Renewable Energy Engineering: Solar, Wind and Biomass Energy Systems
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Lecture - 19
Biomass residues and energy conversion routes

Good morning, everyone. Welcome to Part 1 of Lecture 1 under Module 7. So, in this lecture we will discuss about the biomass residues and biomass utilization through conversion routes.

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Module	Module name	Lecture	Content
07	Biomass conversion routes	01 (Part I)	Biomass Residues, Biomass utilisation through Conversion Routes: Thermo Chemical Conversion

So, in that specifically we will just discuss about in this lecture thermochemical conversion processes. So, biomass residues and energy conversion pathways.

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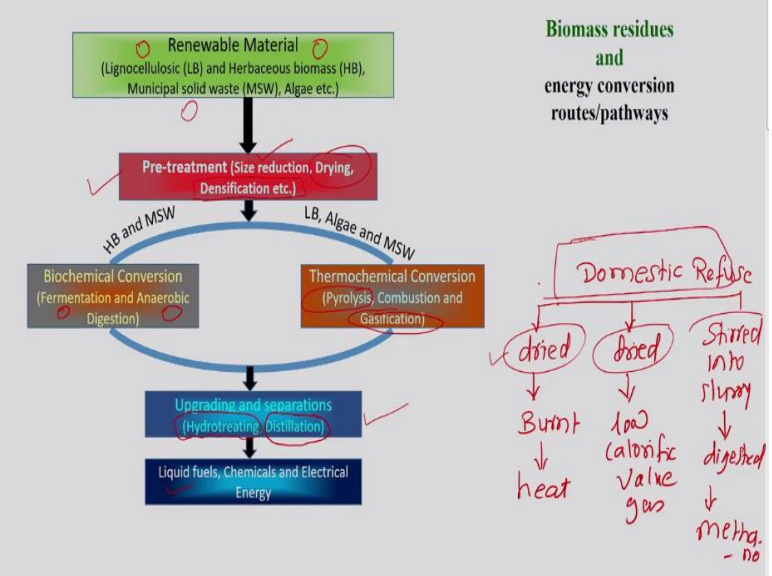

From this particular chart, it appears that wide spectrum of convergent technologies are available for manufacturing premium fuels from the biomass. Some technologies like if you see here, the fermentation and the anaerobic digestion, these are very well understood technologies and are simple. While others like the example is gasification, these kind of technologies have been tested in pilot scale and are now being commercialized.

But if you talk about the fermentation and the anaerobic digestion technologies, so, this kind of technologies are widely being used for the commercial production of the fuel as well as the chemical. Now, if you see here, each biomass resource in the form of say lignocellulosic biomass, herbaceous biomass, municipal solid waste. So, each biomass resource can be treated in many different ways to provide wide spectrum of useful product.

Just take a simple example of domestic refuse. So, in case of domestic refuse the material simply after drying and then it can be burnt. So, after only this kind of material it produce significant amount of heat as the product or the dried material can be converted into low calorific value gas by using pyrolysis process.

But if you see alternative to these particular technologies even, the materials it can be stirred into slurry and then undergo digestion process or you can say it can be digested to produce methane as a gas. So, likewise, different products can be obtained from the same feedstock. So, likewise liquid or the gaseous product for example, ethanol or methane can be obtained or can be manufactured from several different roots or from varieties of the feedstock as well.

But the conversion of these raw material to a specific fuel, it depends on number of factors, for example, the resource and its location the where this particular resource is available, and its condition as well. Apart from that, it all depends on the economics of the particular conversion process. And you can say the economics of the competing process.

If the 2 process are competing in the form of like suppose same product is being formed from the 2 different processes, the economics of that particular competing processes also important in that case. And the last is the availability of the suitable market for the product, because this is very much important for the produced product there should be an available market.

