Energy Conversion Technologies (Biomass and Coal)

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Lecture 5

Environmental aspects of energy

Welcome to part 2 of lecture 3 under module 1. So in this module we will discuss about the biomass resources and biomass structure.

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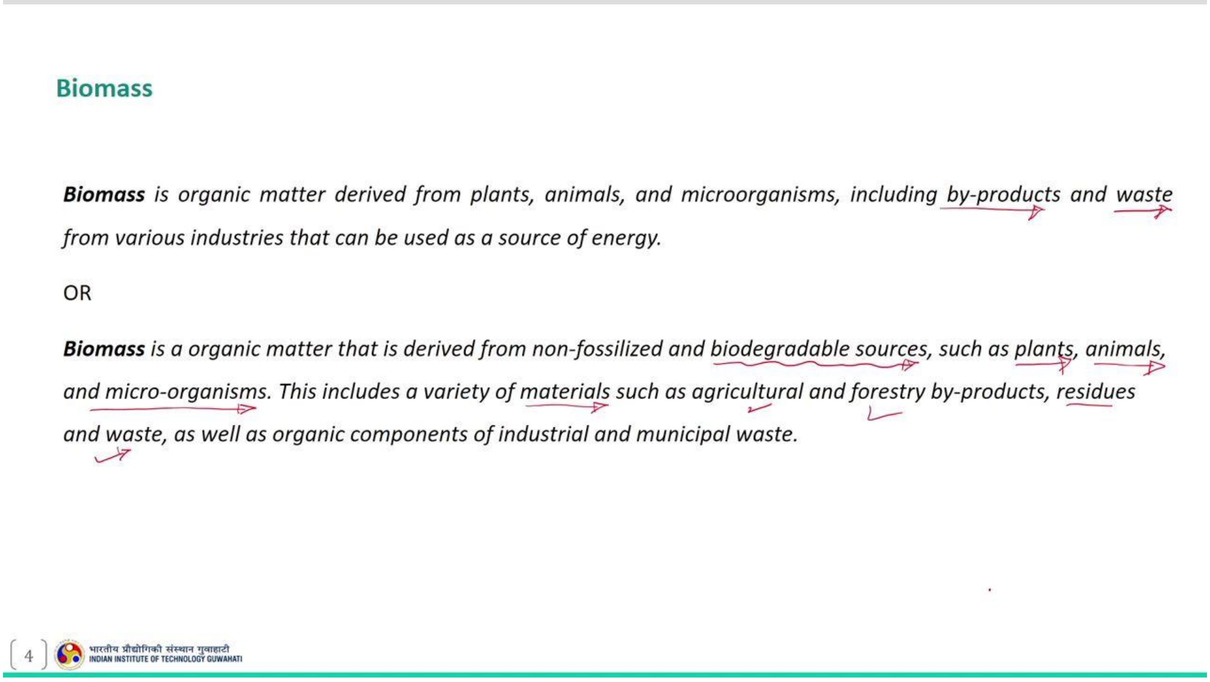

Let us first discuss about what is mean by biomass. Biomass is an organic matter that is derived from plants, animals and microorganisms including byproducts and waste from various industries that can be used as a source of energy. Or in the other words biomass is a organic matter that is derived from non-fossilized and biodegradable sources. So, these sources include again plants, animals, and microorganisms. This also includes variety of materials such as agricultural and the forestry byproducts, residues and waste as well as organic components of industrial and municipal waste. So, these all together comprise the meaning of biomass.

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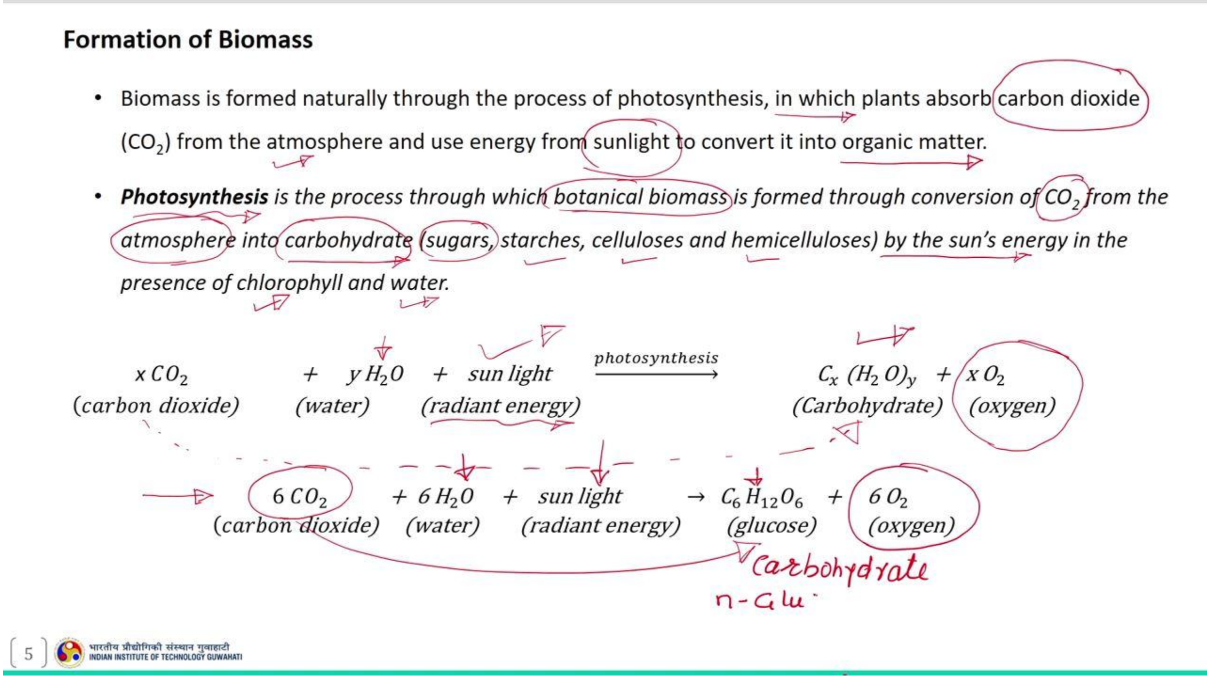

So now let us discuss about the formation of biomass. Biomass is formed naturally through the process of photosynthesis in which plant absorb carbon dioxide from the atmosphere and use energy from sunlight and convert it into organic matter. In the broad sense if you see the photosynthesis is the process through which the botanical biomass is formed through conversion of carbon dioxide from the atmosphere into carbohydrate. So, carbohydrate mainly means celluloses, hemicelluloses, and starches or in the simpler form monomers are nothing but the sugars by sun's energy in the presence of chlorophyll and water. So, the chlorophyll and water these are basically used in this conversion process of carbon dioxide to carbohydrates. So, the general representation scheme of photosynthesis process is shown here, in which carbon dioxide is converted into carbohydrate by sunlight that means sun's energy which is also called as a radiant energy, in the presence of water and chlorophyll which is integral part of the botanical biomass.

So, through this photosynthesis process it converted into carbohydrate and this process also result in net gain of oxygen. That means it also produces oxygen along with the carbohydrates. So, now if you try to see the stoichiometric representation of the photosynthesis scheme, so here 6 moles of carbon dioxide convert into organic matter or we would say here the carbohydrate. So, here we have represented carbohydrate in the form of the glucose molecule and along with this carbohydrate it produces oxygen as well. And this entire process carried out in presence of sunlight, water and chlorophyll.

