Biomass Conversion and Biorefinery
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Lecture 08
Feedstocks and properties

Good morning students. This is lecture 2 under module 3 in which were discussing biorefinery. So, in today's class we will be basically discuss about the biorefinery feedstocks, their properties and integrated biorefinery. So, we have almost discussed feedstocks when we discussed about the Biomass and types and all these things. But here in a biorefinery perspective we will discuss about the different types of feedstocks that can be used, and their properties and what it means by an integrated biorefinery.

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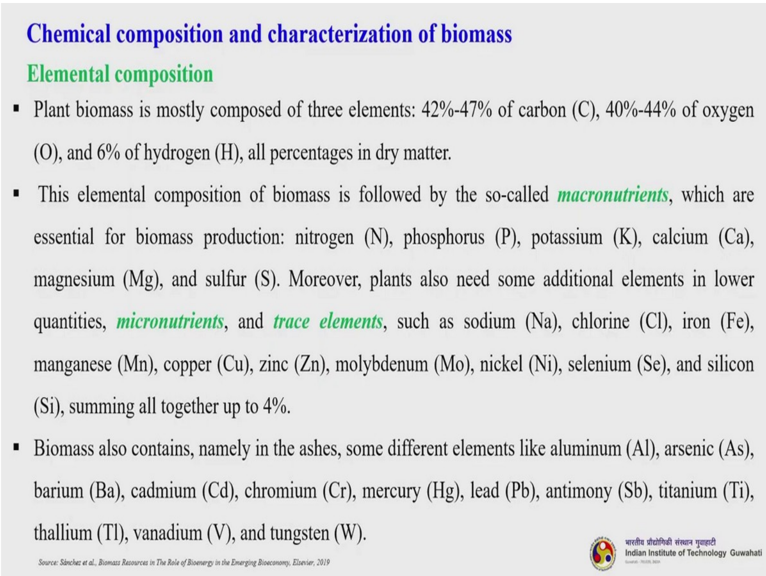

Let us talk about the chemical composition and characterization of biomass. So, there are various things. The first one is the elemental composition. So, plant Biomass is mostly composed of three elements. So, it is 42 to 47% of carbon, 40 - 44% of Oxygen and around 6% of hydrogen. So, all percentages are in dry matter. This elemental composition of biomass is followed by the so-called macronutrients which are essential for Biomass production.

So, they are and nitrogen, Phosphorus, potassium, calcium, magnesium and Sulphur. Moreover, plants also need some additional elements in lower quantities which are known as micronutrients and many times mentioned as trace elements. So some of them are sodium, chlorine, iron, manganese, copper, zinc, molybdenum, nickel, Selenium and silicon. So, all summing together up to almost 4%. Biomass also contains, namely in the ashes, some different elements like aluminium, arsenic, barium, cadmium, chromium, Mercury, lead, antimony, Titanium, thallium, vanadium, tungsten. So, these are some of the heavy metals.

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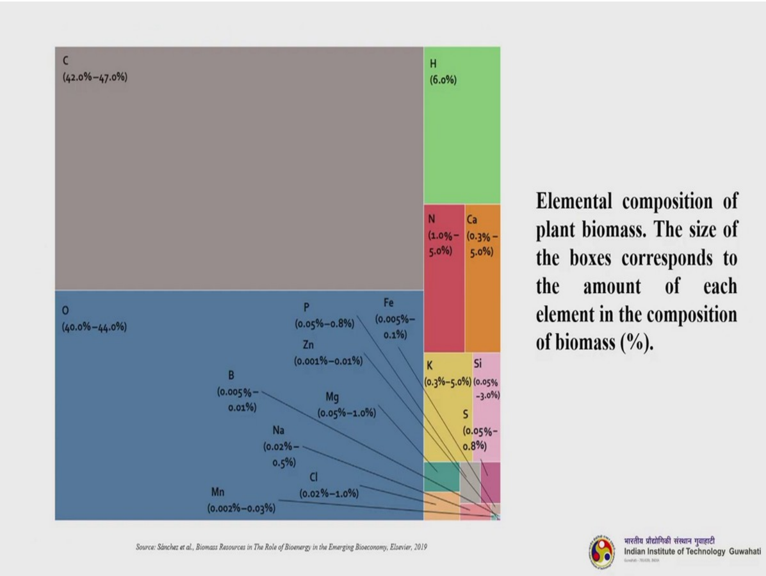

So, this is a classical representation of how the elemental composition of plant Biomass looks like if you have a pictorial presentation. We will take into account the corresponding amount of that particular element in the composition of biomass. As already mentioned you can see the highest is of course carbon, followed by oxygen and then hydrogen, then of course nitrogen, calcium and potassium, silicon all these things.

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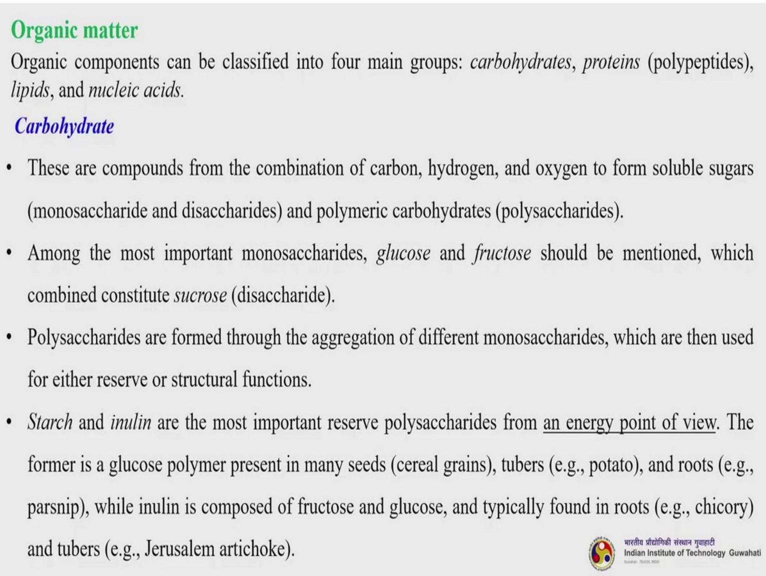

Then comes organic matter. Organic components can be classified into four major groups: Carbohydrates, proteins, lipids and nucleic acids (we will see one by one). So, the first one is carbohydrate. These are compounds from the combination of carbon, hydrogen and oxygen to form soluble Sugars. For example, all the monosaccharides and disaccharides and polymeric carbohydrates such as polysaccharides.

Among the most important monosaccharides, glucose and Fructose should be mentioned. These are the two most important monosaccharides which we'll derive from the Biomass and when they combine, they constitute something called sucrose, which is a disaccharide. So, polysaccharides are formed through the aggregation of different monosaccharides which are then used for either reserve or structural function.

Apart from that, starch and inulin (which are also starchy compound basically) are the most important reserve polysaccharides from an energy point of view. The former is a glucose polymer present in many seeds such a cereal grain and tubers such as potato and roots as for example parsnip. While inulin is composed of fructose and glucose and typically found in roots and tubers.

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- In the bioenergy context, both carbohydrates can be hydrolyzed into monomers and then fermented to produce ethanol or even directly fermented with specific microorganisms.
- Structural polysaccharides are used to build the cell walls and consist mainly of four organic compounds: *cellulose, hemicellulose, pectins,* and *lignin.*
- The cellulose is a polysaccharide made of 200-5000 molecules of glucose, aggregated in linear chains or bundles $[(C_6H_{10}O_5)_n]$ to build microfibers (Ø = 3 nm) and fibers (Ø = 10 nm-0.20 μm).
- The hemicellulose consists of polymers of pentoses and hexoses entangle among the cellulose fibers.
- Both polymers, cellulose and hemicelluloses, are relatively easy to hydrolyze and represent two-thirds of the lignocellulosic biomass.
- *Lignins* $[C_n(H_2O)_m]$ are high-molecular weight, insoluble plant polymers, which have complex and variable structures, made from phenylpropanoid alcohols.
- It requires strong acid or bases or other hydrothermal treatments to be hydrolyzed and make cellulose and hemicelluloses accessible.

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So, in the bioenergy context both carbohydrates can be hydrolysed into monomers and then fermented to produce ethanol or even directly fermented with specific microorganisms. Structural polysaccharides are used to build the cell walls and consists of four organic compounds: cellulose, hemicellulose, pectins and Lignin. Cellulose is a polysaccharide made up of 200 to 5000 molecules of glucose, aggregated in linear chains or bundles to build the microfibers or we called it cellulose microfibrils and of course fibres. So, the hemicellulose consists of polymers of pentoses and hexoses entangled among the cellulose fibres. Both polymers, cellulose and hemicellulose as relatively easy to hydrolyse and represent two thirds of the lignocellulosic Biomass (they are the major component). Lignin is another major component; is a high molecular weight insoluble plant polymer, which have complex and variable structures made from phenylpropanoid alcohols.

Lignin is a complicated structure and it is very rigid. It requires strong acids or bases or other hydrothermal treatments to be hydrolysed and make cellulose and hemicelluloses accessible. That is delignification of course partly we discussed it.

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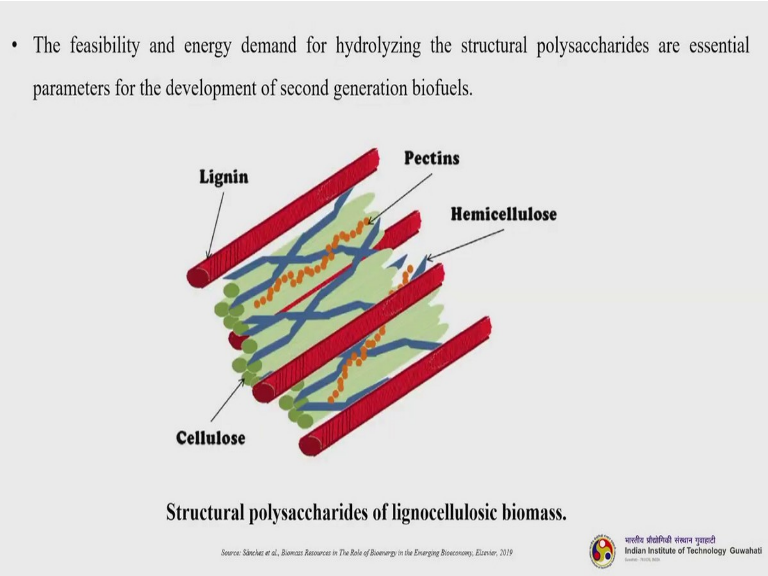

This is how Cellulose, Lignin, pectins and hemicelluloses are bound to each other in a very intricate and complex manner. So, by seeing the structure you can understand that the cellulose and hemicellulose are very much amenable to hydrolysis, but due to this recalcitrant nature and intricate structure, you need to remove the lignin. Once you remove the lignin or delignify it by doing some pre-treatment methods, lignin will be removed, cellulose and hemicellulose also becomes separated and then you can purify them and take it out for various purposes. The feasibility and energy demand for hydrolyzing the structural polysaccharides are essential parameters for the development of second-generation biofuels.

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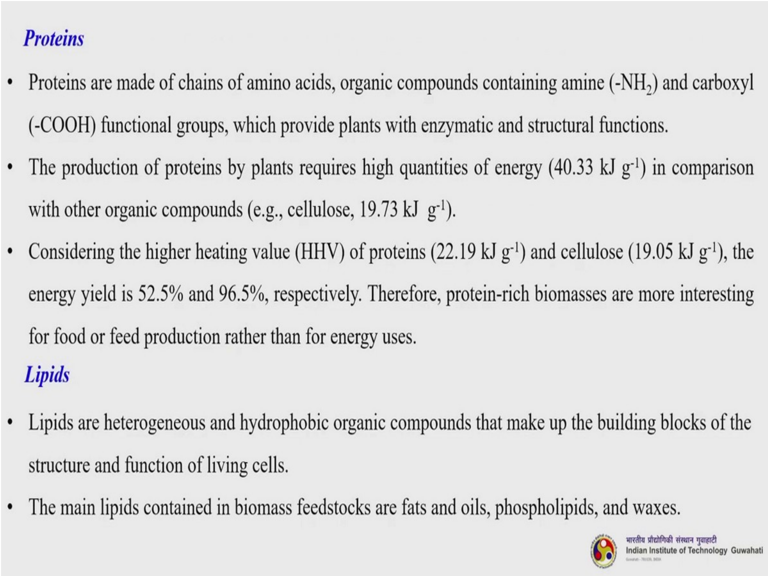

Then protein: Proteins are made up of Chains of amino acids, organic compounds containing amine (that is a $-NH_2$ group) and a carboxyl (-COOH) group which provides plants with enzymatic and structural functions. The production of proteins by plants require high quantities of energy in comparison with other organic compounds. So, considering the higher heating value of protein and cellulose the energy yield is almost 52.5% and 96.5% respectively from protein and cellulose.

Therefore, protein rich biomasses are more interesting for food and feed production rather than for energy uses. And for energy uses we always concentrate on celluloses and sometimes of course hemicelluloses also.

Lipids: Lipids are heterogeneous and hydrophobic organic compounds that make up the building blocks of the structure and function of living cells. The main lipid contained in Biomass feedstocks are fats, oils phospholipids and waxes.

