under the industrial waste.

Now when you talk about a waste oil and fat here, this is a byproduct which is produced during the processing of edible oil seeds in the refinery. While processing the oil seeds in the refinery, it produces waste oil and the fat which also can act as a potential source for energy purpose. The third is forest residue. So, under forest residue bark, leaves, floor residues are termed as the forest residues. And if you talk about the last one that is the municipal waste then municipal solid waste, bio solids and sewage are classified under municipal waste. Now let us discuss these biomass types one by one in more elaborate way.

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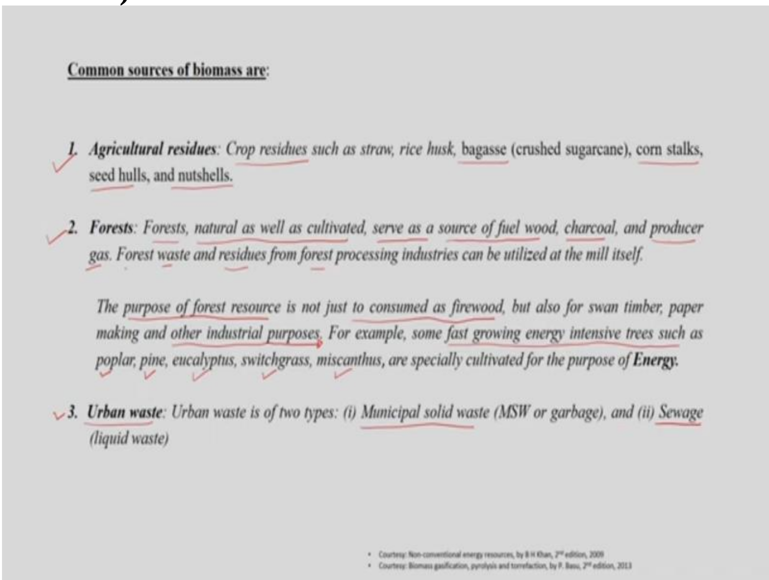

Let us discuss first the agriculture crops, the crop residues such as straw, rice husk, bagasse, corn stalks, seed hulls and nutshells. These resources can be gasified to produce producer gas. Alternatively, these resources can be converted into solid fuel by pelletization or brick wetting, when these resources are available in abundance. So, it is better to utilize these resources in pelletization or in the brick wet form, so that it can be used as an energy source for the combustion purpose.

So, the second one is forest, forests, natural as well as cultivated, serve as a source of fuel wood, charcoal and producer gas. Forest waste and residues from forest processing industries can be utilized at the mill itself. If you just discuss this point in more detail, the purpose of forest resources is not just to consume as a fire wood, but also for timber processing industries, for paper making industries and other industrial processes where it can be used for specific purpose.

For example, some fast growing energy intensive trees such as poplar, pine, eucalyptus, switchgrass, miscanthus are cultivated for the purpose of energy and these are a very widely known, you can say a biomass for the energy purpose. So, the third classification which you have seen is urban waste. So, the urban waste is of 2 types, the first one is MSW which is called as a municipal solid waste and the second is sewage sludge.

Energy from the municipal solid waste can be obtained by combustion or you can say by incineration or it is also available in the form of landfill gas, whereas sewage sludge can be converted into a bio gas by some more stage of transformation. So, these are very widely known example for the energy purpose that is municipal solid waste and sewage sludge.