Now, based on that if you see the conversion technologies need to be selected and the feedstock need to be specified for the specific conversion system. Why it is so? Because as I mentioned, there are different types of biomass resources are available. But each biomass resource can be treated in a many different ways as we have shown here on this particular slide and it can yield to a different kinds of product.

And it all depends on the feedstock specification of the conversion processes. So, if the feedstock is particularly specified for the conversion processes, so, the feedstock need to be preprocessed before feeding into the reactor or the conversion processes to yield a high value product. So, if you see in this particular chart, there are certain pretreatment stages are mentioned here, which includes the size reduction, the drying and gasification.

So, these are not limited to only these kind of physical methods. Apart from that, there are chemical pretreatment method also there. Apart from that there are also biological pretreatment methods that can be used for the pretreating the biomass before utilizing these pretreated biomass for the conversion purpose. Why it is important. That we will discuss now. For example, let us talk about the densification process.

As biomass rarely comes in a ready to use form and biomass being a energy lean fuel this makes this transportation more expensive in terms of megajoule of amount of energy transported. So, to improve its energy density the biomass is often compress to convert into denser pellets or the briquettes. It is a preferred (()) (05:28) for the thermochemical conversion processes. Why?

Because the energy stored in the dry matter either it is a wood, straw or the briquettes or the pellets can be easily released by combusting the particular material in the combustion chamber, although the dry materials can also be converted into the liquid and the gaseous fuel by using a suitable conversion technologies. Apart from that, if you see here, there is one more preprocessing step which is mentioned is drying.

So, as we have recently discussed in this particular slide itself, the drying is important before the material is burning inside the combustion chamber so that it can achieve a high process efficiency. That is what the drying is the most preferred technique in most of the

thermochemical conversion technologies. Apart from that, there is one more physical pretreatment method is mentioned here is a size reduction. Why it is important?

Because the weight organic material can directly be converted into a premium fuels, but in such cases, the weight organic techniques need to be utilized in the form of say alcoholic fermentation or the anaerobic digestion. But the material use in this particular technology is highly heterogeneous and is of inconsistent nature and are of variable composition.

Therefore, to make a homogeneous mixture of this component, it is relevant to reduce the size of this particular material first, and then it can be stirred into slurry so that it can be digested to yield methane as a gas. So, likewise, there are number of pretreatment technologies are available as I mentioned, these are not limited to the technologies which are mentioned here.

But this pretreatment technologies are depends on the feedstock specification of the conversion systems. Accordingly, the specific pretreatment technology need to be selected for the conversion of raw biomass to a value added chemical or high value fuel as a product. Apart from that, in this particular chart, this particular (()) (07:21) also very much important, as I mentioned, the produced product from this conversion technologies is not in the usable form.

So, to convert the particular product obtained from this conversion technology into a usable form. So, this product need to be upgraded using a suitable upgradation technique either it can be a separation or it can be a hydrotreating method, it can be a distillation technique or it can be extraction. So, there are number of technologies are also available and these are also specific to the product which need to be upgraded.

So, for example here if you discuss the one simple technique that is a distillation, so, the distillation is a upgradation technique which is widely used in the alcoholic fermentation process, because the alcoholic fermentation process produces 10% accurate ethanol as a product which is called as a primary product. So, these need to be upgraded to a commercial grade 95% ethanol by using a distillation technique.

And the produced 95% commercial grade ethanol is used as a commercial fuel as well as it can be used as a fuel in the IC engine. Apart from that, if you take a simple example of the pyrolysis process, so, the pyrolysis of biomass in a pyrolyser leads to a 3 different product, char, bio oil and the fuel gas. So, the bio oil produced from the pyrolysis process is also not in the usable form.

So, to improve its fuel value, the bio oil need to be upgraded using the hydrotreating technique, so, which is the widely used technique to upgrade the raw bio oil to a high value fuel. Similarly, there are number of techniques are available as I mentioned. And appropriately this kind of technology need to be selected based on the conversion pathways of the biomass.