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- Major components of fats or oils are *tri-esters of fatty acids and glycerol* (triacylglycerols).
- According to the saturation level of the fatty acids, whether the containing carbon is saturated by hydrogen atoms, double or triple bonds, they are classified as saturated or unsaturated fats, respectively. Saturated fatty acids, as contained in animal fats, have a higher melting point, and thus, they are solids at room temperature.
- Vegetable lipids usually have lower melting point because they contain fatty acids of longer chains and higher proportion of unsaturated fatty acids, and hence they are also called oils.
- *Waxes* are esters made from the union of long chains of alcohols and acids with the aim of acting as waterproof layers and avoiding water loss in certain parts of the plants.
- *Phospholipids*, are composed of glycerol, fatty acids, and a phosphate molecule to provide structure and protection to cells.
- From an energy point of view, the production of fats entails an energy demand of 50.5 kJ g^{-1} with an energy yield of 77.2% (considering a HHV of 38.93 kJ g^{-1}).

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Major components of fats or oils are tri-esters of fatty acids and glycerol which are called triacylglycerols. According to the saturation level of fatty acids whether the containing carbon is saturated by hydrogen atoms, double or triple bonds, they are classified as saturated or unsaturated fats. Saturated fatty acids as contained in animal fats have a higher melting point and thus they are solids at room temperature.

So, you must have heard many times about the saturated, unsaturated, trans fat and all these things. So saturated fats as it is mentioned that it has the higher melting point so it is not good to be taken in the food items. Then there are unsaturated fatty acids; vegetable lipids usually have lower melting point because they contain fatty acids of longer chains and higher proportions of unsaturated fatty acid and hence they are also called as oils. So, all the nuts and all contains so much of these unsaturated fatty acids.

Waxes are esters made from the union of long chain of alcohols and acids with the aim of acting as water proof layers and avoiding water loss in certain parts of the plants. Phospholipids are composed of glycerol and fatty acid and a phosphate molecule to provide structure and protection to cells.

From an energy point of view, the production of fats entails an energy demand of almost 50.5 kilojoules per gram with an energy yield of 77.2 %, if you consider a high heating value of 38.93 kilo joules.

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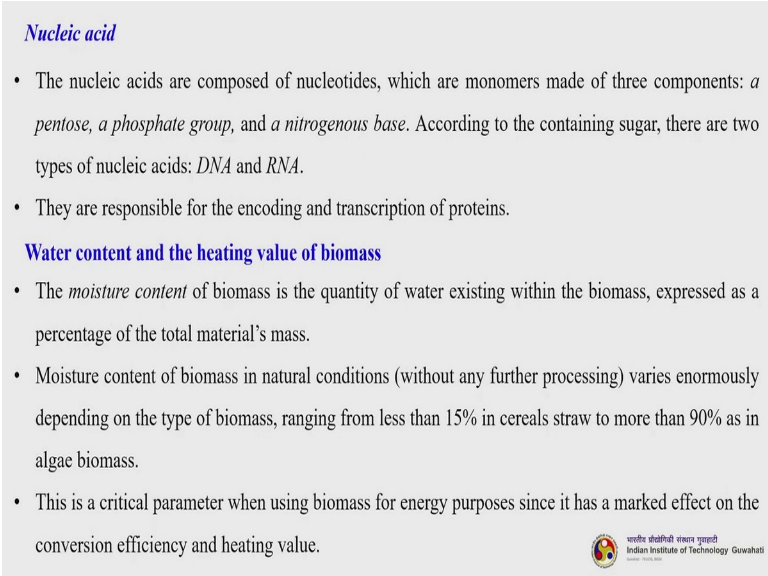

The next one is Nucleic acids. So, the Nucleic acids are composed of nucleotides which are monomers made up of three components. First is a pentose group, then a phosphate group and then a nitrogenous base. Now according to their containing sugars, there are two types of nucleic acid: DNA (which is called deoxyribonucleic acid) and RNA (which is called Ribonucleic acid). And they are responsible for the encoding and transcription of proteins.

Then water content and the heating value of biomass. The moisture content of biomass is the quantity of water existing within the Biomass expressed as a percentage of the total materials' mass. Moisture content of Biomass in natural conditions without any further processing varies enormously depending upon the type of biomass ranging from less than 15% in cereals straw to more than 90% as in algae biomass.

So, this is a critical parameter when using Biomass for energy purposes since it has a marked effect on the conversion efficiency and heating value. So, in no case any Biomass is preferred for conversion whether it is a thermochemical conversion or biochemical conversion, if it has more than 20 to 25% or 30% of moisture, that is not desirable. It is true that last class I was telling you that a certain high moisture containing Biomass can be converted suitably in a biochemical platform. That is true. But more moisture containing also do create problems while processing.

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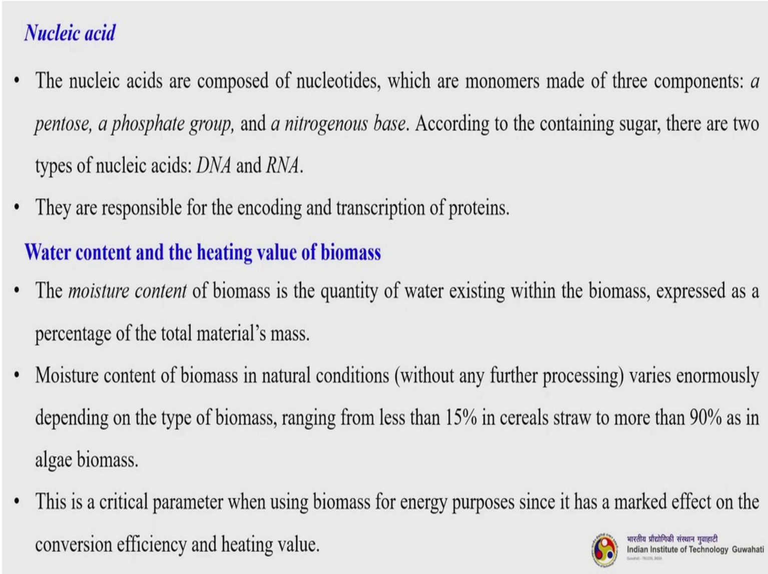

Moreover, high moisture content entails logistic issues since it increases the tendency to decompose that means resulting in energy loss during storage and reduces the energy and cost balances. The heating value of biomass feedstock represents the energy amount per unit mass or volume released on complete combustion. The heating value is referenced into different ways: the higher or gross heating value HHB and the lower or net heating value LHV.

And we have already discussed in one of the class that LHV is the one, which is appropriate value to assess the energy available for the subsequent use in case of bio refinery concept or let us say if you are talking about Biomass to biofuels.

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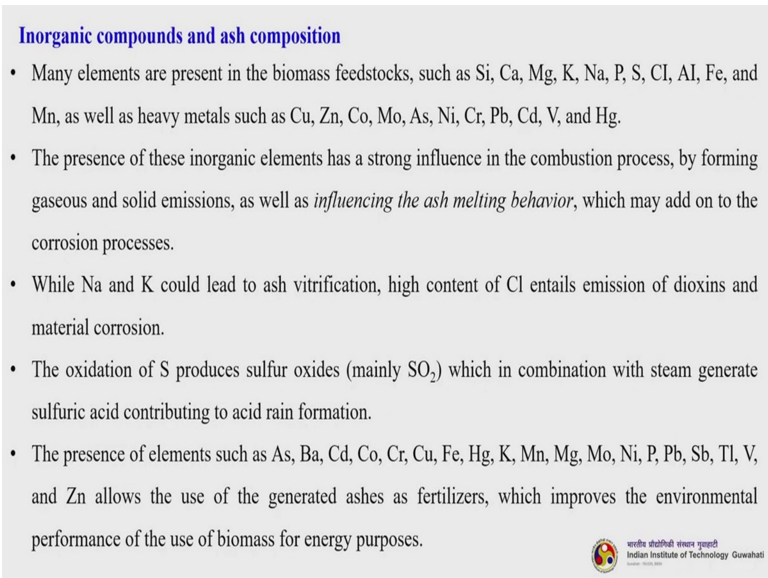

Then inorganic compounds and ash composition: Many elements are present in the Biomass feedstocks such as Silicon, Calcium, Magnesium and there are many. As well as certain heavy metals such as Copper, Zinc, Cobalt, molybdenum etc. The presence of these inorganic elements has a strong influence in the combustion process by forming gaseous and solid emissions as well as influencing the ash melting behaviour which may add on to the corrosion process.

While Sodium and potassium could lead to ash vitrification, high content of chlorine entails emission of dioxins and material corrosion. The oxidation of S produces sulphur oxides mainly Sulphur Dioxide which in combination with steam generates sulphuric acid contributing to acid rain formation. The presence of elements such as Arsenic, barium cadmium all these heavy metals allows the use of the generated ashes as fertilizers which improve the environmental performance of the use of biomass for energy purpose and additional use basically.

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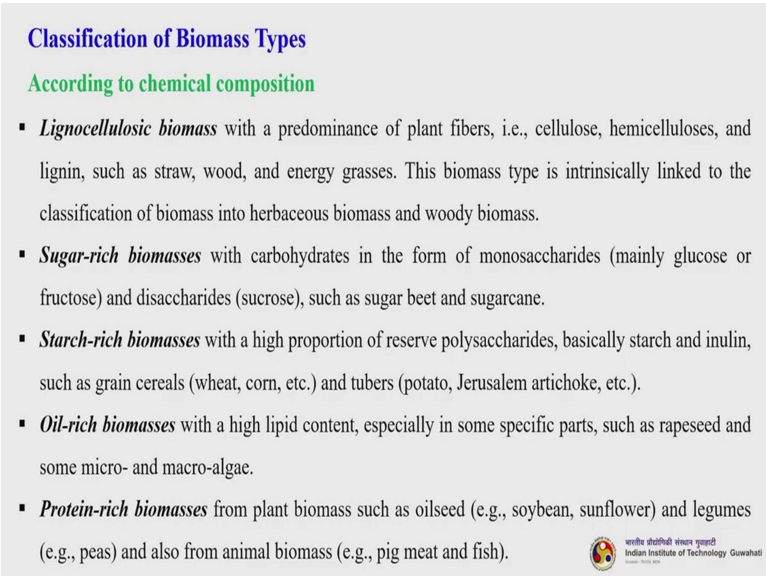

Then we will discuss the classification of biomass types with respect to biorefinery. So, if we classify them according to their chemical composition. So, they can be classified as: lignocellulosic Biomass, sugar rich biomass, starch rich biomass, oil rich biomass, protein rich basically these types. So, lignocellulosic we have already discussed many times so it is containing mostly the plant fibres which contains cellulose, hemicellulose and Lignin. So, wood, starch, straw and energy grasses all this comes under lignocellulosic Biomass and this type of Biomass is intrinsically linked to the classification of Biomass into herbaceous Biomass and woody biomass.

Under sugar rich biomasses, so there enriched with carbohydrates in the form of monosaccharides mainly glucose and Fructose and disaccharides sucrose. Such as sugar beet and sugar cane.

Then if you talk about starch rich biomasses, they have a high proportion of reserve polysaccharides, basically starch and inulin (Inulin is a starchy compound again), such as found in the grain cereals whether it is wheat, corn etc. or tubers, potato, artichoke etc.

Oil rich biomasses; so they have high lipid content especially in some specific parts such as rapeseed and some micro and macro algae.

Then protein rich biomasses. So, from plant Biomass such as oil seed as for example soybean, sunflower and legumes. As for example peas and also from animal biomasses. Pig meat, fish and this so called this meat and fish processing industries.

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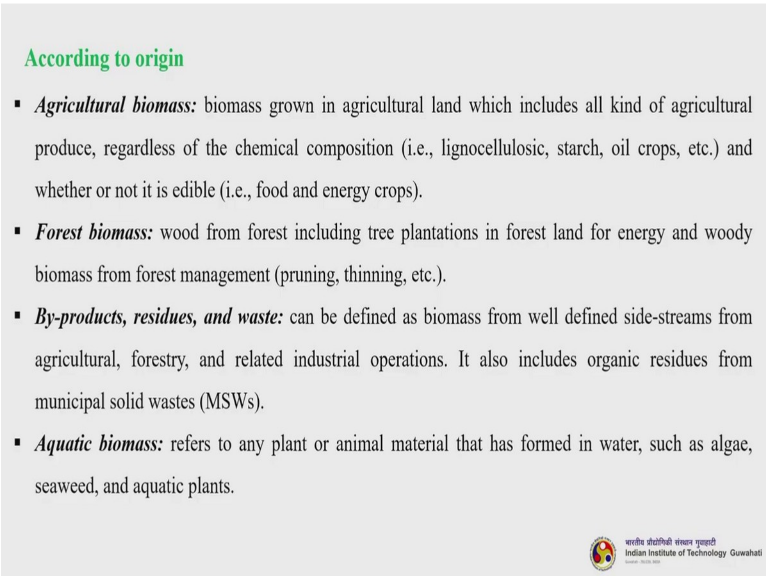

Then agricultural Biomass, forest Biomass, by-products residues and waste, and aquatic biomass. So, biomass grown in agricultural land, which includes all kinds of Agricultural produce regardless of chemical composition, whether it is lignocellulosic, starch, oil crops etcetera and whether it is edible or not.

So then forest biomass; wood from forest including tree plantation in forest land for energy and woody biomass from forest management. So basically, pruning activities and thinning activities all these things. Nobody is going to cut the healthy plants to make biofuel. So, that is not allowed in any country and should not be done also. So, anything that is because falling from the tree or when we are doing this pruning and thinning business that time whatever we are producing the wood or woody products so those can be coupled under the so-called forest biomass.