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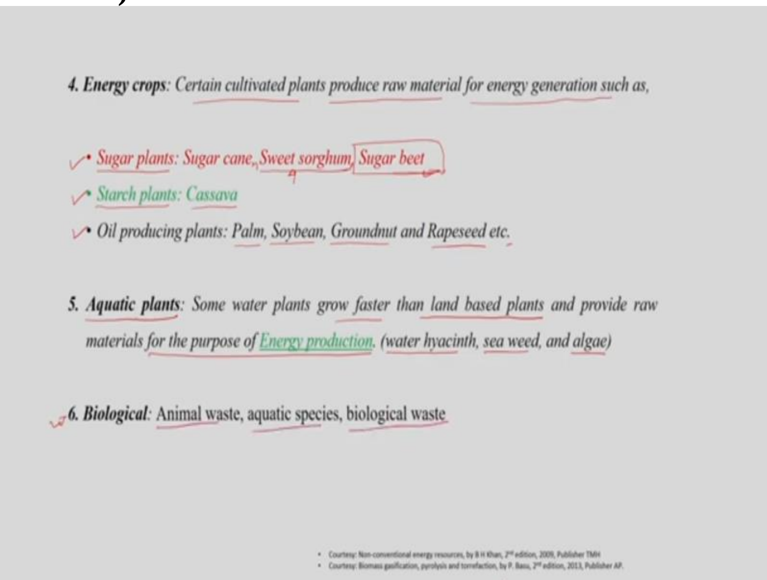

Now let us talk about the next classification that is energy crops, as I mentioned in my previous slide as well, some crops are majorly cultivated for the purpose of energy. So those crops are called as energy crops. Certain cultivated plant produces raw material for energy generation such as if you try to see here, we have divided into 3 sub type. Let us discuss first of all the sugar plant. Sugar plants such as sugar cane, sweet sorghum and sugar beet these are used as a raw material for the ethanol production.

First of all, we just discuss about the sugar cane. The sugarcane while processing in the sugar mill use 2 by product that is molasses and bagasse. These 2 materials can be utilized for the formation of ethanol. Similarly, sweet sorghum is also supplied as a raw material for ethanol production, especially, when the supply of this material is not essentially required in the sugar mill then, this particular material supply as a raw material for ethanol production.

Sometime the sugar beets are majorly cultivated for the production of ethanol, so that it can act as a raw material to produce ethanol. The second sub classification is starch plant and very well, known example is cassava because the starch containing cassava is fairly high. And the third is oil producing plants, oil producing plants such as palm, soybean, rapeseed oil, groundnut oil and many more such examples are there which are used for the production of energy.

Now when we process the seeds of these plant for the production of oil as I mentioned earlier in the previous slide it generates certain amount of waste oil and the fat. Those particular fats and oil can be effectively utilized for the generation of energy as it has sufficient amount of fatty acid composition, hence it can act as a potential source for the production of diesel. The next classification is aquatic plants, some water plants grow at a faster rate than land based plants and provide raw material for the purpose of energy production.

So, in the previous slide, we also discussed this point and the examples are water hyacinth, seaweed and algae. So, the last classification which I mentioned deliberately here in this slide is biological or you can say the biological material or the biological waste. So, the animal waste, aquatic species and biological waste, it can be also used as a source for the energy purpose, so this all accounts to the different types of biomass which can be used as a raw material for energy generation.

Now based on this type of biomass, if you try to decide on which type of biomass can effectively fit into the production of energy then a small questionnaire has been shown here in this slide.

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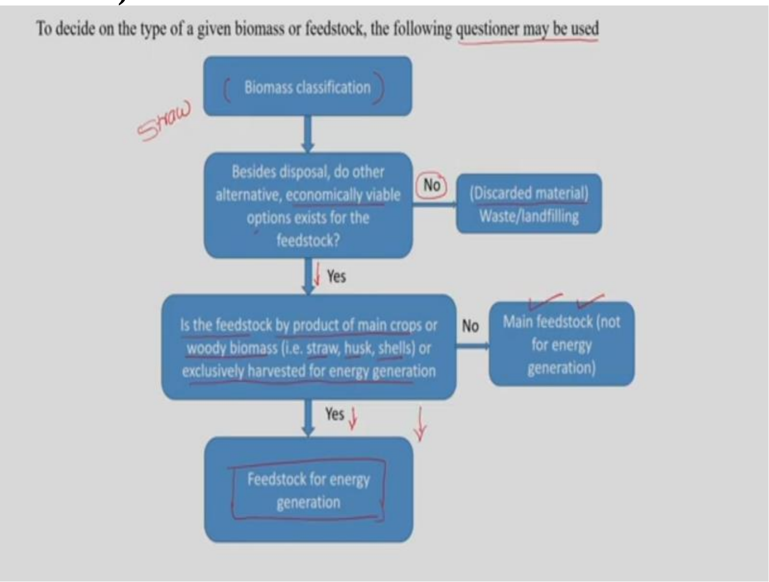