So, the produced finished product obtained either in the form of the high value fuel, value added chemicals or you can say liquid fuel, this can be further converted into the electrical energy. So, likewise, the energy conversion pathway here it involves the number of steps which need to be taken into consideration based on the feedstock utilized for the conversion processes.

So, now, once we understand about this energy conversion pathways, so, the effective utilization of the biomass is essential in the conversion pathways. Because the raw biomass is highly disperse, bulky and contain excess amount of moisture. Apart from that, the inconsistent quality of the biomass and also variable composition, the biomass need to be effectively utilized for the conversion processes.

As I discussed earlier, biomass is a energy lean fuel. So, to improve its energy density, the biomass is often compress and it can be converted into a pellets or the briquettes which is called as a solid fuel.

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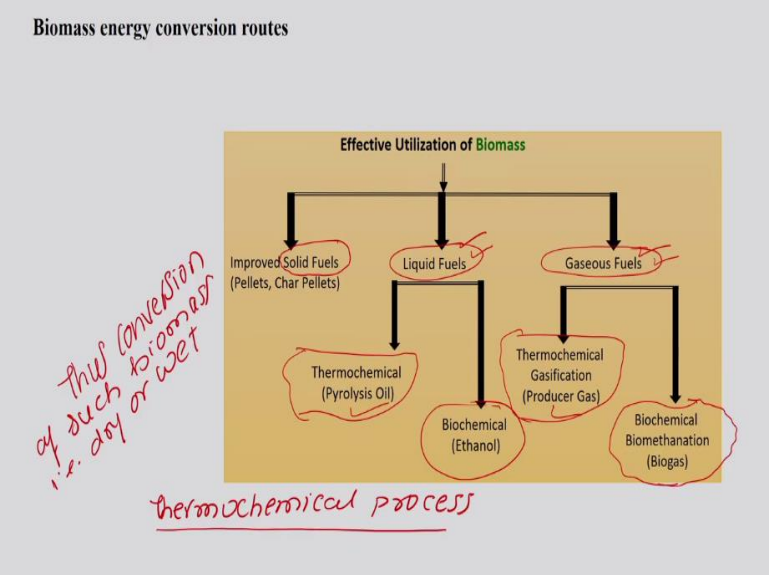

The converted briquettes and the pellets is a preferred feedstock for the thermochemical conversion process to achieve a higher process conversion efficiency as well. Apart from that, the dry material can also be used to produce liquid as well as the gaseous product using a suitable conversion technologies. In case of thermochemical conversion processes, the biomass with moisture content of 10% or less is preferred.

So, that it can yield a good quality product. But, it is not necessary that all the time the moisture content of 10% or less is available for the conversion purpose. So, in that case wet organic material, similar to say MSW or the vegetable waste can also be treated using the thermochemical conversion processes. But, one has to understand in that case, it requires considerable amount of energy to drive up this particular moisture from the combustion chamber.

And this diminishes the use of biomass as a fuel. So, it is more appropriate to use the wet organic material and directly converted it into a premium (()) (11:13) by using a wet conversion processes such as biochemical conversion of biomass to a aqueous ethanol or the biochemical methanation of the heterogeneous mixture of the compound to a biogas.

So, likewise, there are number of technologies are available, which can we effectively use to convert into a suitable product. So, as I mentioned here, there are also we have enlisted certain thermochemical conversion technologies, which are also used to produce liquid and the gaseous product. Thus, conversion of such biomass that is dry or wet biomass can be carried out to produce either a liquid fuel or gaseous fuel.

Thereby, it increases the energy density of this particular material. And this makes this transportation feasible over the long distance. Apart from that the thermochemical processes have typically a high throughput. And in principle, this kind of processes can operate on any form of the biomass. And this is what is the advantage of the thermochemical conversion processes.