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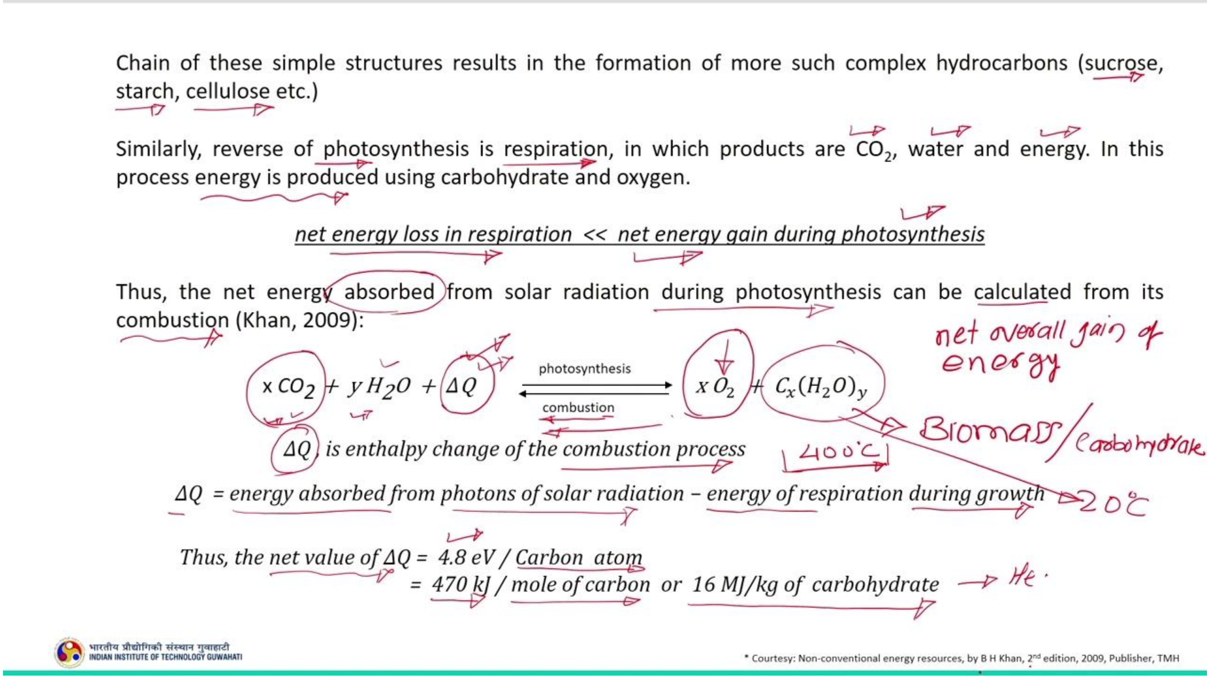

So, when n numbers of these glucose molecules are linked together in a linear aliphatic chain manner, then it results into formation of complex carbohydrate that is sucrose, starch, cellulose, etc. So, basically it means here the chain of this simple structure that means a simple structure is nothing but the glucose. So the linear chain of this aliphatic compounds when it forms a complex structure in the form of like multiple number of the glucose molecules. When they are linked together it forms a complex structure which eventually results into the formation of the cellulose, which is commonly known as an organic biopolymer.

Similarly, reverse of photosynthesis is the respiration process. So, in which the products are carbon dioxide, water and energy. In this process energy is produced, this is basically the energy which is getting produced using carbohydrate and oxygen. There is a net overall gain of energy in this in this process, because if you see here as the rate of energy loss in respiration is much less compared to the net energy gain during the photosynthesis process here.

And this process also results in the net gain of oxygen by fixing carbon in the form of biomass or we can say here the carbohydrate or organic matter. So, now the net energy which is absorbed from solar radiation during this photosynthesis process, it can be calculated from its combustion. So, basically here we are representing respiration as a combustion process which is basically reverse of the photosynthesis process here. Because conventional combustion process required relatively higher temperature say around like 400 degree C or even higher. And in the conventional combustion process it also produces CO_2 and water as a stable product along with the significant amount of the heat.

But as I mentioned earlier, this process of combustion is carried out at relatively higher temperature. However, in the respiration process it requires relatively low temperature, that is close to around we can say 20 degree C. Because this process carries out as catalytic enzyme reaction. And as a reason it requires relatively low temperature by which this respiration phenomena occurs in the botanical biomass and then it produces carbon dioxide, water and energy as the products. So, therefore, if we need to find out this delta-Q that is the enthalpy change of this combustion process that is we can say the respiration process.

So, the delta Q of the energy absorbed from photons of solar radiation minus energy of respiration during the growth that means during the growth of the botanical biomass. So, this net value of delta Q is around 4.8 electron volt per carbon atom. So, now if you convert into a mole of carbon the value is 470 kilo joule and in terms of mega joule it is 16 mega joule per kg of carbohydrate and this we normally referred as a heating value or you can say the calorific value of biomass.

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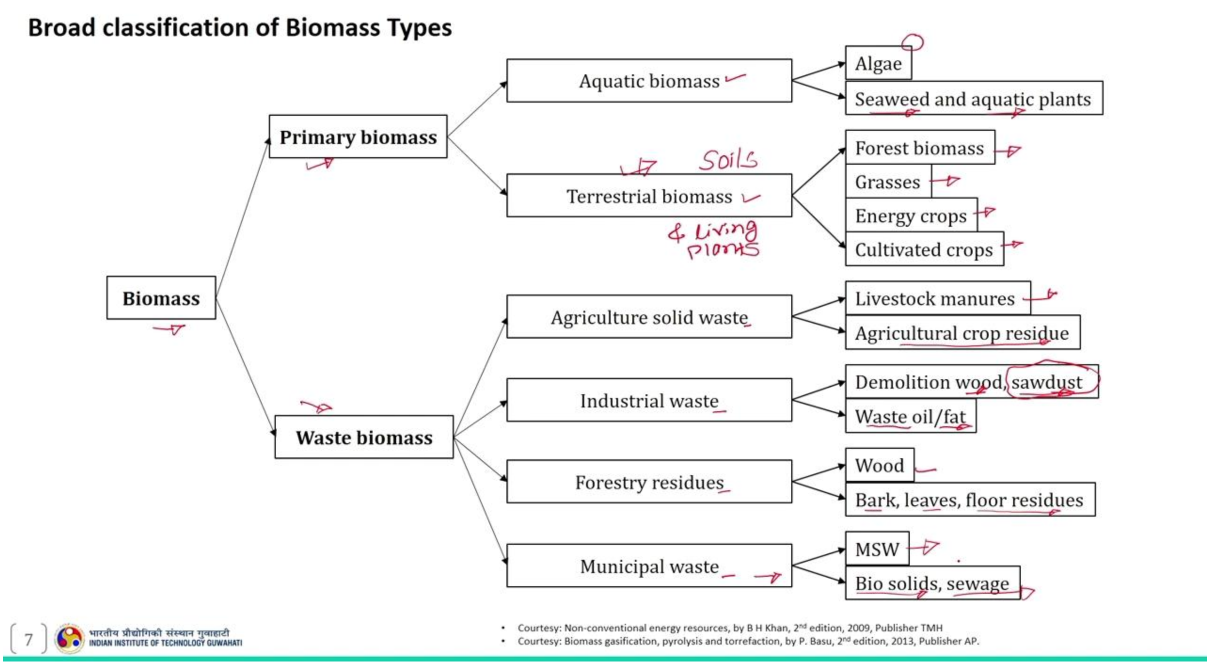

So, after learning about the formation of the biomass, let us discuss about the broad classification of the biomass types. Biomass is broadly classified into primary biomass and waste biomass. So, the primary biomass further sub classified into aquatic biomass and then the terrestrial biomass. Here the term aquatic biomass refers to any plant material that has formed in water such as algae, seaweed and aquatic plant. Similarly, the terrestrial biomass is the organic matter that is present in the soils and in the living plants of the earth's land ecosystem. And examples here are like forest biomass, grasses, energy crops and cultivated crops.

Similarly, the waste biomass has been sub classified into agriculture solid waste, industrial waste, forest residues and municipal waste. So, here the agriculture solid waste includes livestock manures and agricultural crop residue. So, basically the crop residues which are left over after harvesting the crops, these are termed as the agricultural crop residue. And industrial waste includes demolition wood and sawdust, which we can say the byproduct of timber production. So, this particular waste can also be act as a very good source for the energy production.