Then by-products, residues and waste: This can be defined as biomass from well-defined side-streams from either agricultural forestry or related industrial operations. It also includes organic residues from Municipal solid waste, MSW.

Then comes the aquatic biomass, so it refers to any plant or animal material that has formed in water such as algae, seaweed and aquatic plants.

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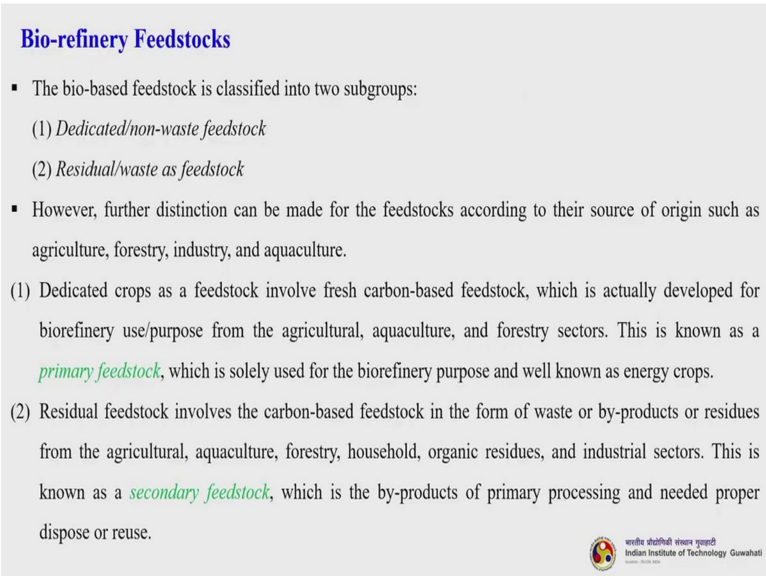

Now let us talk about the biorefinery feedstocks. Broadly we can classify them as either: (1) dedicated or non-waste feedstock; (b) residual or waste as feedstock. So, further distinction can be made for the feedstocks according to their source of origin such as agriculture, forestry, industry and aquaculture we have just seen that.

So (1) dedicated crops as feedstock involve a fresh carbon-based feedstock which is actually developed for biorefinery use or purpose from the agricultural, aquaculture and forestry sectors. This is known as primary feedstocks which is solely used for the biorefinery purposes and are also well known as energy crops. So, they are only planted for the bio-refinery or energy purposes. So then (2) residual feedstock involves the carbon-based feedstocks in the form of waste or by-products or residues from the agricultural, aquaculture, forestry, household, organic residues and industrial sector. This is known as secondary feedstock which is the by-product of primary processing and needed proper dispose or reuse.

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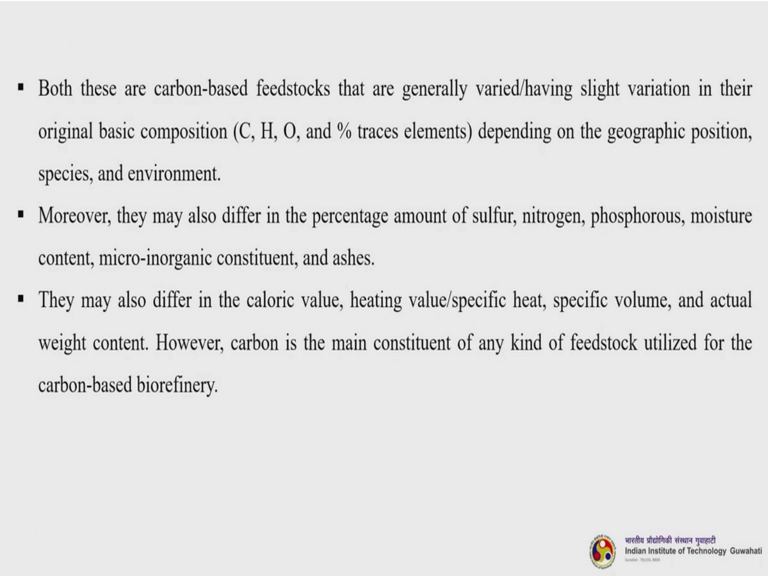

So, both these are carbon-based feedstocks that are generally varied/having slight variation in their original basic composition (of hydrogen, carbon, oxygen and other trace elements) depending on the geographical location or position, species type, and the environment. Moreover, they may also differ in the percentage amount of sulphur, nitrogen, phosphorous, moisture content, micro-inorganic constituents and ashes.

They may also differ in the calorific value, heating value or specific heat, specific volume and actual weight content. However, carbon is the main constituent of any kind of feedstock utilised for the carbon based biorefinery.

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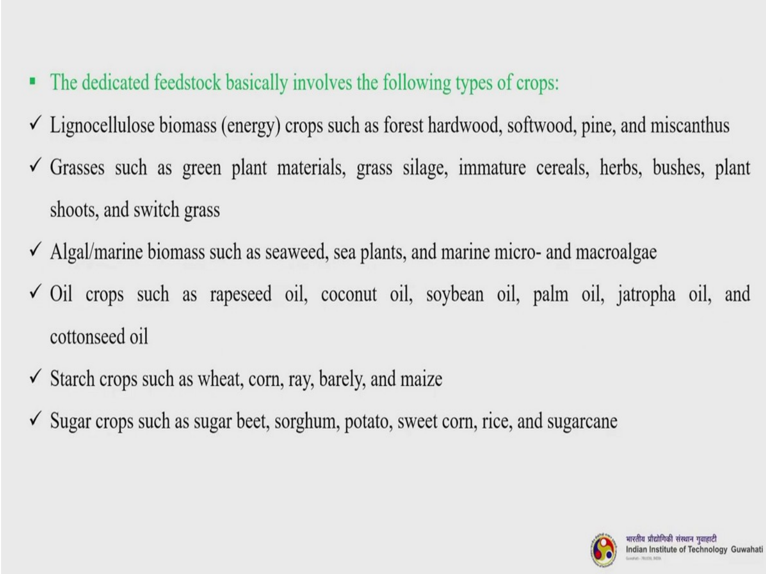

So, the dedicated feedstock basically involves the following types of crops: lignocellulosic Biomasses, that is the energy crops such as forest hardwood, softwood, pine and miscanthus; Grasses such as green plant materials, grass silage, immature cereals, herbs, bushes, plant shoots and switch grass; Algal, or Marine Biomass such as seaweeds, sea plants and Marine micro and macro algae; Oil crops such as rapeseed oil, coconut oil, soybean oil, palm oil, jatropha oil and cottonseed oil and then many others; starch crops such wheat, corn, ray, barely and maize; Then sugar crops such as sugar beet, Sorghum, potato, sweet corn, rice and sugar cane.

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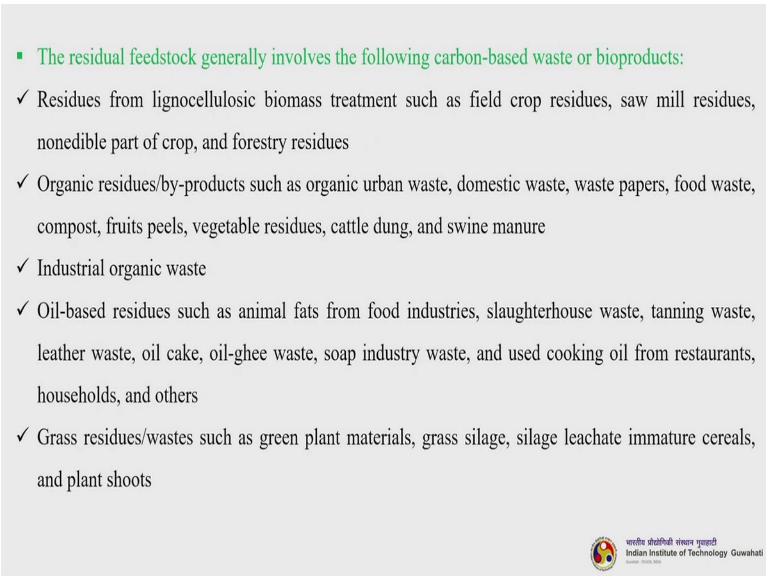

The residual feedstock generally involves the following carbon-based waste or bio-products: Residue from lignocellulosic Biomass treatment such as field crop residues, saw mill residues such as saw dust, nonedible part of the crop and the forestry residues (which are basically left out after the processing); Then organic residues and by-products such as organic urban waste, domestic waste, waste paper, food waste, compost, fruit peels, vegetable residues, cattle dung and Swine manure; Industrial organic waste; Oil based residues such as animal fats from food Industries, slaughterhouse waste, tanning waste, leather waste, oil cake, oil ghee waste, soap industry waste and used cooking oil from restaurants households and others; Grass residues and waste such as green plant materials, grass silages, silage leachate immature cereals and plant shoot.

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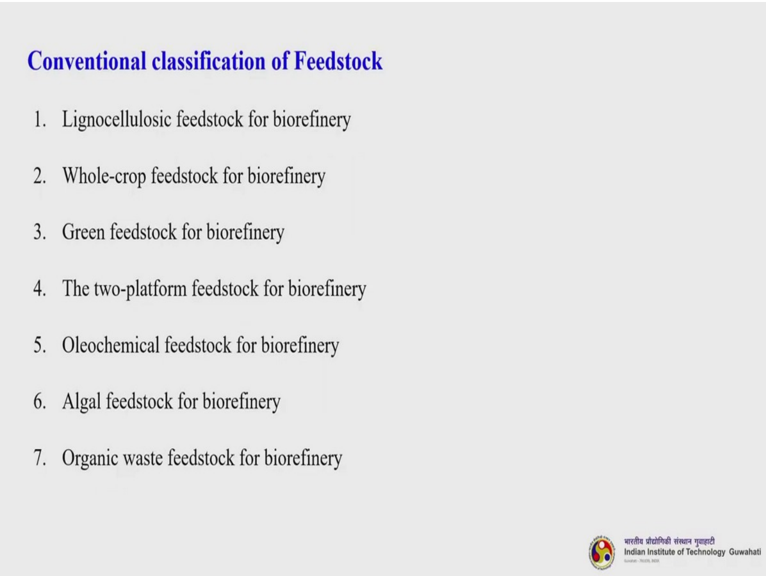

This is the conventional classification of feedstock. I am just telling you again. We have discussed about the biorefinery classification. Again, the feedstock has been also classified in the same way as the biorefineries has been classified: (1) lignocellulosic feedstock for biorefinery; (2) whole crop feedstock for biorefinery; (3) green feedstock for biorefinery; (4) the two platform (the two platform we have already we discussed, please understand and don't get confused. Again, I am repeating that this is the name here whatever listed here you are seeing, all these has been classified as it is for the biorefinery. The types of biorefineries we have discussed in the last class. Now the feedstock for the biorefineries are also classified in the same manner); (5) Oleochemical feedstock for biorefinery; (6) Algal feedstock; and (7) Organic waste feedstock. We will just quickly see what are these types of feedstocks. What are the advantages and disadvantages and how do we process these feedstocks one by one will quickly see.

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Lignocellulosic feedstock; Most successful, primitive, primary, and potential biorefinery feedstock among all the biorefinery feedstock. So, it involves the nature dry lignocellulosic feedstock such as wood material, straw, corn stover other agricultural residues, energy crops and Municipal lignocellulosic wastes. Now this involves three major interior constituents such as hemicellulose, cellulose and Lignin.

So, how do we process these feedstocks? So, pretreatment and dissolution of lignocellulosic biomass (that is the first thing) using a suitable solvent. Then you separate the lignocellulosic feedstocks into basic three components cellulose, hemicellulose, and Lignin. Once that is done, so you take out the cellulose and then you hydrolyse the cellulose. So, you hydrolyse it to what? To fermentable sugars or fermentable glucose.

That can be converted into sugar to biofuels or chemical intermediates like alcohol - basically, it is an alcohol platform (whether it is methanol, ethanol and butanol) and organic acid (succinic acid, lactic acid, levulinic acid etc.) either by chemical and biochemical methodology. Then hydrolysis of the hemicellulose polysaccharides into the xylose sugar that can be converted into biofuels or Chemicals like xylitol and furfurals by using chemicals and biochemical methodology.

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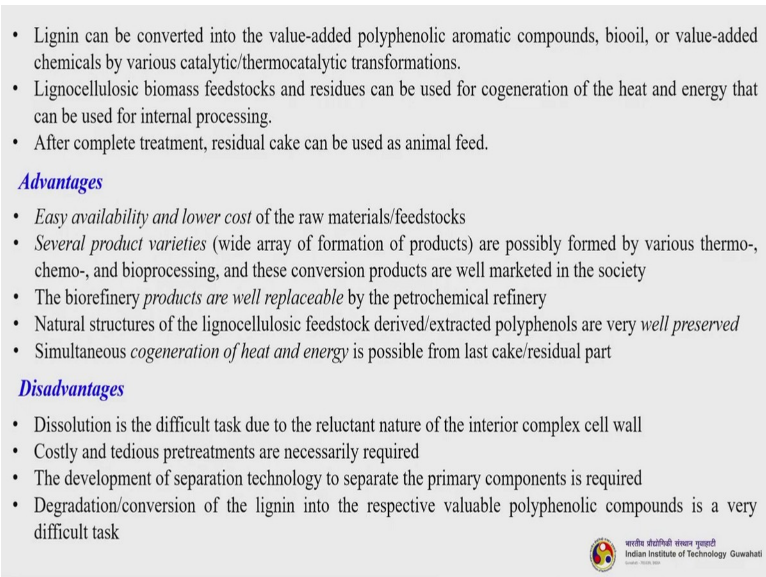

Lignin can be converted into value added polyphenolic aromatic compounds, bioil and value-added Chemicals by various catalytic and thermocatalytic transformation. Lignocellulosic Biomass feedstocks and residues can be used for co-generation of the heat and energy that can be used for internal processing. After complete treatment residual cake can be used as animal feed.