With the help of this questionnaire we can find out whether the specific biomass can be used as a source for energy generation or not. So, let us start with the first that is biomass classification which we already discussed in the previous slide. Now let us say we take one small example of straw here. Now once we say that we know there is a biomass in the form of straw is available for energy generation.

So now, the question which we need to ask is beside disposal do other alternative economically viable option exists for this feedstock if you say no then discard that material. Now if you say the answer is yes then we can proceed further to the next question. Is the feedstock byproduct of main crops or woody biomass that is for example, whether it is a straw, whether it is a husk or whether it is a shell or exclusively harvested for energy generation.

If again the answer is no then it is a main feedstock which we cannot use for the energy generation. And if again the answer is yes then we can consider the specific feedstock for energy generation. So it is very simple to identify a specific biomass either it can act as a feedstock for energy generation or not. Now with the help of this, as we clearly understood how to specify a specific biomass, whether it is a main feedstock or whether it is a feedstock for energy generation. so based on this let us try to find out the biomass structure.

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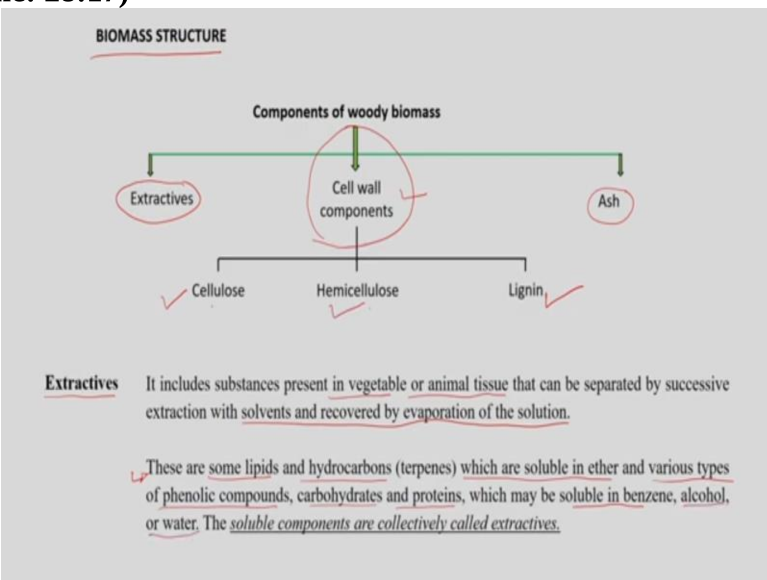

The biomass is a very complex compound which consists of carbohydrate proteins, fats, along with some mineral elements such as sodium, phosphorus, calcium and iron. So now, if you see here the component of woody biomass, these are mainly extractives, cell wall components and ass whereas, cell wall components are further classified as cellulose, hemicellulose and lignin.

Now let us discuss this component one by one, so that we can understand that what is the exact meaning of these extractives in the biomass? What is the cell wall of component of biomass? What is the lignin? What is cellulose and hemicellulose content in the biomass? First let us discuss about the extractives. Extractives include substances present in vegetable or animal tissue that can be separated by successive solvent extraction.

Further, we can recover these extractives by the operation of the solution. So, this is very commonly used technique for the recovery of the extractives from the plant cell wall or we can say from biomass. Extractives are some lipids and hydrocarbons which are soluble in ether or extractives which are also termed as various types of phenolic compounds, carbohydrates and protein which may be soluble in benzene, alcohol or water. These components which are soluble in solvent are collectively called as extractives. Now let us discuss about the cell wall. What is meant by the cell wall?