Apart from that the waste oil, fat which are majorly the byproduct of the food processing industries can also be utilized for the energy production. While the forest residues include wood, bark, leaves and floor residues. So, here the wood, bark and leaves include nothing but the old branches or you can say the fallen branches from the trees, the leaves and the bark. These are considered as the wood material from the forest residues as well as the floor residues of the forest can be utilized for the energy production. Apart from that the municipal waste, it includes the municipal solid waste, biosolids and sewage sludge which is obtained from this particular waste. Sewage sludge can also act as a good source of energy.

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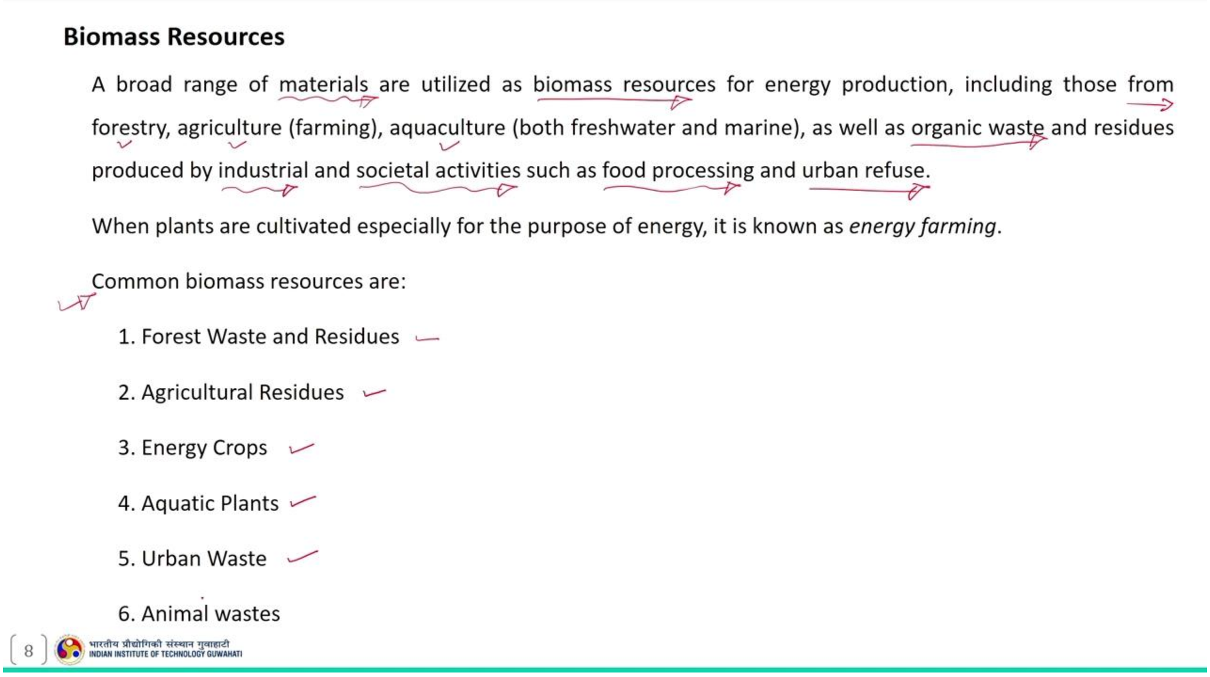

So, after learning about this broad classification of the biomass type, let us discuss about these biomass resources. So, the biomass resources include a wide range of materials that are utilized as a biomass resource for the energy production including those from forestry, agriculture, and aquaculture as well as the organic waste and residues produced by industrial and the societal activities which mainly includes the food processing and urban refuse. When the plants are cultivated especially for the purpose of energy it is known as energy farming. So, there are certain classes of crops which are specifically grown for the purpose of energy and those particular farming of crop are known as energy farming. So, following are the common biomass resources that are forest waste and residues, agriculture residues, energy crops, aquatic plants, urban waste and animal waste.

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1. **Forest Waste and Residues**

- *Forest waste and residues refer to the organic materials that are left over from forest harvesting and processing activities.*
- These can include branches, bark, sawdust, wood chips, and other woody materials that are not used for timber production.
- These residues can be utilized in various ways, including as a source of biomass for energy production.

2. **Agricultural Residues**

- *Agricultural residues refer to the various types of organic materials left over from agricultural production after the crop or other agricultural products have been harvested.*
- These residues can include parts of the plant that are not consumed or used for food production, such as leaves, stalks, husks, stems, and shells.
- Agricultural residues can come from a wide range of crops, such as rice, wheat, corn, sugarcane, and many others.
- These residues can be used for various purposes, including as animal feed and as a source of biomass for energy production.

So let us first discuss about the forest waste and residues. Forest waste and residues refer to the organic materials that are left over from forest harvesting and processing activities. That means during the harvesting of the forest whatever the leftover material is available that is termed as a leftover from forest harvesting as well as the processing activities. So, mainly the sawdust which is produced in the timber production is termed as the residue or we can say the waste produced during the processing activities of those wood materials, and this can include branches bark, sawdust.

And that is what I referred just now, that the processing activities of the forest wood which mainly timber production, it produces byproduct in the form of sawdust. So, this can be act as a very good source of biomass for the energy production along with the wood chips and other woody materials that are not used for the timber production. So, this kind of material can be utilized in various ways and one of the applications of this kind of material is for the energy production. Similarly, the agricultural residues are referred to the various types of the organic materials, which are mainly again leftover from the agricultural production after the crop or the agricultural products have been harvested.

So, it means here whatever the leftover is available after harvesting the crop, so those kind of leftover materials which are mainly in organic form can be used as a source of biomass for the energy production. Apart from that during the processing of these particular crops the agriculture products which are producing a byproduct. So, those kind of byproducts can also be used as a very good source of biomass for the energy production and these mainly includes parts of the plant that are not consumed are used for the food production such as leaves, stalks, husks, stem and shells. So, the agriculture residues can come from wide range of crops like rice, wheat, corn, sugarcane and many others. And these residues can be used for various purposes including as the animal feed and as a source of biomass for the energy production.

So, the leftover of the agriculture crops can be a very good source of biomass for the energy production apart from that when this particular crops undergoes certain processing stage. So, the byproduct of those particular crops, for example, in the form of the rice husk, it can also act as a very good source of biomass for the energy production. Apart from that, the rice straw, the wheat straw, these are nothing but the leftover after the harvesting of the biomass. So, this kind of material acts as a very good source of biomass for the energy production. Although this particular material can also act as a very good animal feed. But the material which is not being used for the consumption purpose that particular material can be diverted as a source of biomass for the energy production.