Now the advantages are: they're easily available and are of course lower cost if compared to any other raw materials and feedstock; several product varieties - that means we get a wide array of formation of products - can be possible from lignocellulosic Biomass by various thermochemical and biochemical platforms. And some of these products are well marketed in the society; So, the biorefinery products are well replaceable by the petrochemical refinery; and natural structures of the lignocellulosic feedstock derived/extracted polyphenols are very well preserved; And simultaneous co-generation of heat and energy is also possible from the last cake or residual part. After processing whatever solid residues is left over that can go to co-generation of heat and energy.

However, there are certain disadvantages also; So, dissolution is the difficult task due to the reluctant nature of the interior complex cell wall. This we have discussed in the slide also I have shown you have noticed how Lignin, hemicellulose, cellulose and pectins are packed together. So, breaking it is a big job or tough job. So, you need huge amount of energy and sometimes Chemicals. So the cost of the process is very high and sometimes it may be time taking process also. So then costly and tedious pre-treatments are necessarily required. The development of separation technology to separate primary components is required. Degradation and conversion of the lignin into respective valuable polyphenolic compounds is a very difficult task and unless and until you have achieved a proper efficiency, we cannot have a sustainable biorefinery that functioning basically.

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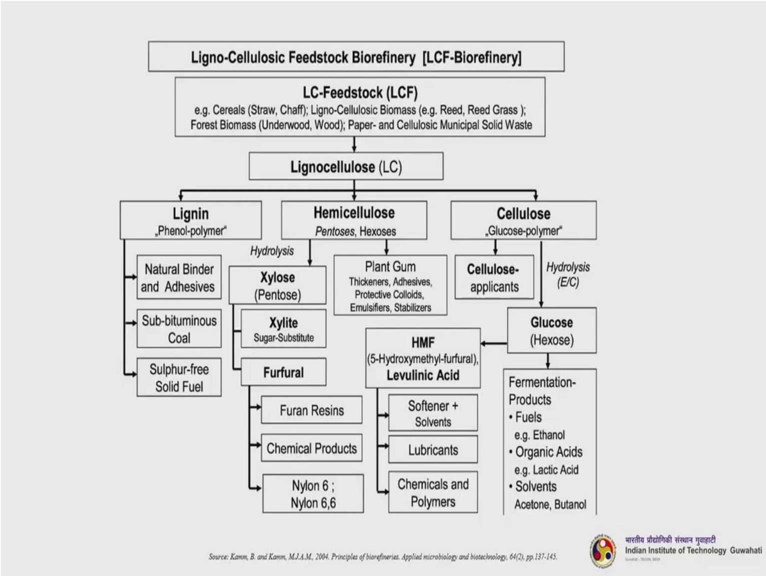

So, yes in a nutshell, please have a look at this particular slide. Where it is lignocellulosic feedstock biorefinery. LCF biorefinery we call it. So various types of feedstock; basically first you divide them, or segregate them, or dissolve them into lignin fraction, hemicellulose fractions and cellulose fraction. So the lignin fraction, lignin is a high value compound so it can be used as a natural binder and adhesives. It can go as a substitute for a sub-bituminous coal and sulphur free solid fuel. Then hemicellulose, if you hydrolyse hemicellulose, such pentoses and hexoses (C5 sugars), so, you get Xylose, Xylite and furfural and then so many other things, some platform Chemicals also. So you can have plant gum, can be used as thickeners, adhesive, protective colloids, emulsifiers and stabilizers.

Now let us look to the cellulose platform. This is the cellulose platform, entire cellulose platform. If you hydrolyse cellulose, we get glucose that is C6 sugars. So it can be fermented and you get fuels the like ethanol, butanol and all these things and some other organic acids. So, you also get HMF hydroxymethyl furfural, Levulinic acid (so these are very high value component) (And HMF is also fuel additive), so then we can also get lubricants, some sort of chemicals and Polymers and some softening agents and solvents. From this we can understand that the lignocellulolytic biorefinery gives us a wide range of products.

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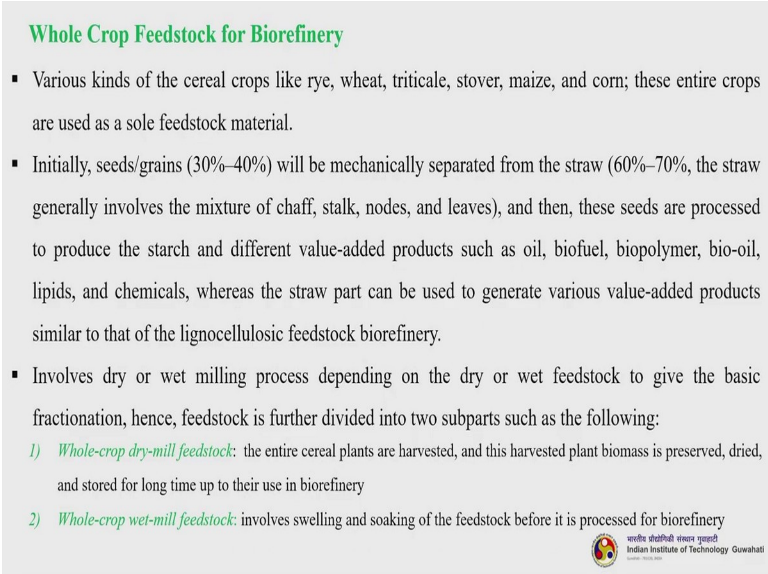

So, the next is whole crop feedstock for biorefinery: So various kinds of the cereal crops like rye, wheat, triticale, stover, Maize and corn and these entire crops as used as sole feedstock material. Initially seeds and grains which is amounting to 30 to 40% of what is harvested, will be mechanically separated from the straw which is 60 to 70% of the total in the weight basis basically.

The straw generally involves the mixture of chaff, stalk, nodes and leaves) and of course then these seeds are processed to produce the starch and different value-added products such as oil, biofuel, biopolymer, bio-oil, lipids and Chemicals. Whereas the straw part that can be used to generate various value-added products. Similar to those of those of the lignocellulosic feedstock biorefinery.

It involves dry or wet milling processes depending on the dry or wet feedstock to give the basic fractionation, hence, feedstock is further divided into two subparts: (1) whole crop dry mill feedstock; (2) whole crop wet mill feedstock. So the dry mill feedstock is basically entire cereal plants as harvested. And this harvested plant Biomass is preserved, dried and stored for long time up to their reuse in biorefinery. And the wet mill feedstock involves swelling and soaking of the feedstock before it is processed for biorefinery purposes.

So how do you process this whole crop feedstock? So first you go for mechanical segregation of the seeds and grains from the straw, you remove them. So, for the dry milling entire harvested feedstock is preserved, dried and stored for long time. While wet milling involves the primary swelling and soaking of the feedstock.

The starch present in the cereal is then hydrolysed into glucose via chemical or biochemical methodology to generate bioethanol or any other alcohol also and other value added side products such as succinic and lactic acid. Further extraction of the remaining grain components provides the polysaccharide-based bio Polymers, some drug intermediate, animal feed and certain other value-added products.

That treated residues or agricultural residues of crops are allowed for the fractionation just similar to that of the lignocellulosic biorefinery. Moreover, it can also be used for the generation of the heat and electricity in the CHP platform.

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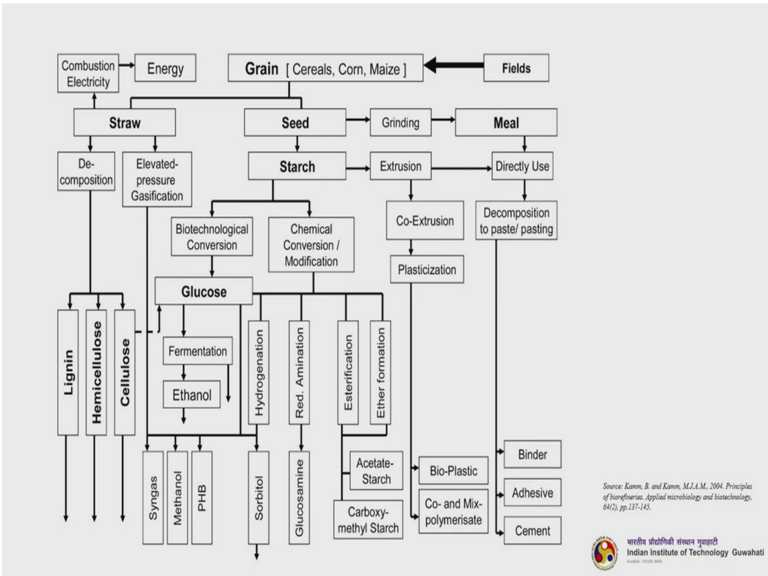

So, please have a look at this particular platform. You can see that from the feeds that grains such as cereals, corn and maize are actually procured or harvested. Then we segregate them into the seed, this is the seed platform. And this is the straw platform. You can see the straw when you decompose then you get the Lignin and hemicellulose and cellulose after the pretreatment.

So then this all can go to subsequent further processing. You go for elevated gasification. You get syngas, methanol all these things. Then seed portion can directly go to meal and can be directly used. Then we can get starch from the seed which can also be extruded and co-extruded go for Making bioplastics and certain other Polymers basically.

Then if you go for a biotechnological conversion. So you get glucose, then the glucose will go for the alcohol platform - fermentation, ethanol. So, you can also have other things also. So then, when you go for a chemical conversion and modification, so you go for hydrogenation, you go for some other esterification and other processes and you get you get many different types of products.

So, in a nutshell we can understand that almost similar type of product also you are getting in this whole crop biorefinery as we get from the lignocellulosic biorefinery. However, in case of the lignocellulosic biorefinery the area of such value-added products that is getting generated or produced is very large compared to other feedstocks.

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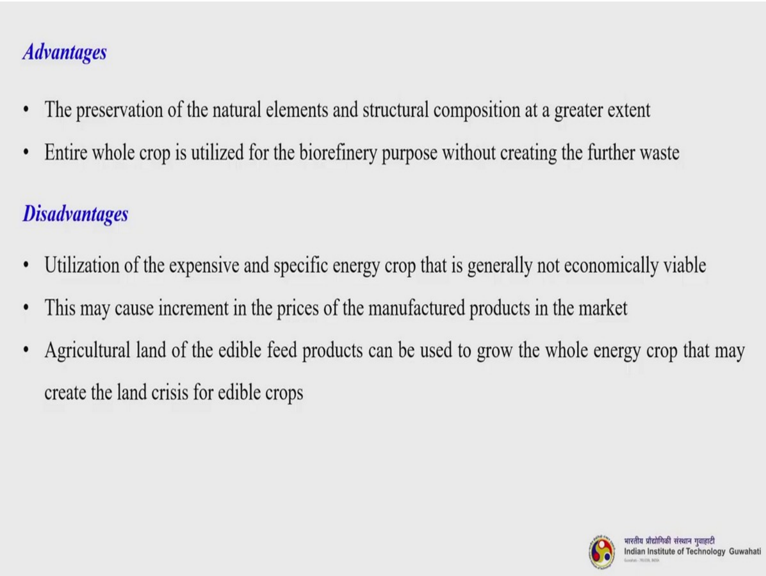

The advantages are the preservation of the natural elements and structural composition is at a greater extent and the entire whole crop is utilised for the biorefinery purpose without creating further waste. So this is one beautiful thing. This entire thing whatever is being harvested is being used for the biorefinery purposes. Nothing is being wasted.

So, the disadvantage is that utilisation of the expensive and specific energy crop that is generally not economically viable. Second, this may cause increment in the prices of the manufactured products in the market. This will happen this thing along with the agricultural land that may be utilised to grow the energy crops. It may happen as in when this so-called biorefinery concept is being applied and there are so many biorefineries are getting set up whether it is in India or other countries. So, people including even the farmers will have a tendency to grow such energy crops which takes less time to produce and which also needs little care during plantation.

And the yield per hectare as well as the energy value and economical value is much much higher than that of the certain agricultural crops. That is some sort of a threat. So thats the disadvantage. However, government should help, I have told you in one of our introduction classes. Again, I am repeating; here comes the government which will play a big role to make a policy so that no dedicated agricultural lands which are having high value land basically or fertile lands, should not be utilised for growing dedicated energy crops.

So that should be the government policy because in a country like India where you have huge population and we need a huge amount of food supply, we cannot do this.