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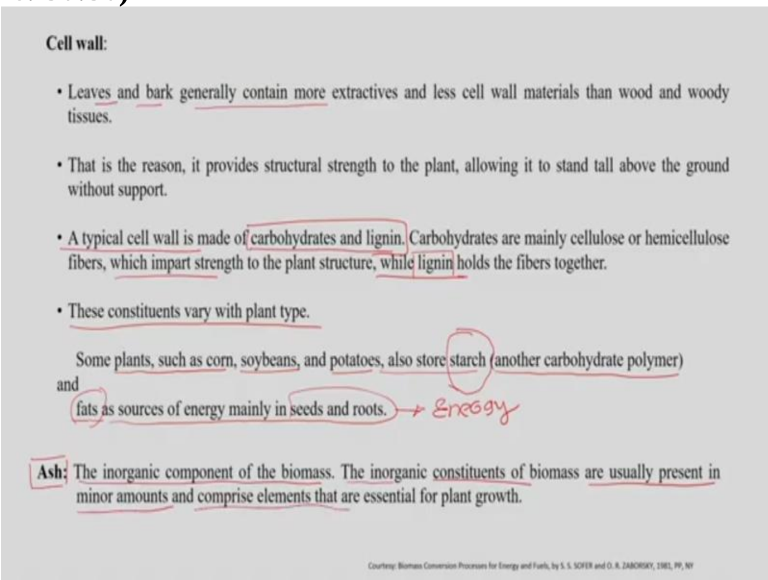

Leaves and the bark generally contain more extractives and less cell wall material than wood and the woody tissues that is the reason it provides structural strength to the plant allowing it to stand tall above the ground without any support. So, this cell wall provides structural strength to the plant and it allows the plant to stand alone above the ground without any support. A typical cell wall is made up of carbohydrate and lignin.

Carbohydrates are mainly cellulose or hemicellulose fiber which imparts strength to the plant structure, while lignin holds the fibers together. So that is the role of lignin which holds these fiber, cellulose and hemicellulose together as a result, this carbohydrate along with the lignin which termed as a cell wall provide structural strength to the plant and it allows it to stand alone in the atmosphere or above the ground without any support.

The constituents of this particular plant material is varies from plant to plant, we cannot say that these particular constituents are same in each and every type of biomass, no it is not possible, because all this biomass as you have discussed under the classification section are classified according to the sub classification that is forest residues, agriculture residues, municipal solid waste and the terrestrial biomass that is the origin biomass.

So, all this biomass has different constituents and as a result, this constitutes and its composition also varies from plant to plant. For example, some plants such as corn, soybeans, potatoes, also store starch. Now you can see here another carbohydrate polymer which is coming in picture which is nothing but starch which also use as a raw material for ethanol production. So, based on this, if you see another example that is fats as a source of energy mainly in seed and roots.

As I mentioned earlier, there are certain plants which are called as a seed, bearing plants which only bear the seeds which can be used as a raw material for oil production and those particular oil can be processed further for the production of energy. So obviously, the composition of such plant will be different than the constituents of the cell wall, so fats and oils as a major composition in terms of fatty acid oil.

So, it consists of different fatty acid composition and these fatty acids are used to produce energy. Similarly, the last is ash, the inorganic component of the biomass. The inorganic constituents of biomass are usually present in minor amounts and comprise elements that are essential for the plant growth. So up to this point, it discusses about the extractives, cell wall and then ash.