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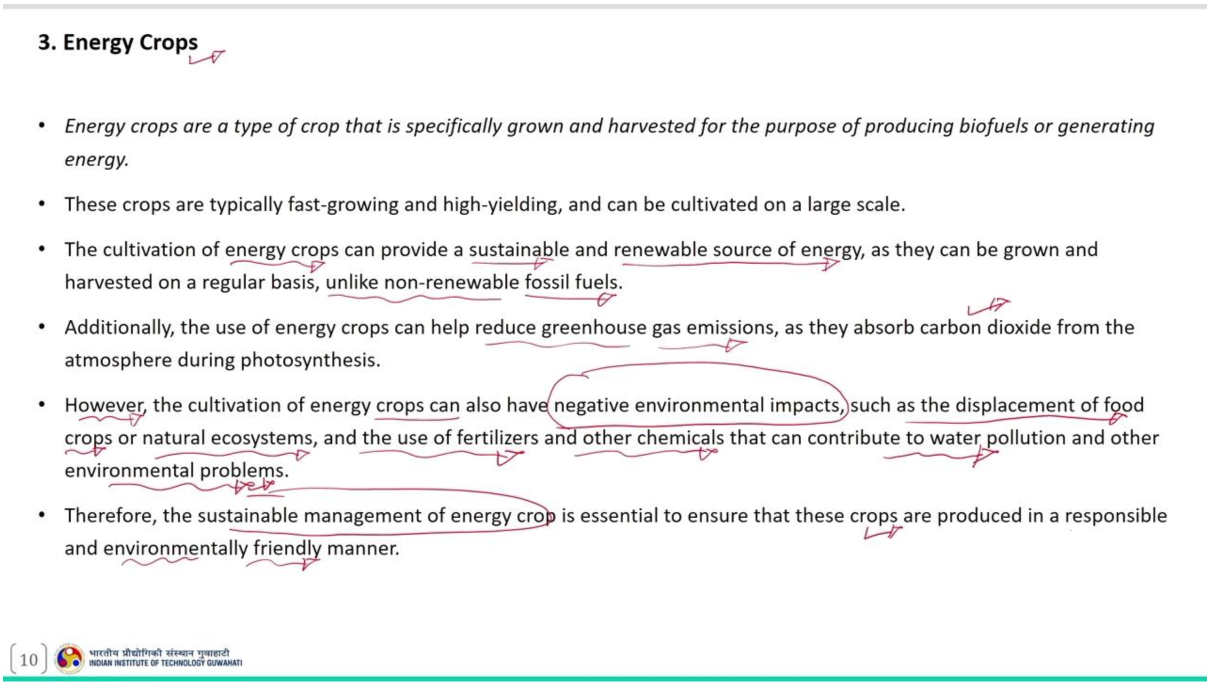

So, the next in the list is the energy crops. So, energy crops are a type of crop that is specifically grown and harvested for the purpose of producing biofuels or generating the energy. The reason is like this kind of crops are typically fast-growing and high-yielding crop and these crops can be cultivated on a larger scale if required. So, that is the advantage of the energy crops.

The cultivation of energy crops can provide a sustainable and renewable source of energy. Because this kind of crop can be cultivated and harvested on a regular basis as and when required that is what is the advantage of cultivating the energy crops, unlike non-renewable fossil fuels or we can say fossil resources. Additionally, the use of energy crops can also help in reducing the greenhouse gas emission as they absorb carbon dioxide from the atmosphere during the photosynthesis process. As I mentioned earlier these are typically fast growing and the high yielding crops. So, these crops help in reducing the greenhouse gas emission because they will absorb carbon dioxide from the atmosphere during the photosynthesis process or we can say during their growth phase.

The cultivation of the energy crops can also have negative environmental impact such as displacement of food crops or natural ecosystem, which means when the energy crops need to be cultivated it required a certain arable land for the cultivation purpose. So, in that case we need to compromise with the food crops. And these particular crops also use fertilizers and other chemicals that can contribute to pollution of the water bodies and other environmental problems. Therefore, the sustainable management of energy crop is essential to ensure that these crops are produced in more responsible and environmentally friendly manner without impacting the environment in the specific location.

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4. Aquatic Plants

- *Aquatic plants, such as algae and seaweed, can be used as sources of biofuels due to their high productivity and fast growth rates.*
- These plants contain high amounts of lipids and carbohydrates that can be converted into liquid biofuels, such as biodiesel and bioethanol, through convenient processes.
- Use of aquatic plants for biofuels can reduce the demand for arable land and freshwater resources.
- However, challenges associated with the aquatic plants include high costs and developing efficient, cost-effective technologies for large-scale production, while also ensuring sustainability.
- The use of aquatic plants as biofuels sources has great potential to contribute to a more sustainable energy future.

11 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI

So, the next in the list is the aquatic plants. So, here the aquatic plants such as algae and seaweed can be used as a source of biofuel due to their high productivity and fast growth rates. And these plants contain high amount of lipids and carbohydrate which can easily be converted into a biofuels such as biodiesel and bioethanol through convenient processes. The use of aquatic plants for biofuels, it can also reduce the demand for arable land and the fresh water. Meaning is if such kind of aquatic plants need to be grown so as these are basically the aquatic plant which can be cultivated in the water. So, it may require a certain reservoir pond system where we can cultivate this kind of aquatic plants.

So, it does not require any kind of arable land for the cultivation of these aquatic plants. Apart from that this aquatic plant can be also grown in the waste water. So, it does not require regularly fresh water for the cultivation purpose. However, the challenges associated with the aquatic plants it includes high cost which means the cultivation of such kind of aquatic plants incurred a high cost. Because, as I mentioned earlier, we need to construct a proper raceway pond system for the cultivation of such aquatic plants. And, also it required a certain media to enhance its growth in the aquatic medium.

So, for that reason it incurred the cost. So, as a result the production of the aquatic plant in a confined system is relatively expensive and developing efficient cost effective technologies for large scale production. Because we need to develop an efficient and cost effective technology so that we can cultivate such kind of aquatic plant on a larger scale. So, these are basically some of the challenges associated with the cultivation of this aquatic plant. While doing so, also we need to ensure the sustainability. The use of aquatic plants as biofuel resource although has a great potential to contribute to more sustainable energy future as I mentioned earlier it includes relatively high cost.

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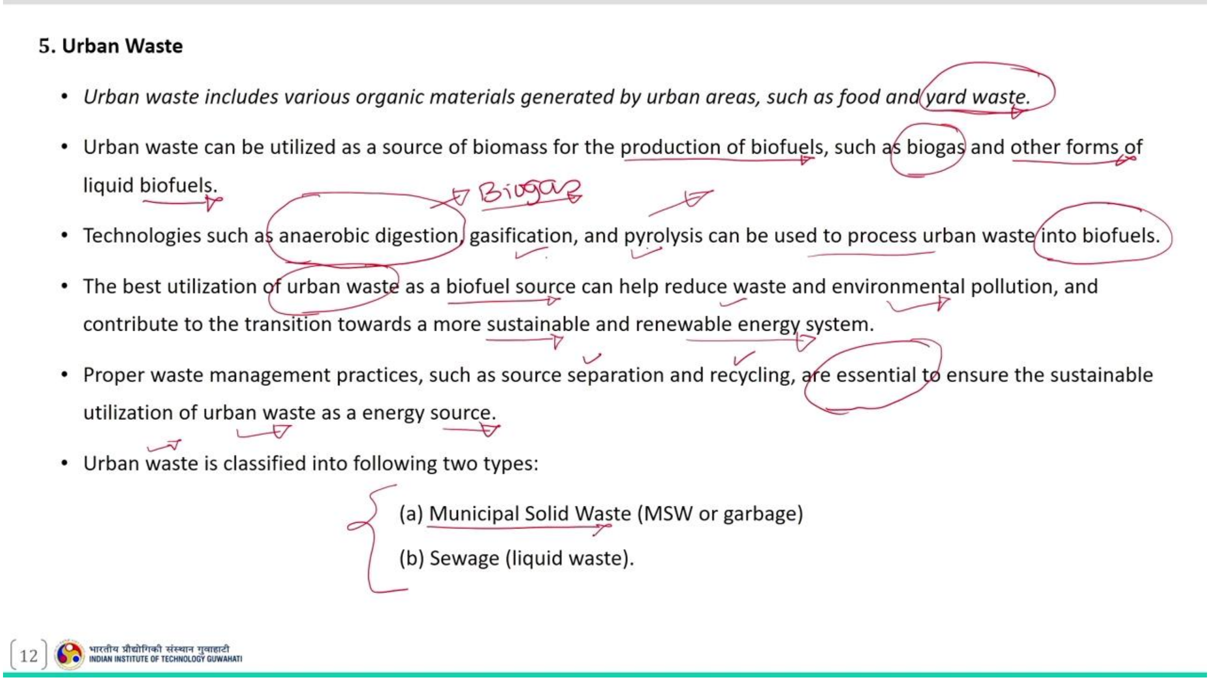

So, the next is the urban waste. Urban waste includes various organic materials generated by the urban areas such as food, and yard waste. So, this urban waste can be utilized as a source of biomass for production of biofuel such as biogas and other form of liquid biofuels. So, the technologies which are basically available for this conversion of urban waste includes the anaerobic digestion with the context of the food waste here. The anaerobic digestion process can be used effectively to convert the food waste into biogas. Similarly, the gasification and the pyrolysis with the context of the yard waste can be used effectively to convert into suitable biofuels. So, the yard waste here includes the leaves, barks or the old or the fallen stem of the trees.