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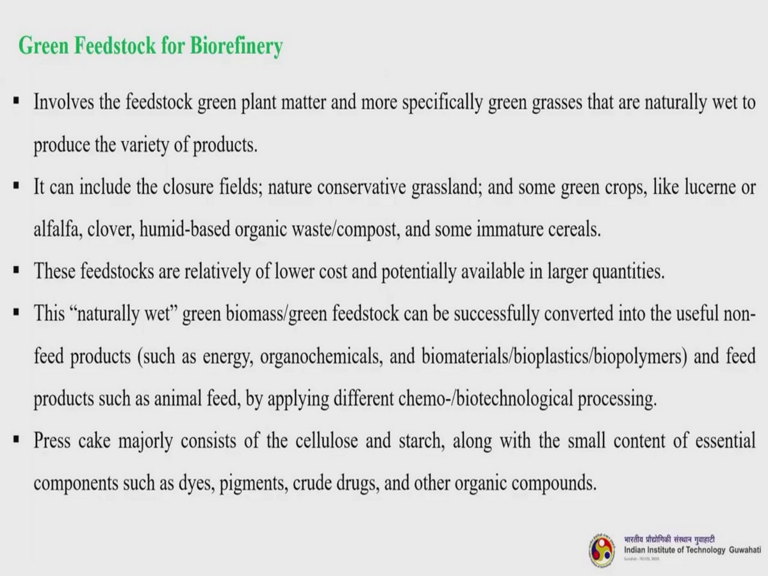

Then green feedstock for biorefinery. So, this involves the feedstock green plant matter and more specifically green grasses that are naturally wet to produce the variety of products. It can include the closure fields; nature conservative grassland; Some Green crops, like lucerne or alfalfa, clover, humid-based organic waste/compost and some immature cereals. Now these feeds stocks are relativity of lower cost and potentially available in larger quantities.

This naturally wet green Biomass or green feedstock can be successfully converted into the useful non-feed products such as energy, organochemicals, bioplastics and even feed products such as animal feed by applying different chemical or biotechnological processing. So once to do that there is something called a press cake or the leftover solid biomass. So that majorly consists of the cellulose, starch along with some small content of essential components such as dyes, pigments, crude drugs and other organic compounds.

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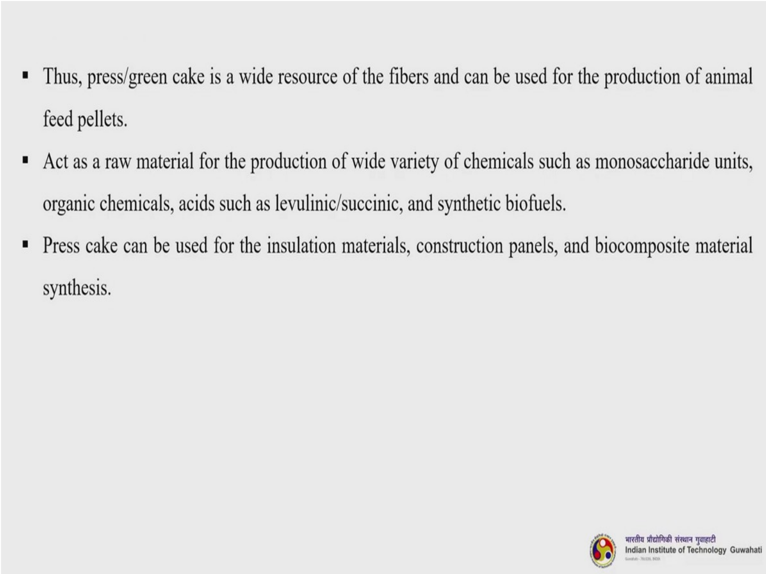

So, this press/green cake is a wide resource for the fibre production and can be used for the production of animal feed pellets. So, it acts as a raw material for the production of wide variety of chemicals such as monosaccharide units, organic Chemicals, acids such as Levulinic or succinic acid and synthetic biofuels. So, press cake can be used for the insulation material, construction panels and bio-composite materials synthesis.

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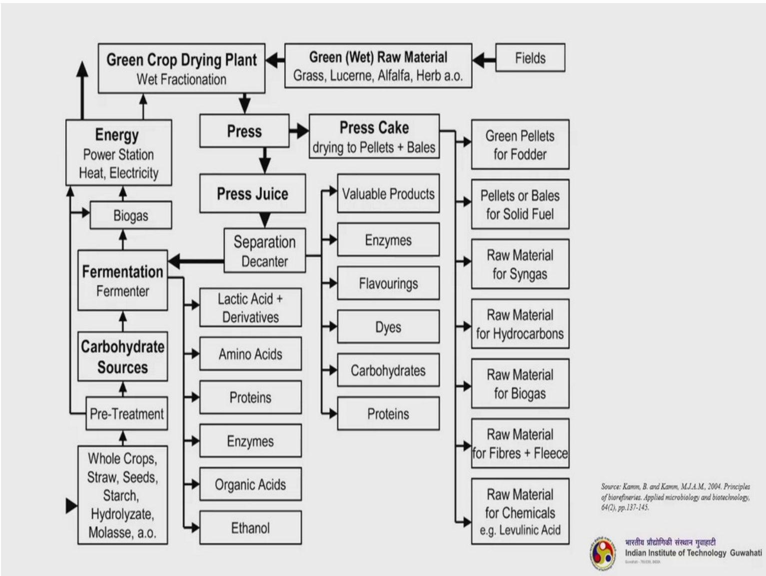

This is again you please have a look to this particular slide. You can see that from the fields we get the green wet raw material grass, lucerne whatever it is and then it can; if you are drying it so you can get a drying material. So, then you can have so many things here. Here you have the press that can goes to the juice platform. We have discussed in the biorefinery concept in the last class.

And whatever left out after the juice is getting extracted is the press cake or the solid part which is carbohydrate rich. So, the juice can go for different platforms such as this valuable products and enzymes, dyes all these things. And press cake can go for so many different types of value-added material, including your biogas, syngas and fibres and solid fuels also.

And whole crops such as straw, seeds, starch etc. you pre-treat them get a carbohydrate source then ferment you may get whatever left out and convert them to biogas and energy generation. So integrated way, it can be operated.

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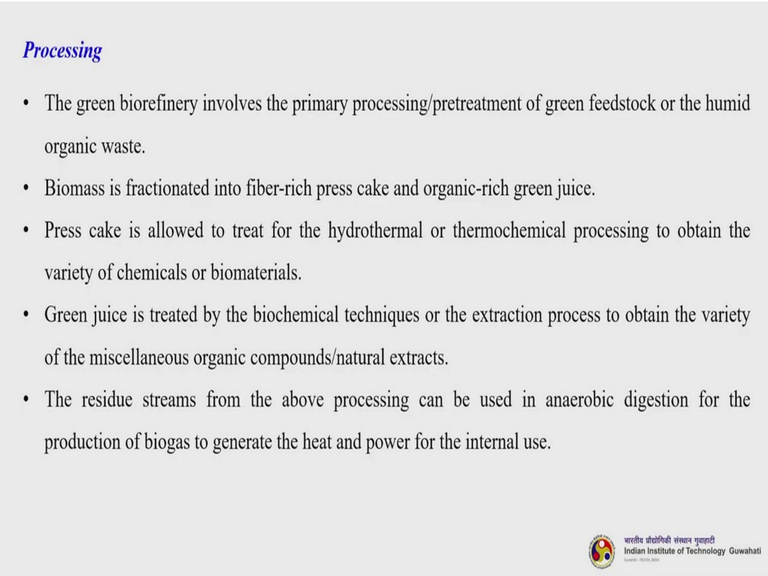

So, how do you process this? So, the green biorefinery involves the primary processing pretreatment of green feedstock or the humid organic waste. Biomass is fractionated into fibre rich press cake and organic rich green juice. Press cake is allowed to treat for the hydrothermal and thermochemical processing to obtain the variety of chemicals or biomaterials. Green juice is treated by the biochemical techniques or the extraction process to obtain the variety of miscellaneous organic compound and natural extracts.

The residue streams from the above processing can be used in anaerobic digestion for the production of biogas to generate the heat and power for the internal use.

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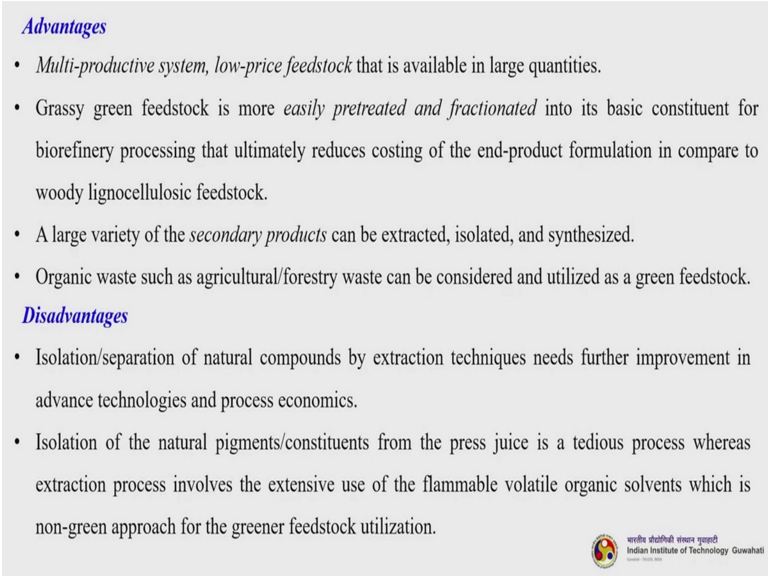

Let us understand the advantages and disadvantages of this particular feedstock. (Advantages) Multi productive system: that is a beautiful thing about this particular feedstock and low price. And these are available in large quantities. So, grassy green feedstock is more easily pre-treated and fractionated (the reason is because it has its contents low amount of Lignin), so it can be fractionated into basic constituents for biorefinery processing that ultimately reduces costing of the end product formulation when you compare it to the woody lignocellulosic feedstock. A large variety of the secondary products can be extracted, isolated and synthesized. Organic waste such as agricultural and forestry waste can be considered and utilised as a green feedstock.

(Disadvantages) And if you talk about disadvantages: Isolation and separation of natural compounds by the extraction technique needs further improvement in advanced technologies and process economics. If you talk about the downstream processing part. Then isolation of the natural pigments and components or constituents from the press juice is a tedious process. Tedious process means it is time consuming and the technology also whatever it is there, the yield is very low. Basically, we need research and more development in the downstream and processing part.

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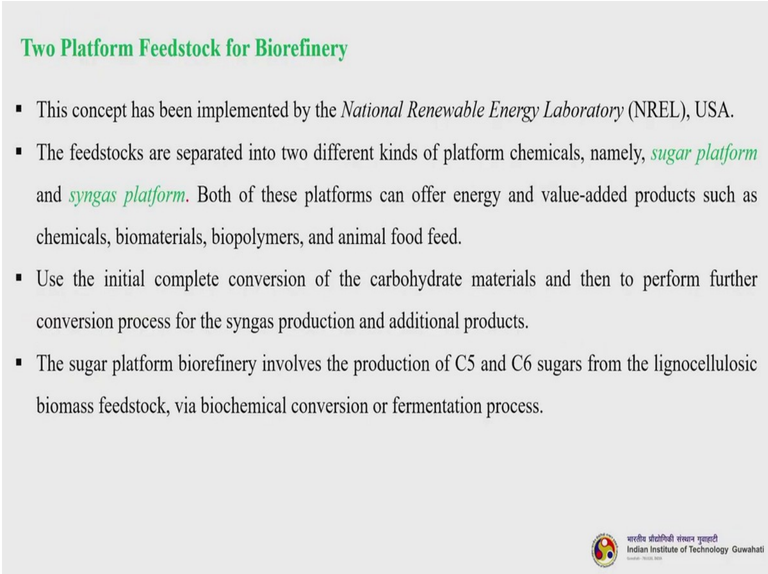

Now let us discuss about the Two platform feedstock for the biorefinery. So, this concept has been implemented by the NREL (National Renewable Energy Laboratory) of the United States. The feedstocks are separated into two different kinds of platforms, one is sugar flatform, another is the syngas platform. Now both these platforms can offer energy and value-added products such as Chemicals, biomaterials, biopolymers and animal food.

Use the initial complete conversion of the carbohydrate materials and then to perform further conversion process for the syngas production and additional products. The sugar platform biorefinery involves the production of C5 and C6 sugars from the lignocellulosic Biomass feedstock via biochemical conversion or fermentation processes.

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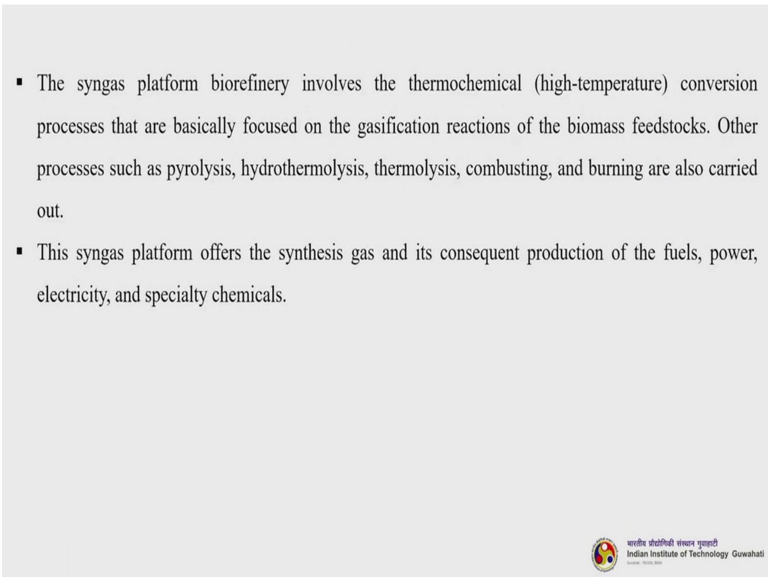

The syngas platform biorefinery involves the thermochemical conversion processes that are basically focused on the gasification reactions of the Biomass feedstock. Other processes such as pyrolysis, hydrothermolysis, thermolysis, combusting and burning are also carried out simultaneously. This syngas platform offers the synthesis gas and its consequent production of fuels, power, electricity and some speciality chemicals.