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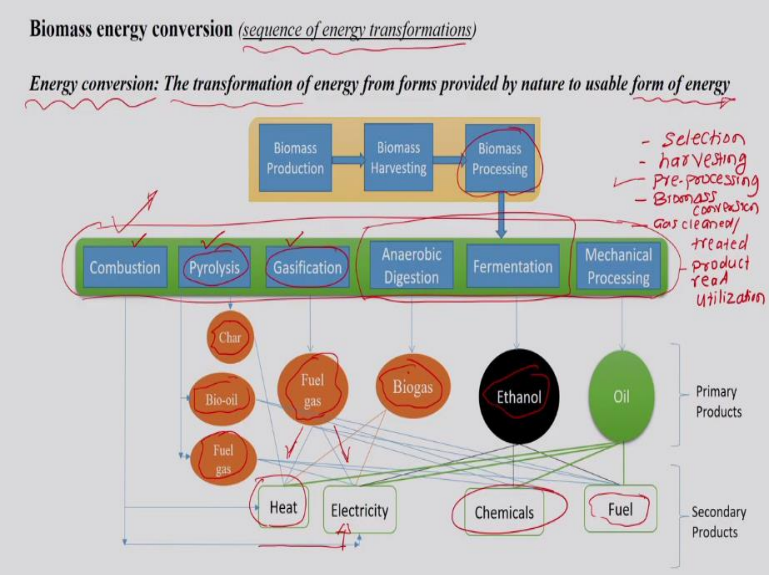

So, now, after understanding about the effective utilization of the biomass, let us discuss about the biomass energy conversion pathways. So, biomass energy conversion it involves the sequence of energy transformation. To be precise, energy conversion is the transformation of energy from forms provided by nature to useful form of the energy. And during these conversion pathways, the specific source of biomass need to pass through a sequence of energy transformation stages.

And this biomass conversion pathway involves major preprocessing stages in the form of selection of the biomass followed by harvesting. Harvesting of the biomass and then preprocessing of the harvested biomass followed by the biomass conversion and produced product can be either liquid or gas. It can be cleaned or if required, can be treated to obtain a high value fuel or the chemical. And after that the product is ready for the utilization. So, why this preprocessing stages are important?

Because the biomass rarely comes in a form ready to fed into the reactor. It is often mixed with the unwanted materials such as you can say the metals, some debris or unwanted

particles, which are need to be separated before use. And for that reason, the preprocessing of the biomass here is a very important concept in the energy conversion pathways as we have discussed in the earlier slide as well.

Apart from that, if you see the preprocessing pathways here, even the moisture content in the biomass is well in excess of what the system is designed for. So, for that reason the biomass need to be dried first before utilizing this particular biomass raw biomass for the conversion purpose. So, depending on the (()) (15:07) stock specification of the conversion system, either the biomass need to be screen or need to be crush or (()) (15:14) before subjecting it to the conversion technologies.

Apart from that, most of the auxiliary equipment which are required in the combustion, pyrolysis and the gasification plant would be similar in nature. And hence it can be used effectively for the thermochemical conversion processes. Apart from that, if we talk about the fermentation technique like alcoholic fermentation or anaerobic digestion, the equipment would be of different nature because of the different kinds of feedstock handled by this technique.

So, the preprocessing steps are mostly depends on the conversion technology, which is adopted for the conversion purpose. So, one such technology which is in commercial use that uses biomass to produce energy is a combustion technology. So, instead of using the raw biomass directly into the combustion process, so, it can be converted into a denser pellets so that it can improve its energy density.

And the produced heat from the combustion chamber can be used as a processed heat also can be converted into the electricity. More over the denser pellets or the briquettes as I mentioned earlier also it is a preferred feedstock for the pyrolysis process as well as for the gasification process to achieve a higher process efficiency. So, the briquettes or the pellets after gasifying in the gasification chamber, it releases fuel gas as a product.