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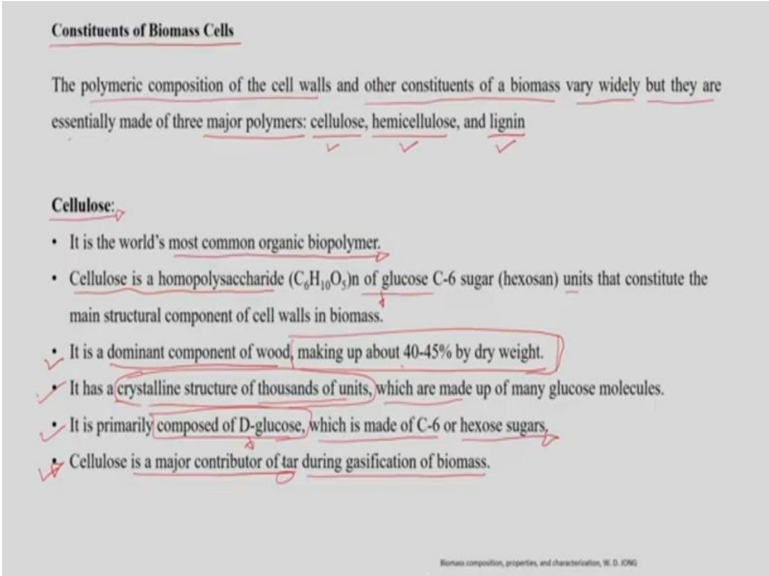

So, the next point is constituents of the biomass cells. The polymeric composition of cell walls and other constituents of biomass vary widely, but they are essentially made up of 3 major polymers and that is what I mentioned in the previous slide. The cell walls are majorly made up of 3 polymers these are cellulose, hemicellulose and lignin. First of all, let us see what is meant by the cellulose?

It is the world's most common organic bio polymer. Cellulose is also termed as the most common organic bio polymer. Cellulose is a homo polysaccharide of glucose C 6 sugar units that constitute the main structural component of cell walls in biomass and sugar in the form of glucose can be obtained from this cellulose biopolymer. Cellulose is a dominant component of wood making up about 40 to 45% by dry weight. So, this is found in the biomass in majorly 40 to 45% by dry weight.

Cellulose has a crystalline structure of thousands of units which are made up of many glucose molecules and that is the reason it is used for the energy generation, but it is not that easy to utilize the cellulose for the production of ethanol. So, we need to go for certain harsh pretreatment processes to break down this crystalline structure of cellulose and to make it more amorphous. So that it can be utilized for the energy purpose.

It is primarily composed of D glucose which is made up of C 6 or hexose sugars, as I mentioned. So, it is primarily composed of D glucose units. So, once you try to break the complex structure of cellulose, so it releases mostly sugar in the form of glucose unit, so that it can be conveniently converted into ethanol. This point to be noted here, cellulose is a major contributor of tar during the gasification of biomass.

Therefore, while selecting the feedstock for the gasification process we need to always be very careful considering this particular point into account that cellulose majorly contribute to the tar during gasification process. So, we should select such a biomass where the cellulose composition is relatively less and hemicelluloses is more, so that you can get better yield during the gasification process.

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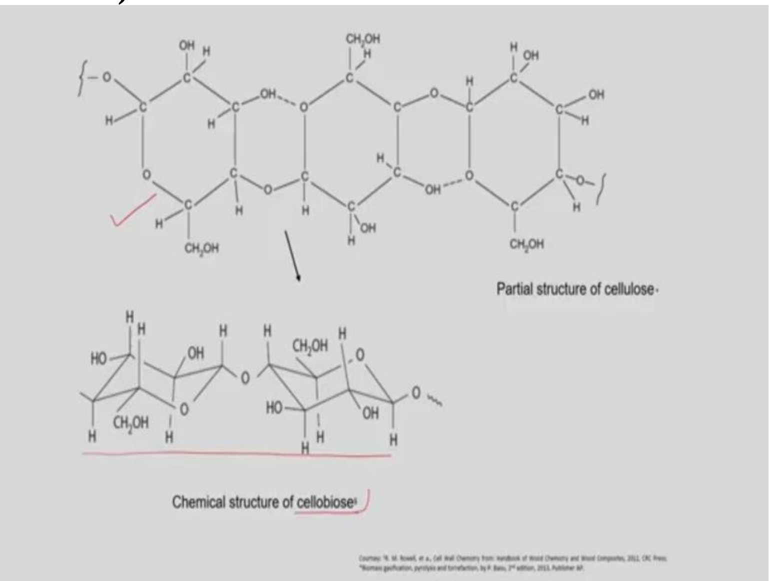