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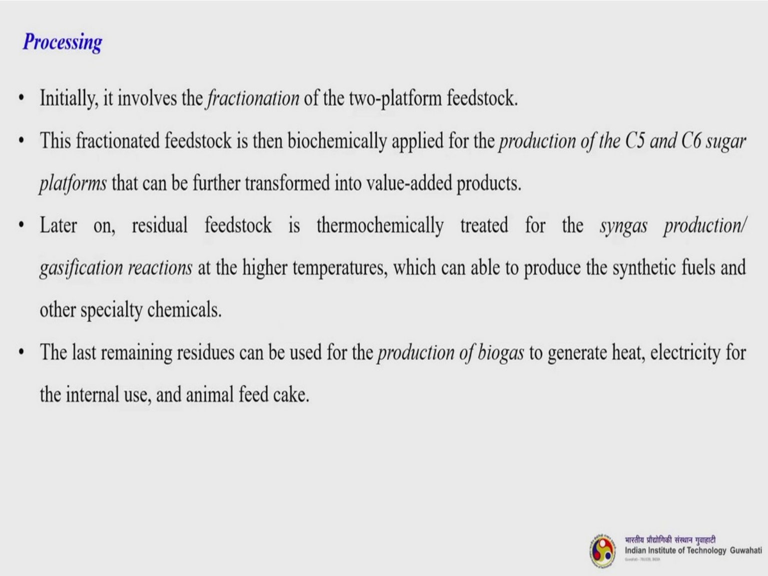

So how do you process this feedstock? So initially we have to fractionate them to two platforms basically. So, this fractionated feedstock is then biochemically applied for the production of the C5 and C6 sugar platforms that can further be transferred into the value-added products. So, it is a pentose and hexose platform. Then later on whatever the residual feedstock is left out that is thermochemically treated for the syngas production or using the gasification reactions at the higher temperatures which can be able to produce the synthetic fuels and other speciality Chemicals.

The last remaining residues can be used for the production of biogas to generate heat and electricity for the internal use and animal feed cake.

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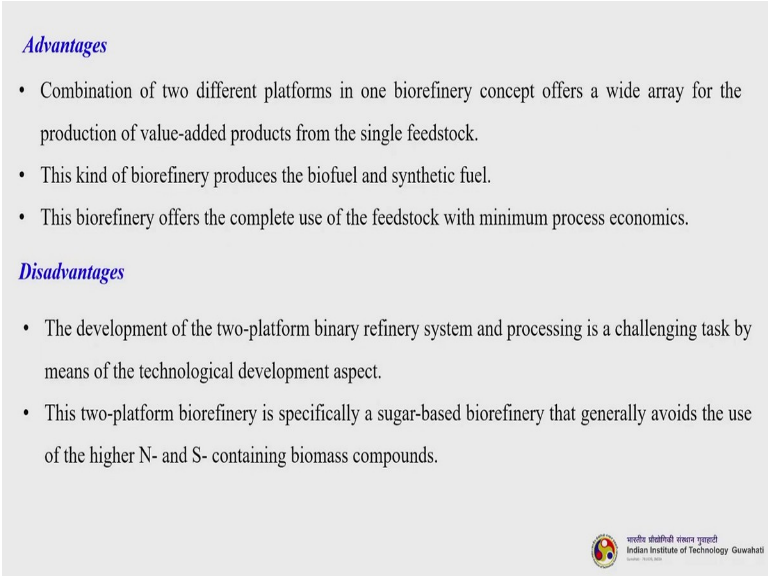

If you talk about advantages and disadvantages; (Advantages) the combination of two different platforms in one biorefinery concept offers a wide array for the production of value-added products from the single feedstock. So, this kind of bio refinery produces the biofuels and synthetic fuel. This biorefinery offer the complete use of the feedstock with minimum process economics.

(Disadvantage) is that, the development of the two-platform binary refinery system and processing is a challenging task by the means of technological development aspect. The two platform biorefinery is specifically a sugar-based biorefinery that generally avoids the use of the higher nitrogen and sulphur containing Biomass compounds.

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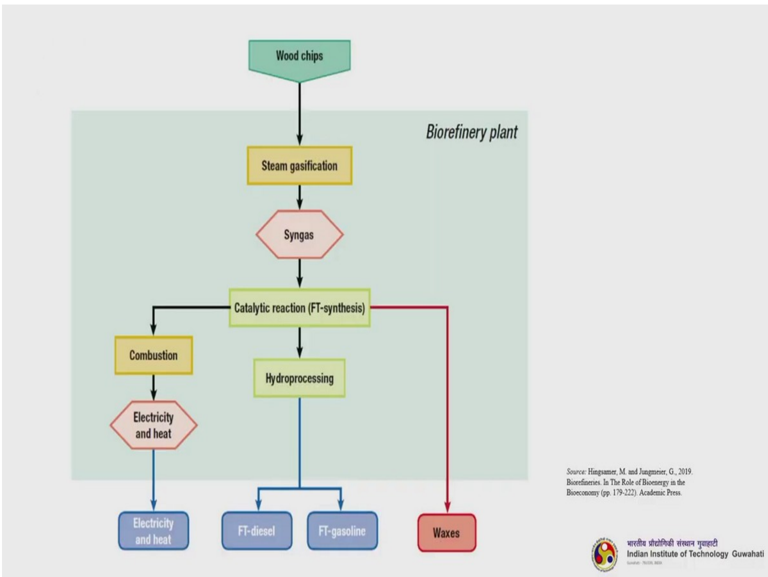

You can see this particular slide. So, this is one typical example from the wood chips. It is a biorefinery plant concept. So the wood chips goes to the steam gasification. So, you get syngas. So, syngas you catalytically convert using the Fischer Tropsch (FT synthesis basically). Then when it goes to combustion, we get electricity and heat. So you further process it (hydroprocessing basically). So, you get the Fischer Tropsch diesel and you get the Fischer Tropsch gasoline, fractionate them.

And then whatever is left out solid part that is basically the wax. This is one of the simplest platforms.

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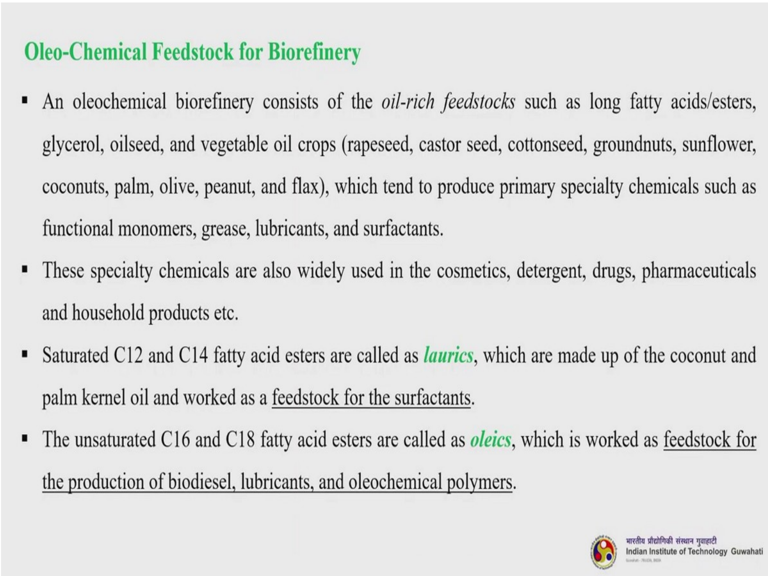

Then let us understand the oleochemical feedstock for the biorefinery. So, an oleochemical biorefinery consists of the oil-rich feedstocks such as long fatty acids and esters, glycerol, oil seed and vegetable oil crops (There are many, rapeseeds, castor seed, cotton seed we have seen it in one of the class) which tend to produce primary speciality Chemicals such as functional monomer, grease, lubricants and surfactants. These speciality chemicals are also widely used in cosmetics, detergent, drug, Pharmaceuticals and household products. Saturated C12 and C14 fatty acids are called the ***laurics***, which are made up of the coconut, palm kernel oil and worked as feedstock for surfactants. Then the unsaturated C16 and C18 fatty acids are called as oleics, which is worked as feedstock for the production of the biodiesel, lubricants and certain oleochemical Polymers.

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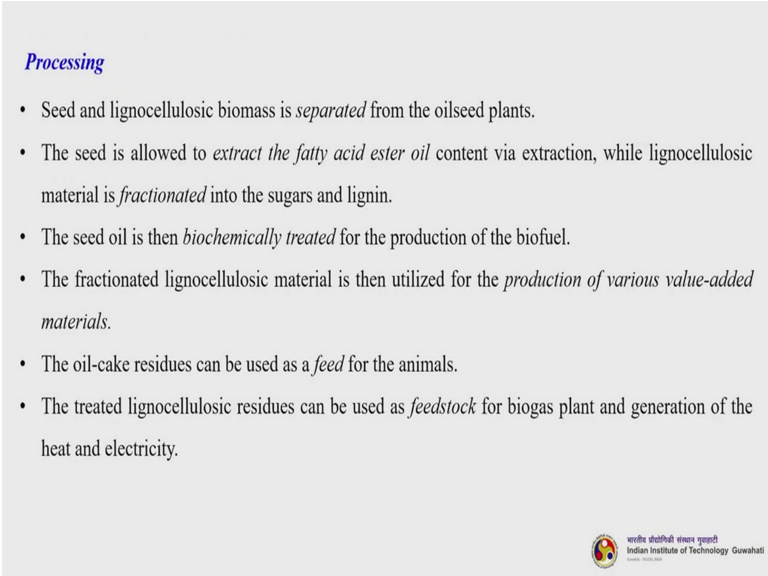

How do you process them? So seed and lignocellulosic Biomass is separated from the oil seed plants. The seed is allowed to extract the fatty acid ester oil content by extraction while the lignocellulosic materials which is left of the solid parts (so basically, the oil and removed part), is fractionated into the Sugars platform. And of course, the Lignin is generated, so the lignin goes to various end use.

So, the seed oil is then biochemically treated for the production of the biofuel. The fractionated lignocellulosic material is then utilised for the production of various value-added material or products. The oil cake residues can be used as a feed for the animals. The treated lignocellulosic residues can be used as a feedstock for the biogas plant and the generation of the heat and electricity.

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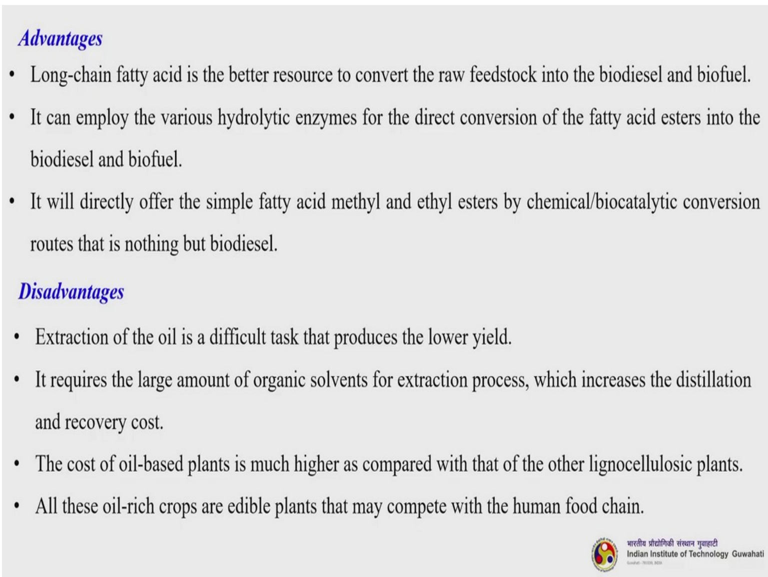

So, if we talk about the advantages and disadvantages of this particular feedstocks. (Advantages) It is a long chain fatty acid, so it's a better resource to convert the raw feedstock into biodiesel and biofuel (yield will be basically very high if we compared to other biomasses). So, it can employ the various hydrolytic enzymes for the direct conversion of the fatty acid esters into the biodiesel and biofuel. It will directly offer the simple fatty acid methyl and ethyl esters by chemical and biocatalytic conversion routes that is nothing but biodiesel.

(Disadvantages) So, disadvantages are, the extraction of the oil is a difficult task that produces the lower yield (because of this extraction technology - need to work more on that). So, it requires the large amount of organic solvents for the extraction process, which increases the distillation and recovery cost. The cost of oil-based plants is much higher as compared to that of the other lignocellulosic plants. All these oil-rich crops are edible plants that may compete with the human food chain.