So, the fuel gas can also be used as a heat source or can be used as a energy source to produce the electricity. Apart from that the material which is pyrolyzed in the pyrolysis reactor use 3 kind of product. That is a char, bio oil and fuel gas. So, bio oil obtained from this particular

process can also be used to produce chemical or can be upgraded as we have discussed in the first slide itself using a hydrotreating technique to produce high quality fuel.

So, the char produced during this process can also be used to convert into pellets or the briquettes. And it act as a feedstock for the heat generation. So, likewise, there are number of ways are available for the utilization of the raw biomass. But again, it is depends on the preprocessing stages of the conversion process. Apart from that, there are wet organic techniques are also available, which can be used to convert the wet organic dry material directly into a premium fuels using these technologies.

Because it is more appropriate to use the wet organic material into these wet processes. So, that it can effectively convert the raw material into a either biogas or aqueous ethanol. So, although the wet organic materials these are heterogeneous in nature, as we have discussed earlier and of inconsistent quality, because of its variable composition.

So, this particular materials can be stirred into slurry first so that it can makes a homogeneous mixture of all this component. So, once the homogeneous mixture is available for the microorganism, they can easily digest this material to convert into the biogas. Apart from that, this kind of wet organic materials can also be pretreated using a suitable pretreatment technique.

And the complex (()) (18:32) molecules of this inconsistent nature of the raw material can be converted into a simple sugar molecules which can be again easily digested by the yeast or the saccharomyces cerevisiae as a microorganism in the ethanolic fermentation. And it produces the aqueous ethanol as a product. So, after upgrading this aqueous ethanol to 95% ethanol, it can also use as a commercial grade chemical.

Or, it can also be used as a fuel in the IC engine. So, accordingly there are number of techniques available for the conversion of raw biomass to a useful product. So, up till now, the conversion technology which you have studied, these are mostly a biochemical and a thermochemical conversion technique. Apart from that, there are also some techniques which are widely being used to convert the raw biomass into a fuel.

So, one such technology is mechanical processing of the biomass. So, the fuel oils can be extracted from the plant parts by expelling them. Apart from that also the light hydrocarbon materials or the product can be obtained from certain plant parts in the similar way as that of the production of the rubber. And the product obtained from this plants can be used as a petroleum substitute.

So, after learning this energy conversion pathways and the number of steps which are involved in the energy conversion pathways, let us first discuss about the physical methods.

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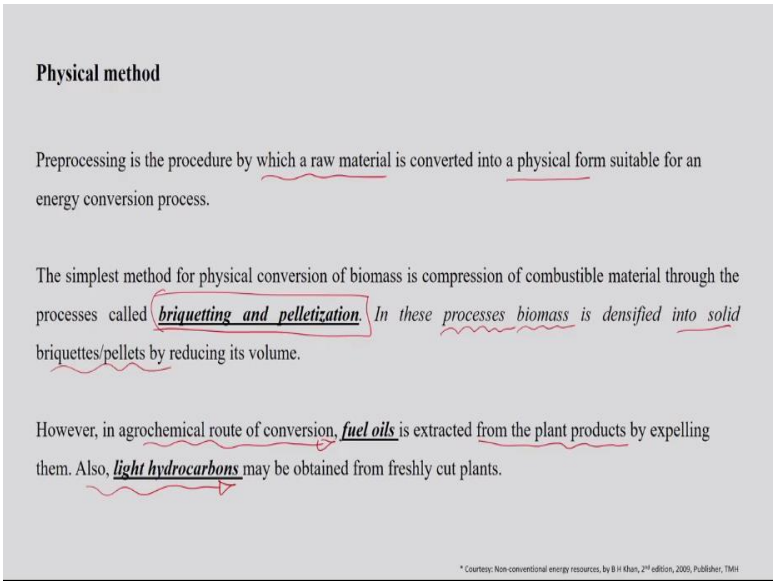

So, physical conversion method is preprocessing is the procedure by which the raw material is converted into a physical form which is suitable for the energy conversion processes. The simplest material which is used for the physical conversion of the raw biomass is the briquetting and the pelletization process. So, in this process, the biomass is converted into a densified solid briquettes or the pellets by reducing its volume.