These are basically referred as the yard waste. The best utilization of the urban waste as biofuel source can also help in reducing the waste and reducing the environmental pollution and contribute towards the transition towards more sustainable and renewable energy system. The practice of proper management of this urban waste such as separation and recycling are really essential to ensure that the sustainable utilization of the urban waste as a source of energy is happening. This particular urban waste is classified into following two types that is municipal solid waste and then the sewage sludge.

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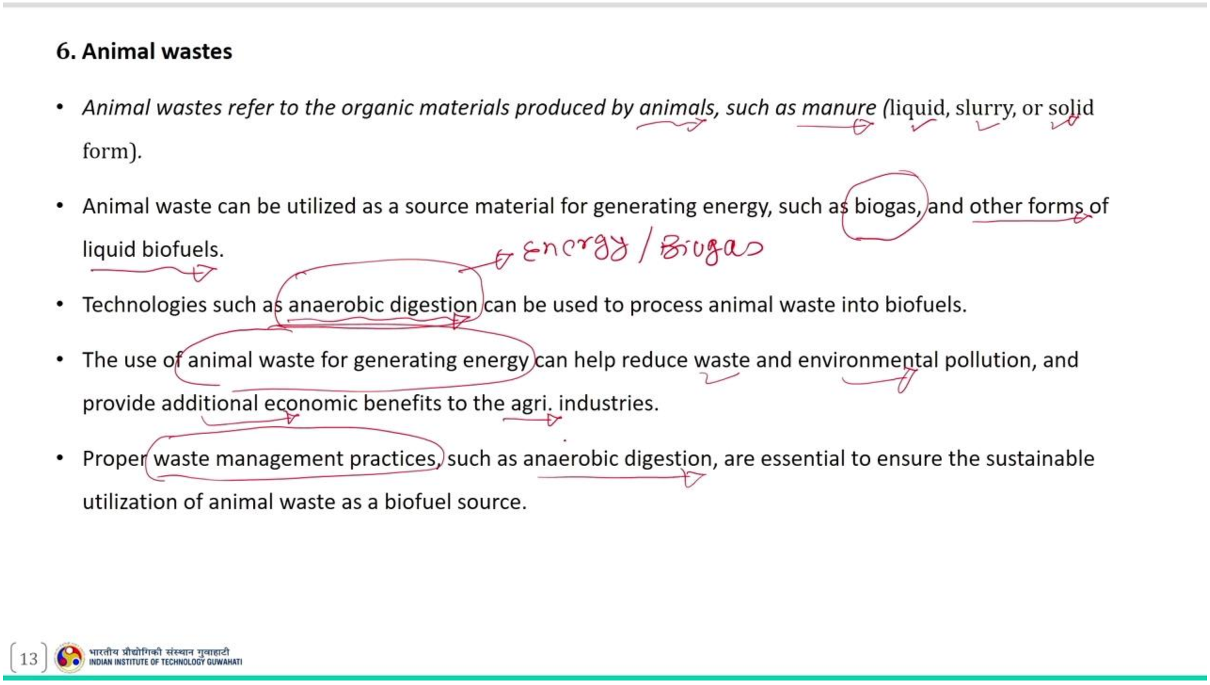

So, the next in the list is the animal waste. So, here the animal waste refers to the organic materials produced by animal and mainly we can say the manure which are either liquid, slurry or in the solid form. And this animal waste can be effectively utilized as a source of material for generating the energy majorly biogas. Or apart from that other forms of biofuel also can be produced from this kind of manure but majorly as I mentioned is the biogas. The technologies which are available for such kind of waste are anaerobic digestion. So, by this technology we can efficiently convert such kind of animal waste into energy majorly biogas as I mentioned earlier.

And the use of such animal waste for generating the energy can also help in reducing the waste and the environmental pollution. Apart from that the major advantage of utilization of such waste for the energy generation includes the additional economic benefit to the agri industries or you can say the small farms. And the proper waste management practices such as anaerobic digestion are essential to ensure the sustainable utilization of the animal waste for biofuel source. So, this includes the details about the common forms of the biomass.

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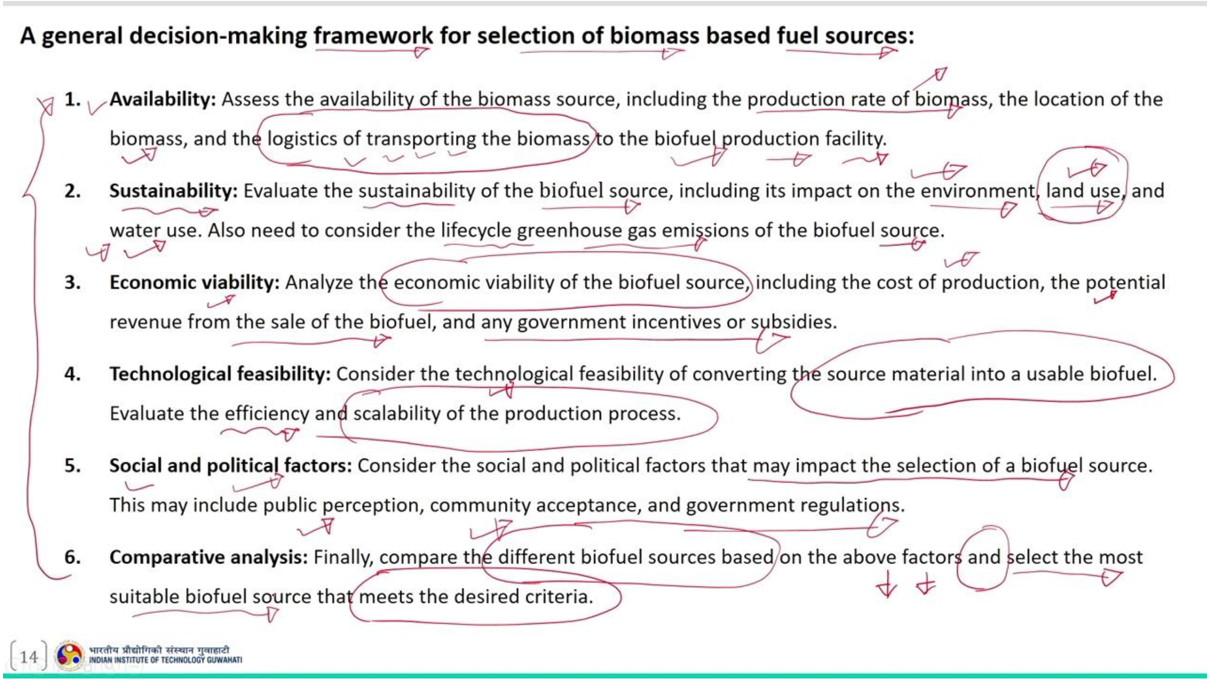

After learning about the common forms of biomass, let us discuss about a general decision making framework for selection of biomass based fuel sources and it includes following points. So, the first in the discussion is the availability. That means one need to assess the availability of the biomass for the production of the energy and it includes production rate of biomass, location of the biomass. And one of the important criteria in the availability is the logistic of transporting the biomass to the biofuel production facility. That is one of the most important criteria while selecting any kind of biomass for the production of the biomass. So, that it is available in the nearby location as well as the production rate of that particular biomass is relatively high and these are basically high yielding crops. So, these kinds of biomass need to be selected for the production of the energy.