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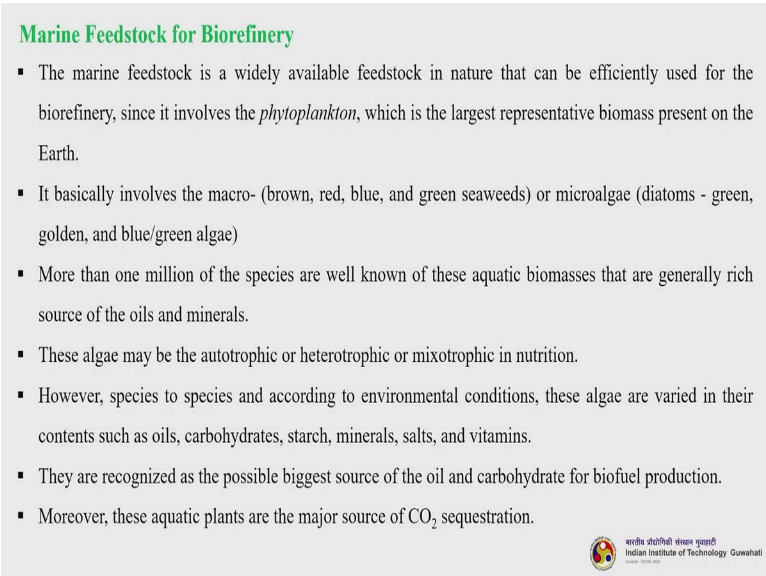

The next one is the Marine feedstock for biorefinery. So, the marine feedstock is a widely available feeds stock in nature that can be efficiently use for the biorefinery purposes. Since it involves the phytoplanktons which are the largest representative biomass present on the earth. It basically involves the macro or micro algae. So more than 1 million of the species are well-known and these algae maybe autotrophic and heterotrophic or mixotrophic.

However, species to species and according to environmental condition, the Algae are varied in their content such as oil, carbohydrate, starch, minerals, salts and vitamins. So, they are recognised as the possible biggest source of the oil and carbohydrate for biofuel production. Moreover, these aquatic plants are the major source of carbon dioxide sequestration. This is the most interesting part of the so-called algal business macro or micro algae whatever it is, as I told you in one of the introduction classes; why so much people are talking about algae and algal biorefinery nowadays? Why many people across the globe working on algae? The reason is that, it is its carbon dioxide sequestration or Carbon dioxide uptake capacity which is almost ten times or even more than that of the Terrestrial plants. So that is one of the most important aspect of this algal business.

So, you are growing algae, and then you are taking the biomass and you are doing the bio-processing to get the biofuels, value added products and what not. At the same time, you are also doing the carbon dioxide sequestration.

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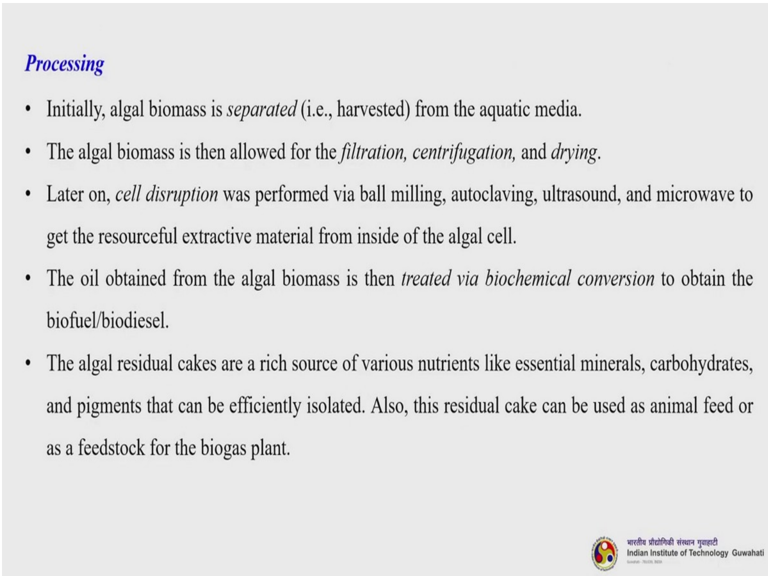

So how do you process them? So initially the biomass is separated or harvested from the aquatic media. The harvesting of algal biomass is itself is very, very time taking and again whatever (harvesting) methods are available, they are not so efficient. So, people still working on that. So, the algal Biomass is then allowed for the filtration, centrifugation and drying.

Then you do the cell disruption. So, you do cell disruption by so many different methods. You can go for mechanical methods like milling, you go for autoclaving, you go for ultrasound assisted methods, microwave radiation methods. So, (cell disruption is done) to remove the components which are present inside the cell of the algae and take it out basically.

So, the oil that is obtained from the algal Biomass is then treated by biochemical conversion to obtain the biofuel and biodiesel. The algal residual cakes are a rich source of various nutrients, like essential minerals, carbohydrates and pigments that can be efficiently isolated. Also, this residual cake can be used as animal feed or feedstock for the biogas plant.

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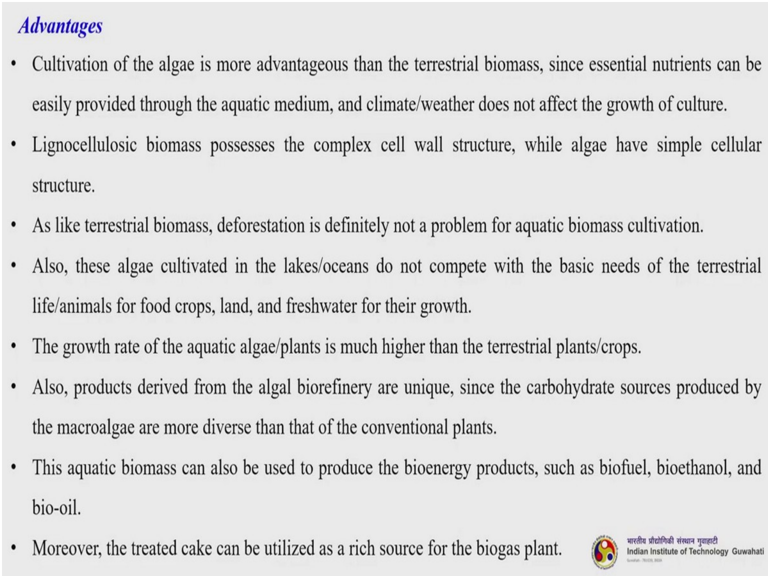

So, advantages are: of course the cultivation of algae is more advantages to the terrestrial Biomass. Carbon dioxide sequestration is a biggest advantage. Then Algae are very well known to adjust to the climatic conditions harsh or mild. So lignocellulosic biomass possesses the complex cell wall structure while algae have simple structure. And so, you can easily basically pre-treat them. So like terrestrial biomass, deforestation is not a problem in case of aquatic biomass.

Algae cultivated in the lakes and oceans do not compete with the basic needs of the terrestrial life/animals for food crops, land and freshwater for their growth. Another important aspect. So, the growth rate of the aquatic plants or algae is much higher than the terrestrial plants. Also, products derived from the algal biorefinery are unique since the carbohydrate sources produced by the macroalgae are more diverse than that of the conventional plants. This is another important aspect. Now this aquatic biomass can also be used to produce the bioenergy products such as biofuel, bioethanol and bio-oil and treated cake can also be utilised as a rich source for the biogas plant.

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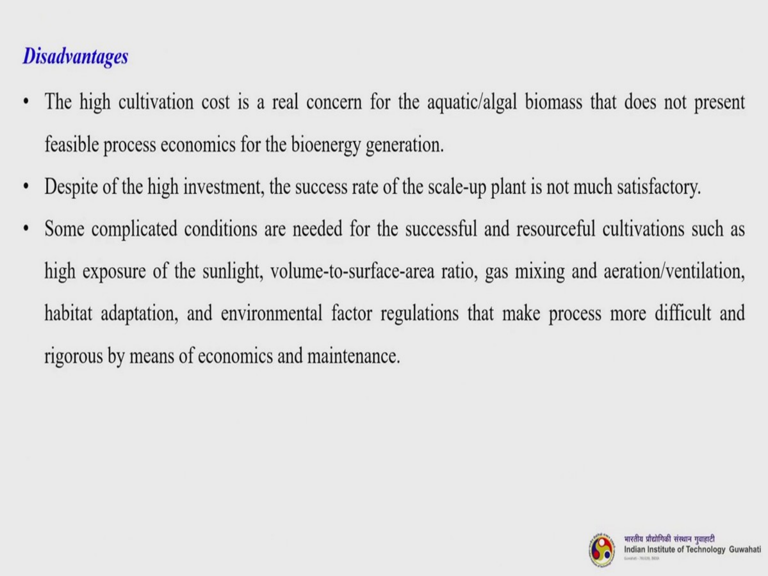

Of course, having said that there are certain disadvantages like the high cultivation cost. So, you know algae be needs a growth medium. It is not only water. You need to supply food to them and apart from that they also need the macro and micronutrients. So, the existing commercial growth media, which is available, which is BG11 or there are many others such commercial growth media, they are very costly.

So, if you go for a **raceway pond** culturing and any such photobioreactor in a large scale, then the entire cost of this cultivation becomes too much. And ultimately your product cost will be so high that it cannot be commercially viable. So that is why the people are still working on how to produce algae on waste water streams? Many people are working and my group is also currently working on this particular aspect that how do we grow algae on low cost media and different wastewaters, whether it is domestic wastewater or Industrial waste water.

Some complicated conditions are needed for the successful and resourceful cultivation such as high exposure of Sunlight, volume to surface area ratio, gas mixing, aeration/ventilation etc. Economics also not so favourable right now, but so much of work has been going on and I am sure that in the next decade algal biorefinery will take a centre stage in the entire biorefinery business.

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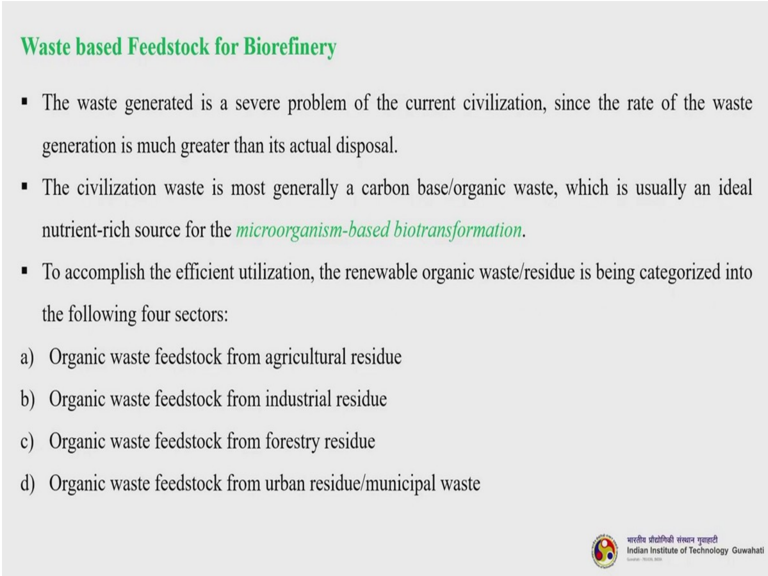

So, then the last one is waste based feedstock for biorefinery. So, the waste generated is a severe problem of the current Civilization since the rate of waste generation is much, much greater than its actual disposal. That is why you will find waste everywhere. So, the Civilization waste is most general a carbon based or organic waste which is ideally a nutrient rich source for the microorganism-based biotransformation.

So, to accomplish the efficient utilisation, the renewable organic waste residues is being categorised into the following four sectors:
(a) Organic waste from agricultural residue; (b) Organic waste from industrial residue; (c) Organic waste from the forestry residue and; (d) Organic waste from the urban residue or Municipal waste.

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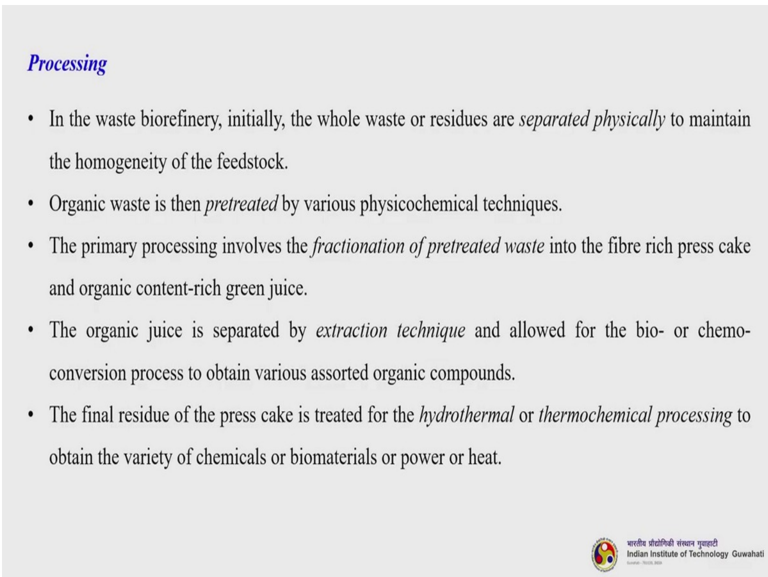

Again, the processing is similar type: separated physically, to maintain the homogeneity of the feedstock. You pre-treat them by various physicochemical techniques. Fractionate the pre-treated waste into fibre rich press cake and organic content rich green juice. Then you follow the extraction technique and other hydrothermal and thermochemical processing to get various platform Chemicals, fuels, heat and other Polymers.