Apart from that there are also some agrochemical routes are also there. In this particular agrochemical route of conversion in such cases, the fuel oil is extracted from the plant products by expelling them as I just mentioned earlier, are also the light hydrocarbons may be obtained from the freshly cut plants or you can say by cutting the stem or the trunk of such kind of plants.

And this particular light hydrocarbon which is obtained from such materials is act as a petroleum substitute. So, likewise the physical methods are there. So, now, let us discuss this

physical methods one by one. So, before that let us discuss about the pelletization process or the briquetting process. So, pelletization it is a process in which the dry wood material is pulverized.

So, the dry wood material in the sense is like suppose the wood material is available in this particular form.

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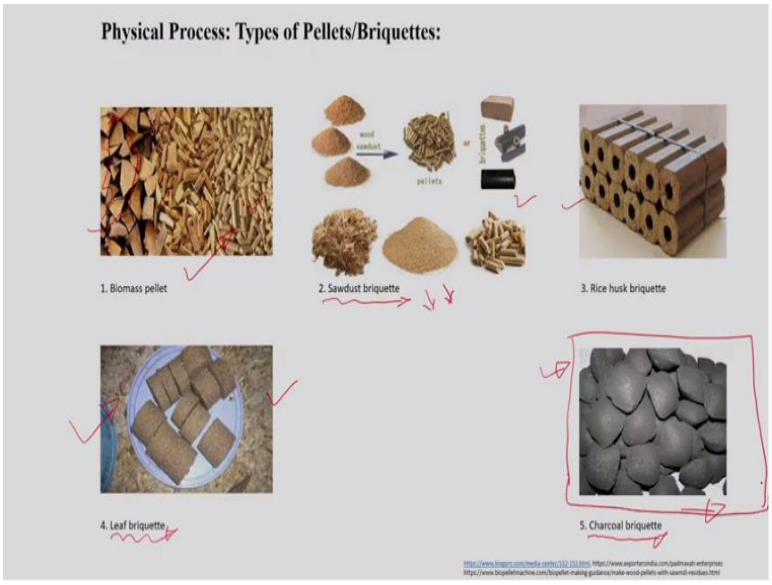

So, before converting into the pellets, this wood need to be screened and crushed into a small particle size material. After reducing the size of the wood material, it can be pulverized to produce the pellets. So, the wood pellet is the widely use in the thermochemical conversion processes. Apart from that, the sawdust which is a byproduct of the timber industries, which also is a fine powder can be effectively used to convert into a pellets and a briquette.

And also it is used as a preferred feedstock in the thermochemical conversion processes. Apart from that, the rice husk can also be converted into a briquette or the pellet. In the similar line agriculture residues as well as the forest residues in the form of (()) (22:04) materials can also be converted into a leaf briquettes. And this particular leaf briquettes can also find its application in the thermochemical conversion processes.

So, all these 4 examples, these are mostly talks about the conversion of raw biomass into a pellets or the briquettes. So, one more example which you can see here which is of charcoal briquettes. So, in case of charcoal briquettes, the raw biomass first carbonize to produce a

charcoal. And the produced charcoal can be converted into a charcoal briquettes and which act as a replacement to a fossil fuel such as coal.

So, this is a widely known example for the conversion of raw biomass into a charcoal briquette. So, now, after understanding about this charcoal briquettes and the pellets, let us discuss about the process of pelletization and the briquetting.