So, let us try to see some partial structure of cellulose in the next slide, if you see here, it represents the partial structure of cellulose, where we can see that the repetitive units of glucose are bind together so like this you can see the number of units will be there which constitutes a single cellulose molecule. Whereas 2 glucose molecules which unites together which form a cellobiose molecule which is also present in the cellulose, when you break down this particular cellulose during the harsh processing or you can say some pretreatment processes.

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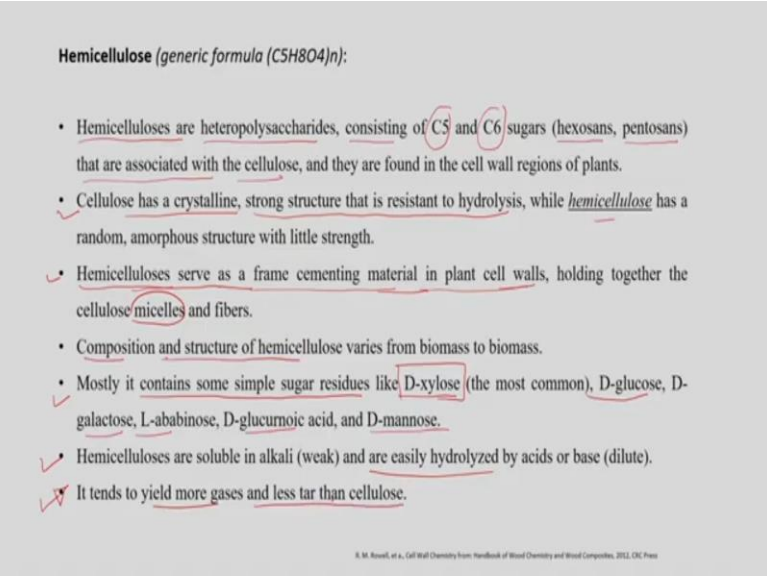

So next let us see, the hemicellulose fraction of the cell wall. Hemicelluloses are hetero polysaccharide consists of C 5 and C 6 sugars that is called as Hexosans and Pentosans. That are associated with the cellulose and they are found in the cell wall regions of the plants. So, as I mentioned earlier, cellulose and hemicellulose are majorly a fiber compound which you observe in the cell wall of the plant and lignin try to bind these fibers together along with the cellulose and hemicellulose which completes the cell wall structure of the plant.

Cellulose has a crystalline structure strong that is resistance to hydrolysis, while hemicellulose has a random amorphous structure with very little strength hence it is very easy to hydrolyze the hemicelluloses fraction than the cellulose. Hemicellulose serve as a frame cementing material in plant cell walls holding together the cellulose, micelles and fibers. Composition and structure of hemicellulose varies from biomass to biomass.

As I mentioned earlier also, we cannot expect the same composition or same composition as well as structure of hemicellulose in each and every biomass, it varies from biomass to biomass which I will explain in my subsequent slide. Mostly it contains more simple sugar residues like D-xylos, D-glucose, D-galactose, L-ababinose, D-glucurnoic acid and D-mannose. So, it contains all these simple sugars together whereas, majorly it contains D-xylose.

Hemicelluloses are soluble in alkali and are easily hydrolyzed by acids or alkali. Here also it has to be noted that the hemicellulose yield more gases and less tar than cellulose as I mentioned while discussing the cellulose part, if the biomass contains more hemicellulose, it is bound to produce more gas and less tar compared to the cellulose and hence the biomass with higher hemicellulose fraction can best suited for gasification process to produce producer gas.