Second is sustainability. One need to evaluate the sustainability of the biofuel source which includes its impact on the environment, land use and water use. So, based on that specific biomass source need to be selected, so that it does not have any negative impact on the environment, the land use and water use. It does not require excessive water for the cultivation purpose and as the crops are high yielding and fast growing, so much area of the land is not getting occupied during this cultivation. So, that is basically the meaning of this sentence here and also need to consider the life cycle greenhouse gas emission of the biofuel source. This is one of the important criteria while selecting the specific biomass for the energy purpose.

And the economic viability is another important parameter here. Because we need to analyze the economic viability of the biofuel source as well which includes the cost of the production. That means the biomass source which is being considered for the energy purpose is not having a high cost for its cultivation that is the meaning of this. Apart from that, the potential revenue from the sale of the biofuel should be substantially high. And any government incentives and the subsidies need to be considered while analyzing the economic viability of the specific biofuel source.

Technological feasibility in the sense is like we need to consider the specific technology which is highly efficient and effective for converting the selected biomass material into usable. That means as I mentioned we need to evaluate the efficiency and the efficacy of the specific process. Similarly, the process should be scalable for the large scale production. So, based on that a specific technology needs to be selected for the conversion of biomass into usable biofuel. Social and the political factors these are very important and that may impact the selection of the biofuel source because it includes the public perception; acceptance of the community because the community should be aware about such kind of biofuels which can be used for the energy purpose; and obviously the government regulations also need to be taken into consideration while producing such kind of biofuels using selective biomass as a source.

And at the end comparative analysis of different biofuel sources based on the above factors need to be done and after understanding of its environmental impact as well as the cost implication as well as the technological efficacy and the scalability. So, one need to select the most suitable biofuel source that meets the desired criteria. So, these are basically some key points which need to be considered while selecting a biomass as a source for the energy purpose.

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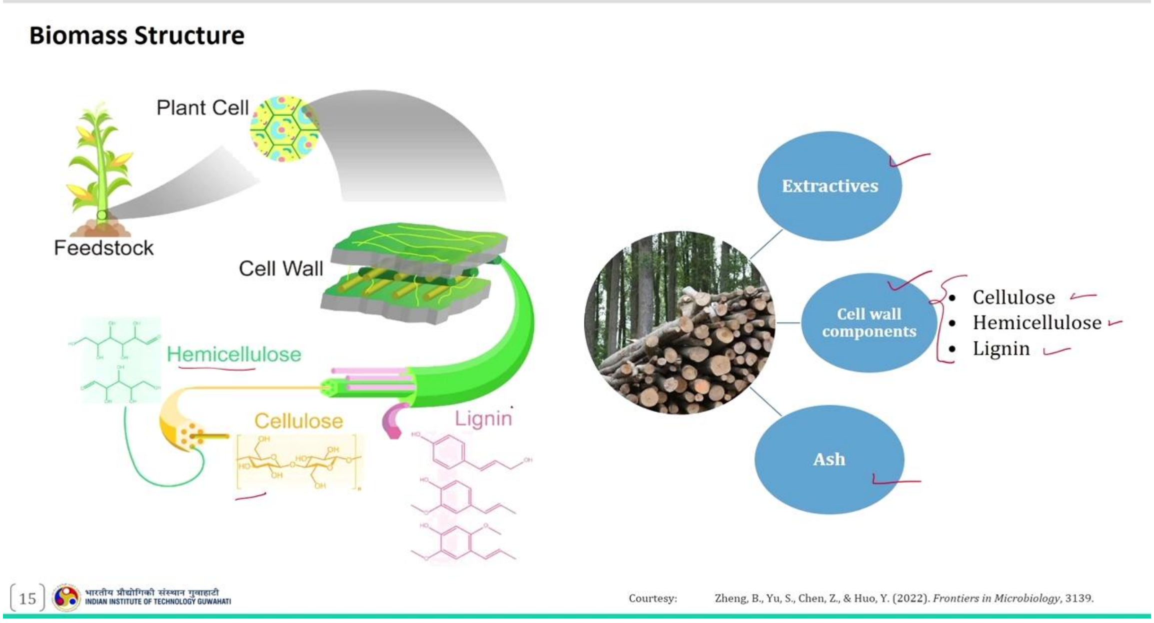

So, now after understanding about the biomass resources and then its selection criteria, let us discuss about the biomass structure. The biomass structure mainly consists of extractives cell wall components and ash. So, in that cell wall component mainly consists of cellulose, hemicellulose and lignin and the structure of cellulose, hemicellulose and lignin are shown here on the screen. So, now let us discuss about these components of the biomass structure one by one.

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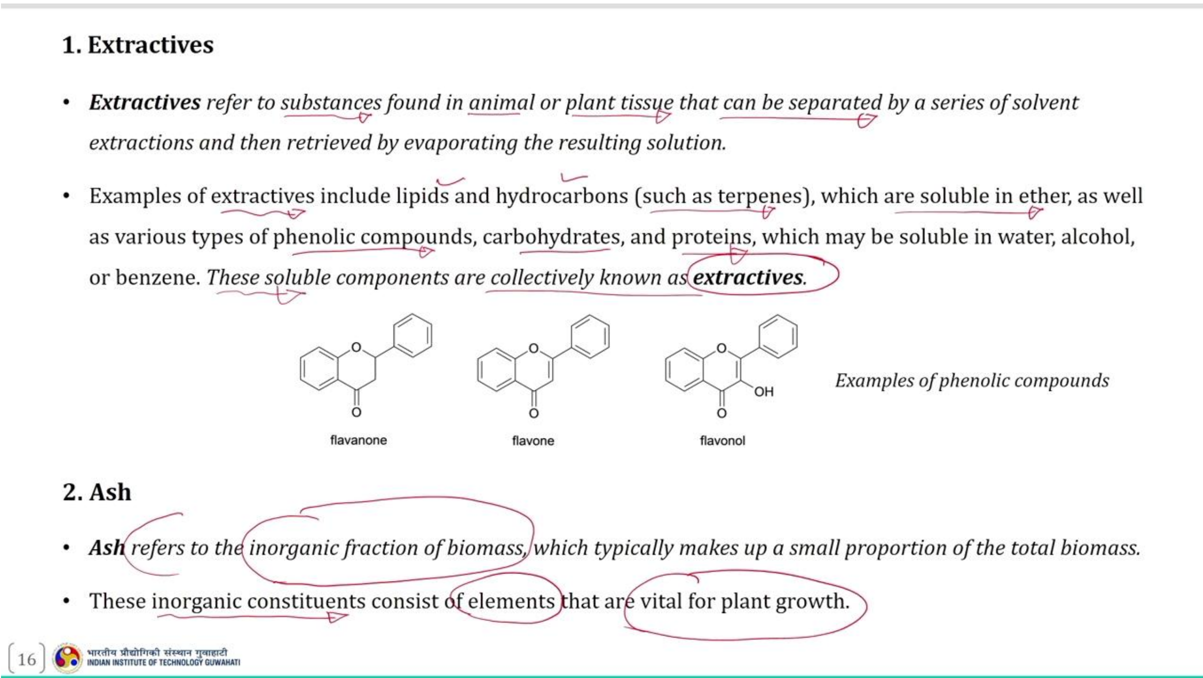

So, here the extractives refer to substances found in the animal or plant tissues that can be separated by series of solvent extraction. That means here the extractives are mainly refers to substances which are found in the plant and animal tissues that can be separated by series of solvent extraction. And at the end of the extraction process the specific solvent can be recovered by operating this particular solvent and the solid extracts left over is called as extractives from the specific source. Example of the extractives include lipids and hydrocarbon such as terpene, which are basically soluble in ether as well as various types of phenolic compounds, carbohydrates and proteins which are soluble in water, alcohol or benzene.

These soluble components are collectively known as extractives and the example of the phenolic compounds is shown here on the screen. Similarly, ash here refers to the inorganic fraction of biomass which typically makes up a small proportion of biomass. These inorganic constituents consist of the elements that are vital for the plant growth.