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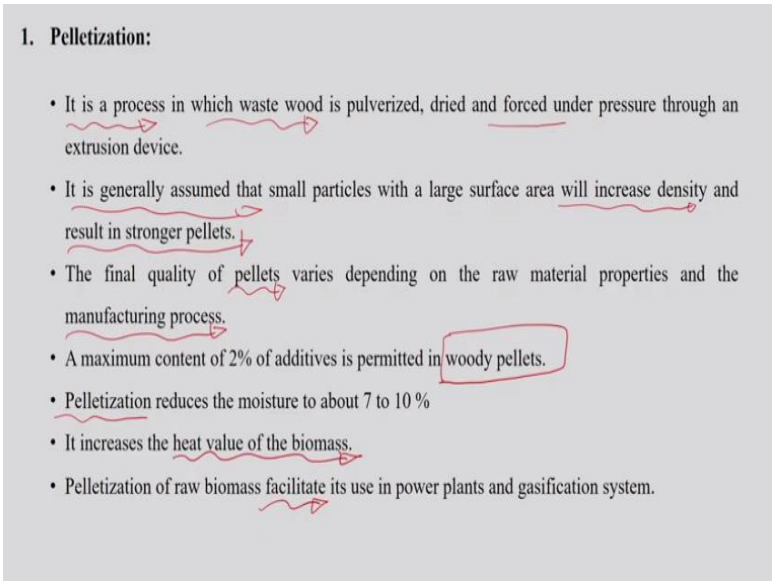

So, pelletization, it is a process in which the waste wood is pulverized, dried and forced under pressure through an extrusion device. It is generally assumed that small particles with large surface area will increase the density of the material and will results in the stronger pellets. Apart from that the final quality of the pellets or the briquette varies depending on the raw material which is used for the preparation of the pellets and the briquettes.

Apart from that, it is also depends on the manufacturing processes. A maximum content up around 2% of the additives is allowed in the wood pellets to make a solid piece. Pelletization, it also reduces the moisture to about 7 to 10%. And as a result, it increases the heat value of the biomass. Pelletization of the raw biomass facilitate its use in power plant and in the gasification system.

And if you can see there are number of advantages of pulverizations are there instead of using the raw biomass as such, it is more appropriate to convert it into the pellet first and then use as a raw material for the thermochemical conversion processes. So, another method in the

physical conversion process is the briquetting. So, briquettes are made from the woody matter and are considered as a replacement to the fossil fuels such as coal or the charcoal.

And it can be used as a heat source in boiler in a manufacturing plants. Utilization of the briquette is more beneficial than that of the utilization of the green firewood. Because the moisture content in the briquette is as low as 4% whereas the moisture content in the green firewood is as high as 65%.

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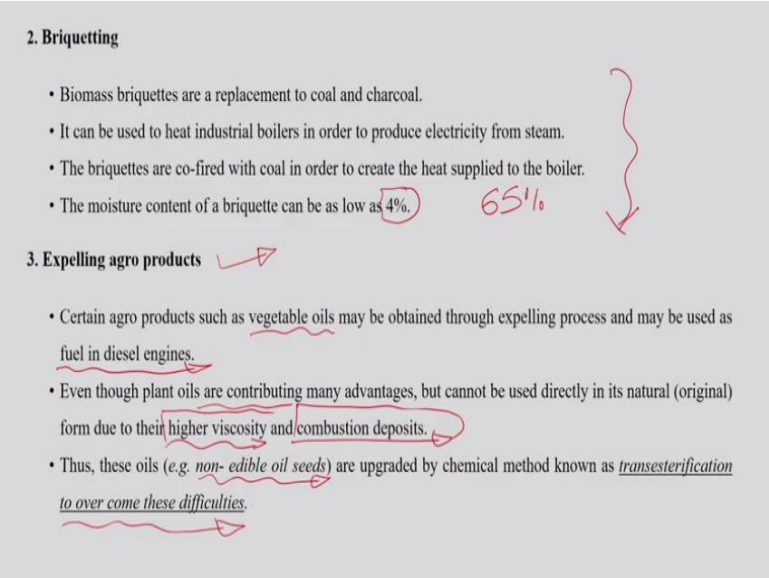

So, therefore, it is more beneficial to use briquette instead of using the green firewood in the combustion process as well as in the thermochemical conversion processes. Briquettes are made by compressing the specific raw material and by breaking down the elasticity of this particular material. So, once these raw materials are compressed, so, it squeeze outs the moisture from the raw material and also breaks down the elasticity of the raw material.