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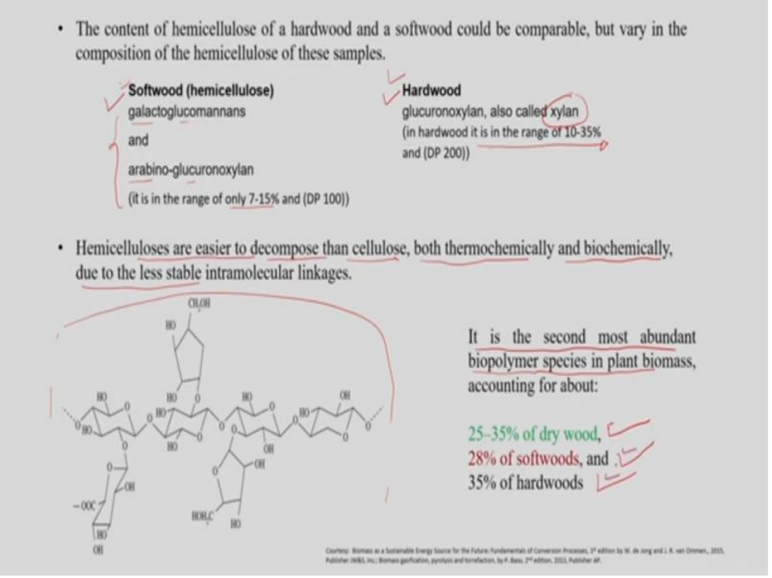

The structure of hemicelluloses we can see here in this slide, it represents the structure of hemicellulose. Now as I mentioned earlier, the composition as well as the structure of hemicellulose it varies from plant to plant. Let me brief you here in this slide, how it varies and how also the composition of hemicellulose varies from plant to plant. Let us take the example of softwood and hemicellulose content of the softwood and then hardwood and hemicellulose content of that particular hardwood.

If you try to see softwood galactoglucomannans and arabino glucoronoxylan are the major component you can see in the softwood which represent hemicellulose and it is in the range of 7 to 15%. Now if you talk about the hardwood it mostly contains xylan and it is in the range of 10 to 35%. So, it shows here how hemicellulose and its composition as well as its structure also changes from softwood to hardwood.

And you can also see the difference in the compound which are present in these particular woods which indicate itself that the composition as well as the constituents of the hemicellulose also varies from plant to plant. Now if you try to see here, the hemicelluloses are easier to decompose than cellulose, both thermo chemically and biochemically due to the less stable intramolecular linkage.

So that is the reason I mentioned that it is very easy to hydrolyze the hemicellulose molecule rather than the cellulose molecule and it is considered as the second most abundant biopolymer species in the plant biomass, accounting for about 20 to 35% of dry wood, 28% of softwood and 35% of hardwood, so hemicellulose its composition it always varies in this particular range in dry wood, softwood and hardwood.

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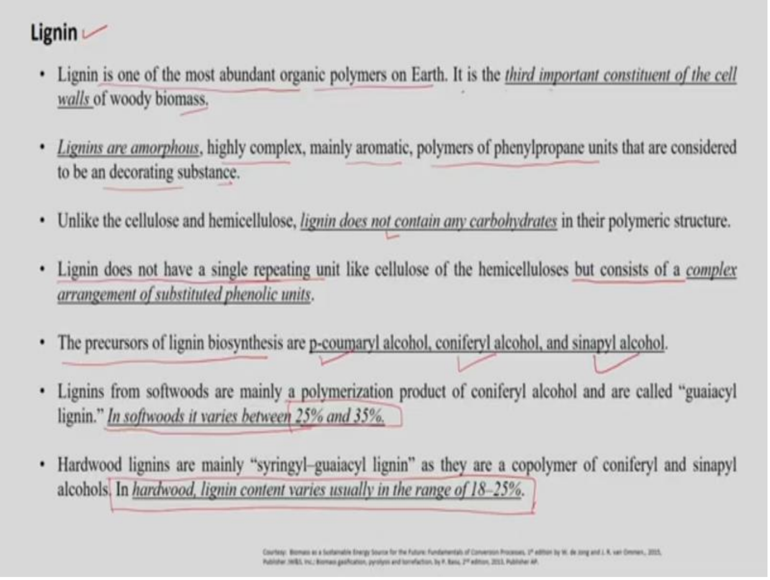