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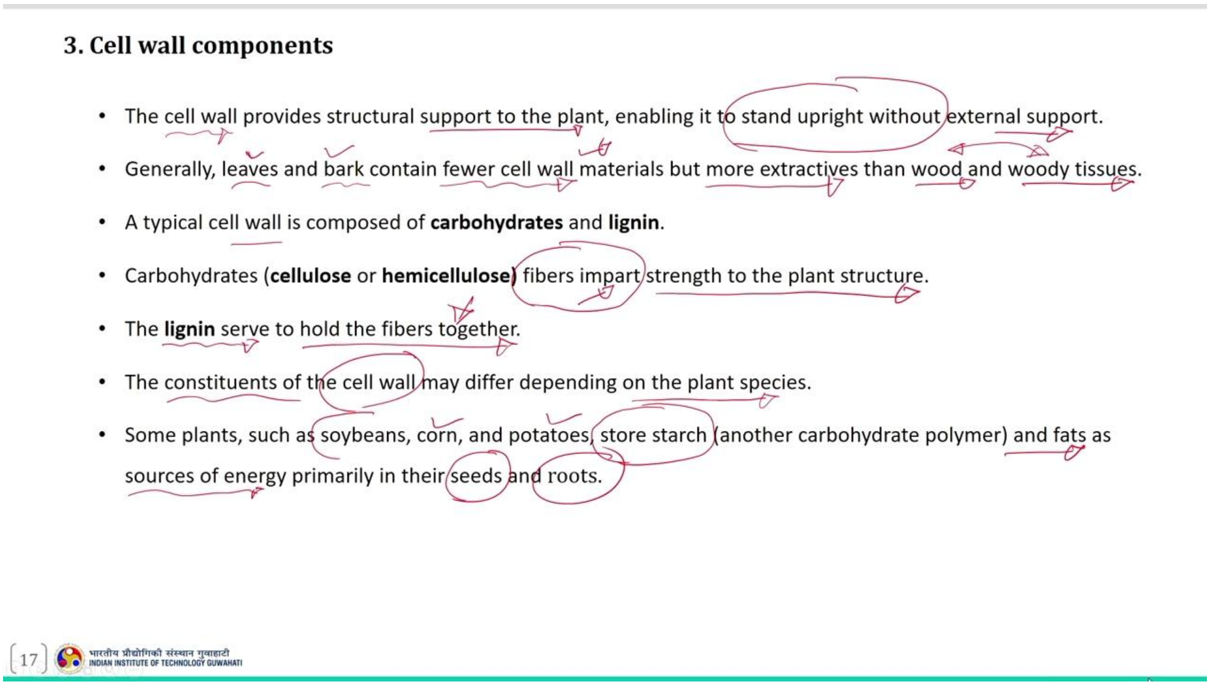

So, the next is cell wall components. The cell wall basically provides structural support to the plant enabling it to stand upright without any external support and that is what is the purpose of the cell wall in the biomass structure. Because if you see generally the leaves and the bark contain the fewer cell walls but more extractives than wood and the woody tissues. Because wood and the woody tissues contain more cell wall than that of the bark and the leaves. As a result, leaves and the bark may not have more strength, but wood and the wood tissue have more strength compared to that of the leaves and the bark. Because wood and the wood tissues contain more cell wall material.

Typical cell wall is composed of carbohydrates and lignin. And carbohydrate here includes cellulose and hemicellulose. And these carbohydrates it imparts structural strength to the plant materials. The lignin serves to hold these fibers together. So, this carbohydrate fibers as mentioned earlier, it imparts structural strength to the plant materials or you can say it imparts strength to the plant structure. And the lignin source to hold this fiber together and the constituents of the cell-wall.

It may differ depending on the plant species. For example, in some plant such as a soyabean, corn and potatoes it stores starch and fats as source of energy primarily in their seeds and roots. So, now let us discuss about this component of the cell wall that is cellulose, hemicellulose and lignin in more detail.

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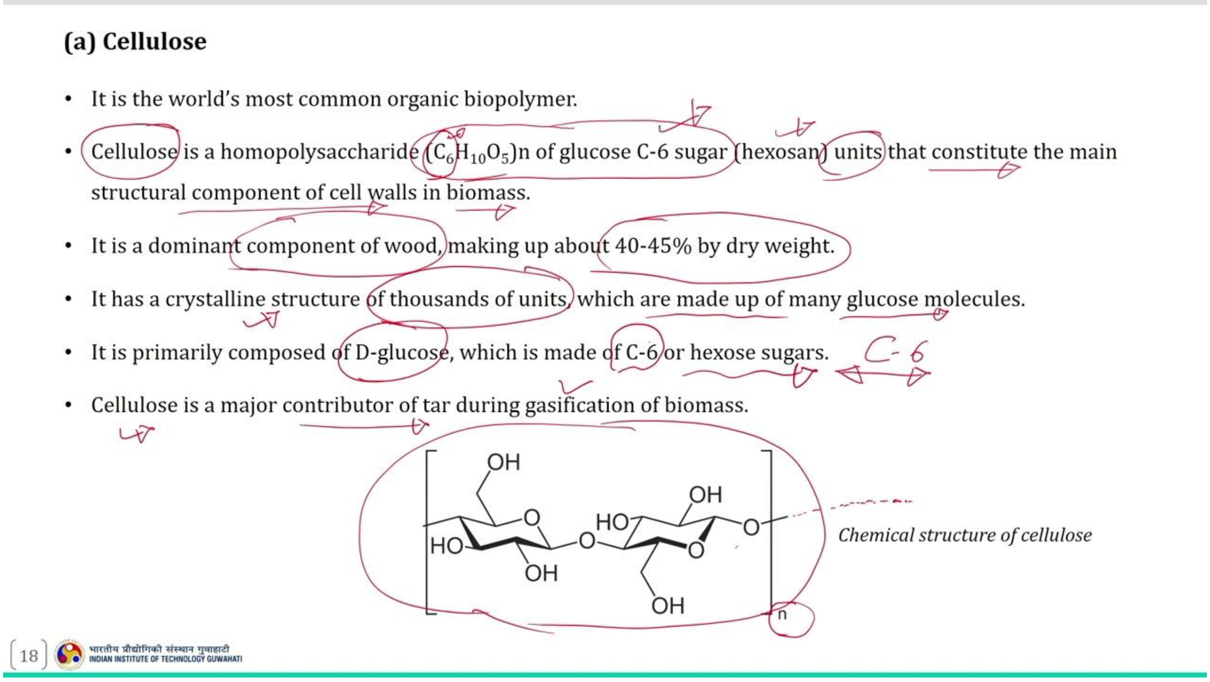

Cellulose it is world's most common organic biopolymer. Cellulose is basically a homopolysaccharide. That means it consists of n-number of glucose molecule that is C6 sugar and also known as the hexogens units. That constitutes the main structural component of the cell wall in a biomass and that is called as cellulose. It is a dominant component in the wood material, making about 40 to 45 percent by dry weight. Cellulose basically is a crystalline structure of thousands of units. So, as mentioned earlier n number of these glucose molecules are linked together in a chain and it forms very complex hydrocarbon which is basically cellulose. And it is basically a crystalline structure which is made of many glucose molecules.

And it is primarily composed of D-glucose units which are made up of C6 or you can say the hexose sugar because it has 6 carbons and that is why it is referred as C6 or hexose sugar. Cellulose, it is a major contributor of tar during the gasification of the biomass and this particular structure it represents the chemical structure of the cellulose. When n-number of this kind of structures attach in a linear chain, and then it forms a very complex structure and which is referred as cellulose.