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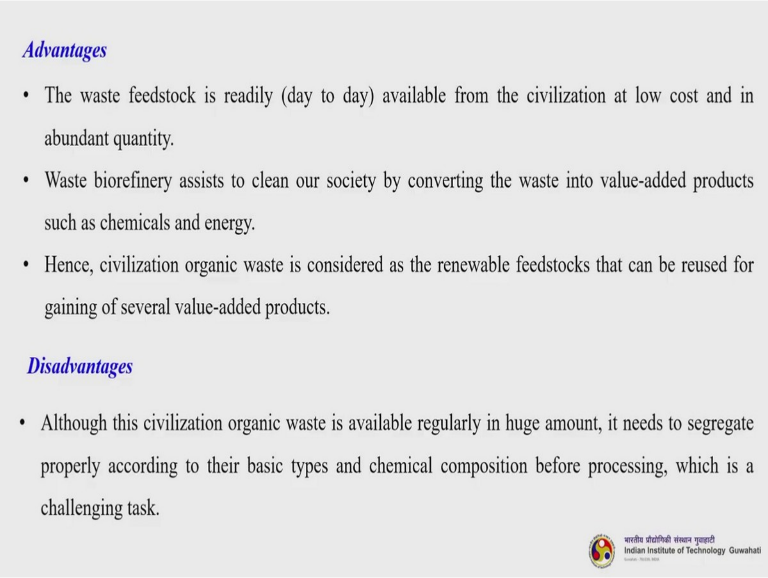

So, advantage is that: You are generally talking about waste, which is already waste. So, you have to basically collect it, segregate it and then of course use it. So, waste biorefinery assist to clean our society by converting the waste into value added products such as Chemicals and energy. Hence, civilization organic waste is considered as the renewable feedstock that can be reused for gaining several value-added products.

Having said that there is a disadvantage also, that this is available regularly in huge amount and it needs to segregate properly according to their basic types and chemical composition before processing. So, this segregation is a big task. The municipal solid waste contains so many things. It contains metals, it contains plastic, polythene and all these things, food waste then organic waste, then waste from industries and there are so many things.

So, everything together cannot be dumped to a thermochemical or biochemical platform, you cannot do that. So, you need to segregate it. So that segregation itself is a big task and if we educate people to segregate that at source, which is the best possible method to do that when we generate it, then is good. Otherwise, it is very difficult.

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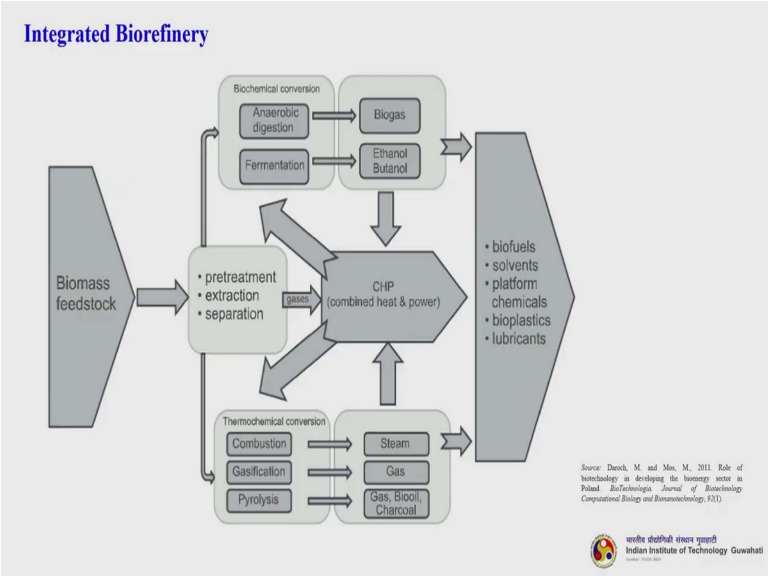

So, let us talk in a glance how the integrated biorefinery looks like. So have a look at this. So, Biomass feedstock is coming (any biomass feedstock). It is pre-treated - you do the extraction, separation and whatever it is. Then it goes for thermochemical conversion using either combustion, gasification, or pyrolysis. You get steam, gas, bio-oil etc. and you further get these things.

Then you basically convert it in the biochemical conversion platform using either anaerobic digestion or fermentation. So, you get biogas and the alcohol platform (this is bioethanol, biobutanol all these things). And all these things can be combined together to produce the CHP or the combined heat and power and further electricity generation. So this is an integrated approach.

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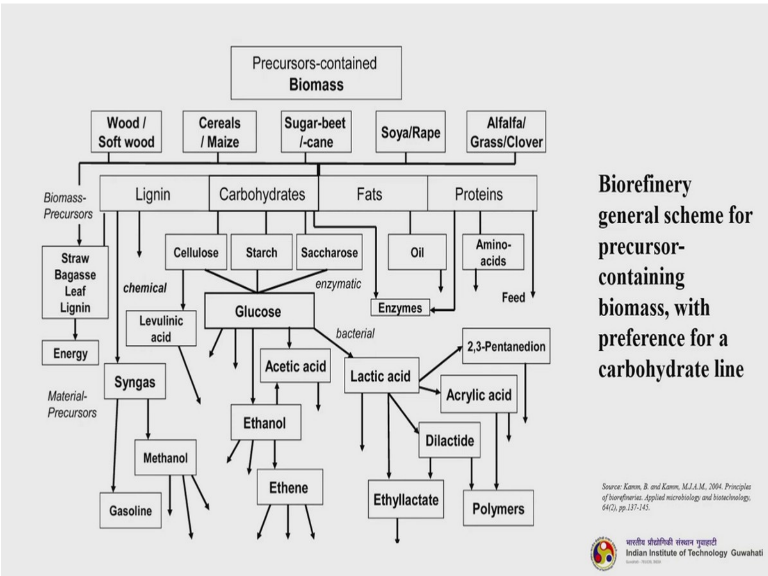

Another one, this is a biorefinery general scheme for precursor containing biomass with preference for a carbohydrate line. So basically, with more emphasis on carbohydrate. So you can see this soft wood, cereals, maize, sugar beet all these things, mostly carbohydrate rich; you fractionate them. Lignin, carbohydrates, fats and protein. So, lignin part can come to syngas and syngas can be converted to methanol, gasoline and all these things.

Some of the Biomass precursors like straw, bagasse etc. can be converted to energy by gasification, pyrolysis. Then the carbohydrate platform goes to glucose, then ethanol, ethene all these things. Certain organic acids will come here. Fats, proteins will also go for so many other products like enzymes, some animal feed etc.

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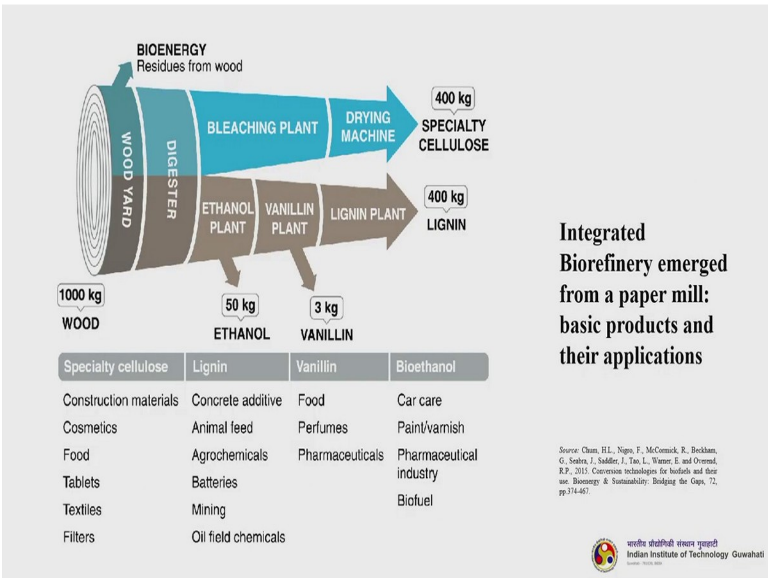

So, another one. This is an integrated biorefinery emerged from a paper mill: basic product and their applications. So, this is an example of a thousand kilogram of wood. So, wood yard, then it is digester, then there is a Bleaching Plant, and it is going to drying machine. Then the ethanol plant, where we are getting almost 50 kg of ethanol per 1000 kg of the wood processed. Then Vanillin, it is a very high value product. Three kg vanillin, so it's a very small amount with respect to 1000 kg of the wood that is processed and the Lignin. You see the amount of the Lignin. So for hard wood the Lignin content is very high. Its almost 40% straight away; for 1000 kg wood processed we get 400 kg of Lignin. And remember, this is a huge amount of lignin and if we can have a lignin biorefinery here further that side, then this entire concept of this integrated biorefinery along with this Pulp and Paper Mill will be a sustainable biorefinery process. You get so many products of course.

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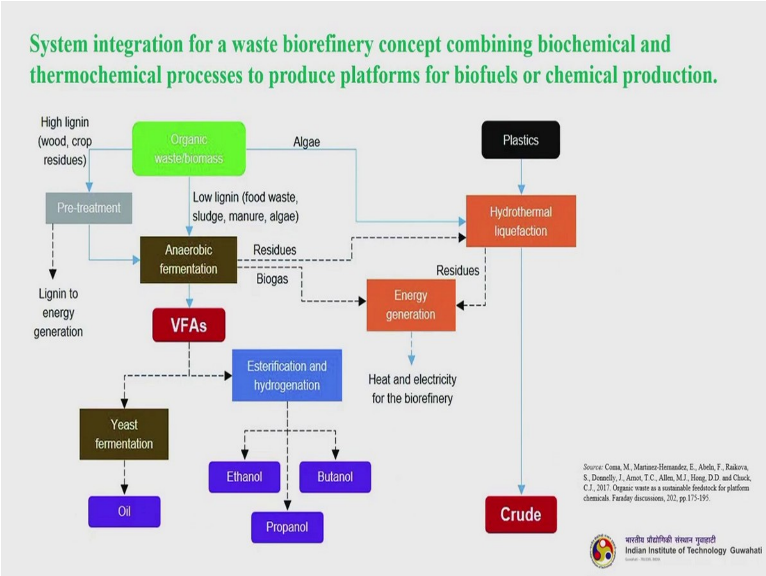

This is one last slide I wish to show you. So, this is the system integration for a waste biorefinery concept combining biochemical and thermochemical processes to produce platforms for biofuels and chemical products. So, have a look at the organic waste and biomass, if it is having algae, it goes to hydrothermal liquefaction, one of the most important technique will learn about this later on.

So, you get the biocrude. This crude if I process and distil I will get the similar cuts I get in a traditional refinery - petroleum, diesel, naphtha all these things. Beautiful technique, please try to understand, you will be wondering where did the plastic emerge from? So, this plastic is an add-on thing. So, if I can mix plastics with these algae (We have also done some work on that), it will produce excellent quality of biocrude and the quality of the fuel that will come from this biocrude will be much, much better than the “only algal” biocrude. And in this way we are also taking care of the plastic utilisation or waste plastic utilisation. So, then, the high lignin materials will go to pre-treatment. Then lignin, this is the lignin platform, then whatever solid that is left out, you can anaerobically digest it.

So, you get basically the volatile fatty acid (VFAs). So then yeast fermentation - you get oil. Esterification and hydrogenation we get ethanol, butanol, propanol. Again, this is the alcohol platform. Now anaerobic digestion - we get biogas, biogas can be converted into energy generation. It can be directly integrated to the grid also, by adopting proper technology. Heat and electricity from the biorefinery.

Now, whatever hydrothermal liquefaction residues will be there (very less) that can also be combined with this anaerobic digestion process to produce electricity. So, do you understand it is a beautiful process and a complete integrated refinery concept in which a particular waste can be segregated and another waste like plastics also can be integrated to take care of the solid waste management or plastic waste management problem. And so as to get a better fuel quality also.

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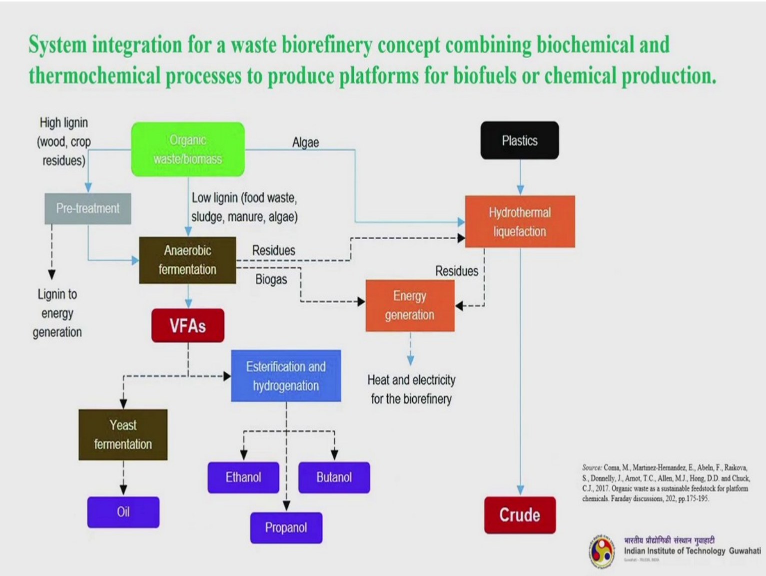

So, another one just quickly will go through. It is an integrated 4-platform (biogas, green juice, green fibres and electricity and heat) biorefinery using grass silage and food residues for bioplastic, insulation material, fertilizer and electricity. So, the grass silage - process it and separate, you get green juice. And then green juice can be anaerobically fermented. Separate, you get fertilizer, biogas platform this is you get heat and electricity. Natural gas also can be combined with this. This is another integrated four platform bio refinery concept.

With this I conclude and thank you very much. If you have any query, please write a mail to me at kmohanty@iitg.ac.in. You can also drop your query in the Swayam portal. And in the next class which is module 3 and lecture 3 we will discuss about the economics and life cycle assessment of the biorefineries. Thank you very much.