So now the last component of the cell wall is lignin. So now lignin is one of the most abundant organic polymers on Earth, it is the third important constituent of the cell wall of woody biomass. Lignin are amorphous, highly complex, mainly aromatic polymers of phenylpropane units that are considered to be decorating substances, unlike cellulose and hemicellulose, the lignin does not contain any carbohydrate in their polymeric structure.

So, if you see the polymeric structure of cellulose and hemicellulose it is evident that it contains the carbohydrate molecule in their polymeric structure whereas, lignin does not contain any carbohydrate molecule in their polymeric structure. Lignin does not have a single repeating unit like celluloses of the hemicelluloses, but consists of a complex arrangement of substituted phenolic units. And that is the major difference between the lignin and cellulose and hemicellulose as it does not contain any carbohydrate polymeric unit.

Secondly it also does not contain repeating units like cellulose and the hemicellulose. The precursors of lignin biosynthesis are termed as p coumaryl alcohol, coniferyl alcohol and sinapyl alcohol. Lignin from softwoods are mainly a polymerization product of coniferyl alcohol and in softwood it varies between 25 to 35% whereas, if you see in the hardwood, the lignin content varies regionally in the range of 18 to 25%. So, this is also a very good concept here to understand how the lignin composition varies in the softwood as well as in the hardwood which can be seen here from this particular slide.

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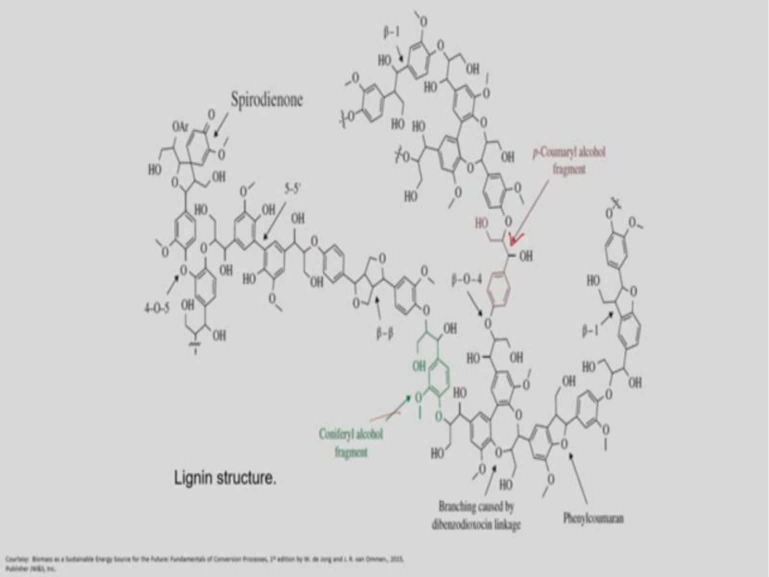

In the next slide, we can see here the structure you can say the partial structure of lignin only because the structure of lignin itself is a very large structure which you cannot represent in the single slide. So, for the representation purpose we have just shown here a small structure of lignin, just to represent here, how this coumaryl alcohol, coniferyl alcohols are forming a complex structure which accounts together the lignin structure.

So, to conclude this class, in this class we discuss about the biomass. Then we discuss about the types of biomass, we further try to classify it, the biomass and then biomass structure. Based on the cell wall component of the biomass we also discuss the cellulose, hemicellulose and lignin content of the biomass. Now in the next lecture that is lecture 2, under the same model, we will try to discuss characteristics of biomass, properties of biomass and structural component of biomass. Thank you very much. Regarding this lecture, if you have any queries, feel free to contact me at vvgoud@iitg.ac.in. Thank you very much.