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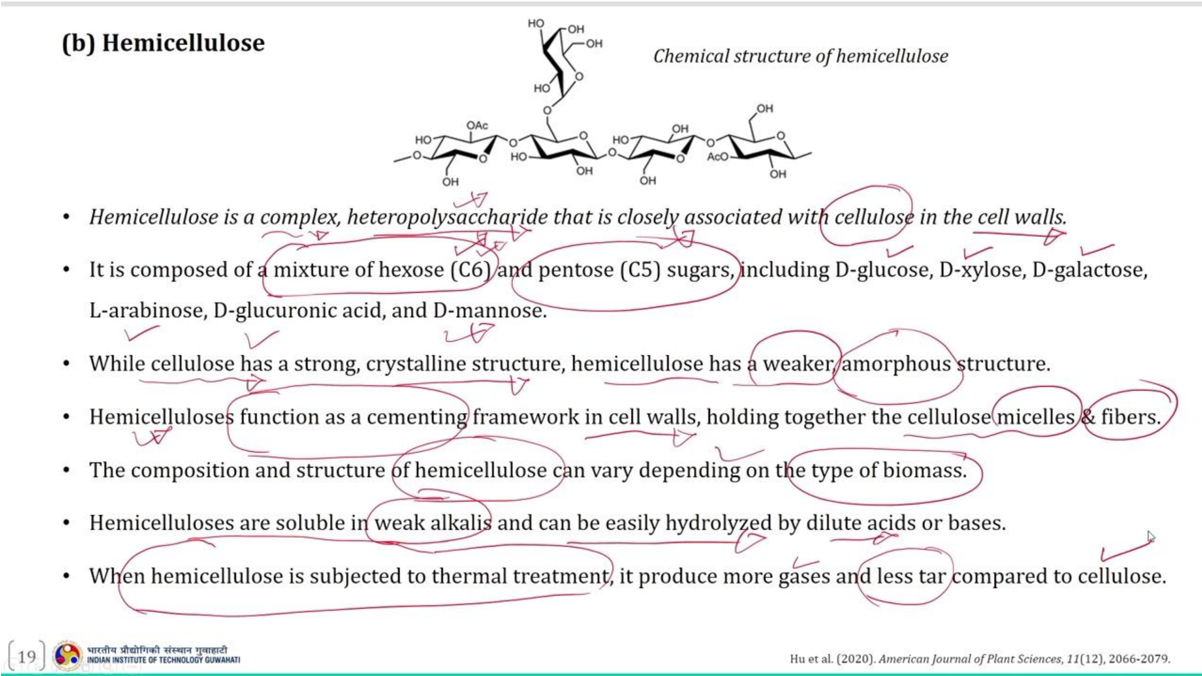

So, next component in the cell wall is hemicellulose. So, hemicellulose is a complex but it is a heteropolysaccharide that is closely associated with cellulose in the cell walls. So, it is composed of mixture of the hexose and pentose sugars including D-glucose, D-xylose, D-galactose, L-arabinose, D-glucuronic acid and D-mannose. So, this is a basic difference between the cellulose and the hemicellulose. Cellulose is a homopolysaccharide whereas hemicellulose is a heteropolysaccharide, which means it contains both C6 and C5 sugar compounds in its structure. Whereas, cellulose has only C6 sugar in its structure. While cellulose has a strong and crystalline structure, hemicellulose has a weaker and the amorphous structure.

This is also a major difference between the cellulose and the hemicellulose. Hemicellulose basically function as a cementing framework material in the cell walls and it tries to holds together the cellulose missiles and the fibers. And that is what the purpose of the hemicellulose in the cell wall is. The composition and the structure of the hemicellulose this can vary depending on the type of biomass as well. And the hemicelluloses are soluble in weak alkalis but can be easily hydrolyzed by dilute acids or base. Similarly, when the hemicellulose is subjected to the thermal treatment it produces more gas but less tar compared to that of the cellulose.

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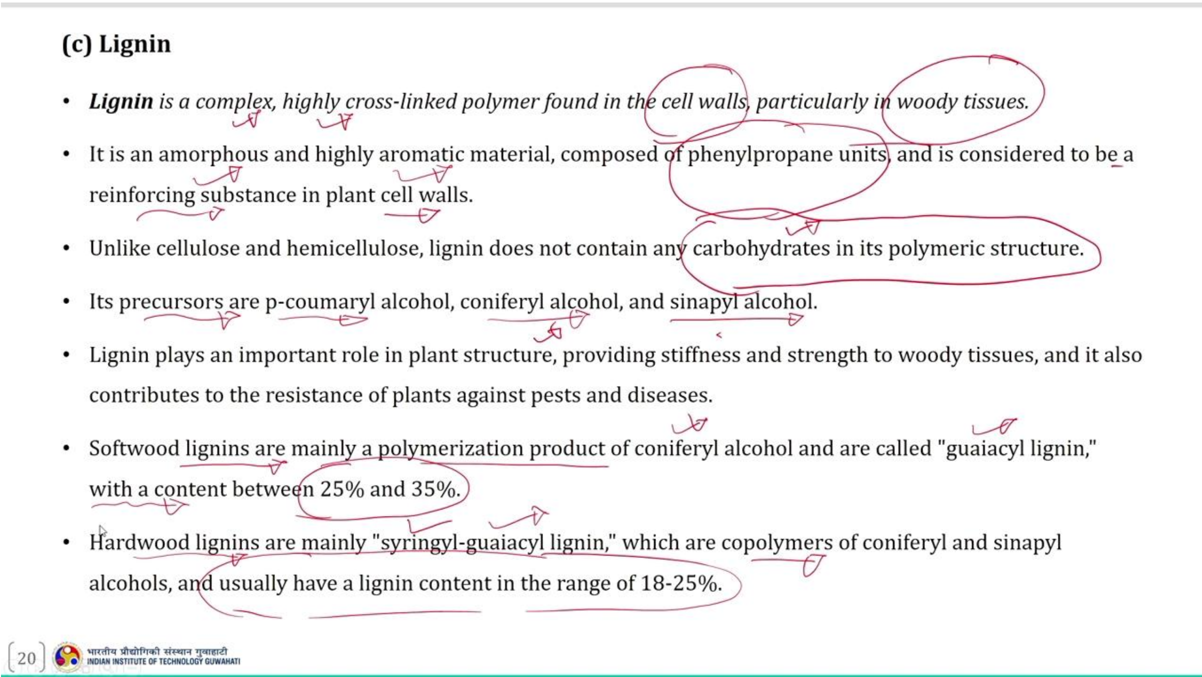

So, the last in the list of plant cell wall is the lignin. Lignin is a complex highly cross-linked polymer found in the cell walls, particularly in the woody tissues. Although it is amorphous and highly aromatic material and it is composed of phenyl propane and is considered to be a reinforcing substance in the plant cell wall. So, if you see here the lignin is mostly composed of the phenyl propane units and it does not contain any carbohydrate in its polymeric structures. Unlike cellulose and the hemicellulose, the lignin does not contain any carbohydrate in its polymeric structure, whereas cellulose and the hemicellulose are mainly carbohydrate structures. And the precursors of the lignin are P-coumaryl alcohol, coniferyl alcohol and the synapyl alcohol and it plays a very important role in the plant structure.

So, basically lignin it provide stiffness and strength to the woody tissues, and also act as a resistance of plant against pest and diseases, and it holds together the cellulose and hemicellulose, and act as a kind of a outer shield or cover to the plant material. Softwood lignins are mainly a polymerization product of coniferyl alcohol, and are called 'guaiacyl lignin', and its fraction varies between 25 to 35 percent in the plant matrix. Similarly, the hardwood lignins are mainly syringyl and guaiacyl lignin, which are copolymers of coniferyl and the synapyl alcohol, and usually have a lignin content in the range of 18 to 25 percent. So, this together describes about the cell wall component in the biomass structure mainly cellulose, hemicellulose and lignin.

So, with this we will end our lecture here. So, in the next lecture we will discuss about environmental aspects of energy, utilization of conventional energy resources and their importance. Regarding this lecture, if you have any doubts, feel free to contact me at vvgoud@iitg.ac.in.

Thank you.