So, once the elasticity of these raw materials are broken down, then it can be converted into a pellets. In case if this elasticity is not removed properly. So, then compression volume of the biomass will regain its pre compression volume. In this particular case, the lignin available in the biomass itself act as a binder. And it binds the solid particles of the wood to convert it into a solid piece.

And then the solid piece which is formed during this process is called as a briquette. So, this is about the briquetting of the biomass. So, another physical method which is widely used in the process industries is the expelling of the agro product. Certain agro products such as

vegetable oils may be obtained through expelling process and may be used as a fuel in the diesel engines.

Even though, the plant oil are contributing many advantages. Apart from these advantages, this plant oil also has certain disadvantages in terms of the higher viscosity and combustion deposits. Therefore, to improve these properties of the vegetable oil, it is often upgraded using the chemical conversion technique that is called as a transesterification process.

And by using this particular technique, this low grade oil can be also converted into a high value product which can overcome also these difficulties of higher viscosity and the combustion deposits. So, for this kind of conversion processes, even the low quality oil can also be used to convert it into a high quality fuel. For examples, the non edible oil seeds which are of no use can also be used to convert into a high quality fuel.

So, apart from that, there is one more physical method which is used in the process industry is the fuel extraction. So, sometimes if you see the (()) (27:14) kind of materials are obtained from the plant cuts. And these materials are called as a exudates and is obtained by cutting the stem or the trunk of the living plants.

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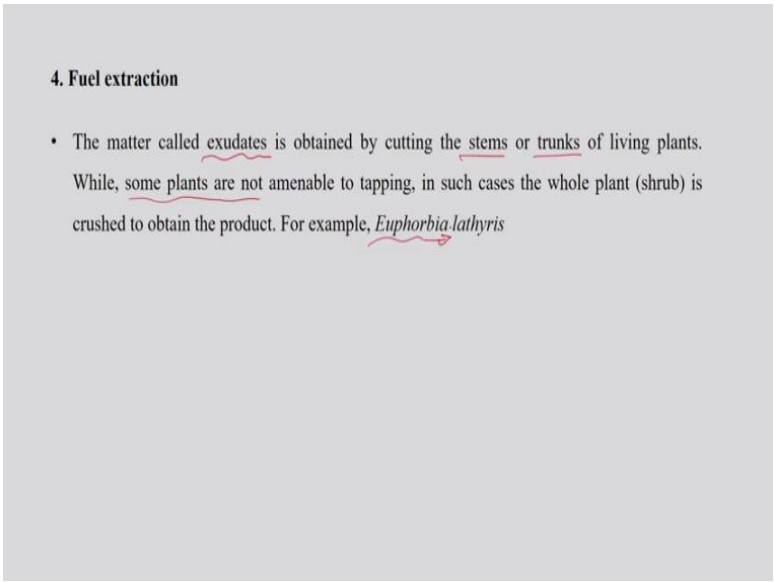

While, some plants are not amenable to such kind of tapping, so, in such cases what happens is like the entire plant is crushed to obtain the product. And the widely known example for this kind of process is the Euphorbia plant. So, the Euphorbia plant can be crushed to obtain a

product of less molecular weight than the rubber and the produced product can be used as a petroleum substitute.

So, these are talks about the physical preprocessing stage which are required before utilizing this particular material for the conversion processes. So, once we understand about the physical conversion processes, now, let us talk about the how to convert this particular material into a product. So, for that reason, (()) (28:08) of the technology need to be selected.

It may be a thermochemical conversion process or it may be a biochemical conversion process. So, let us first discuss about the thermochemical conversion process.

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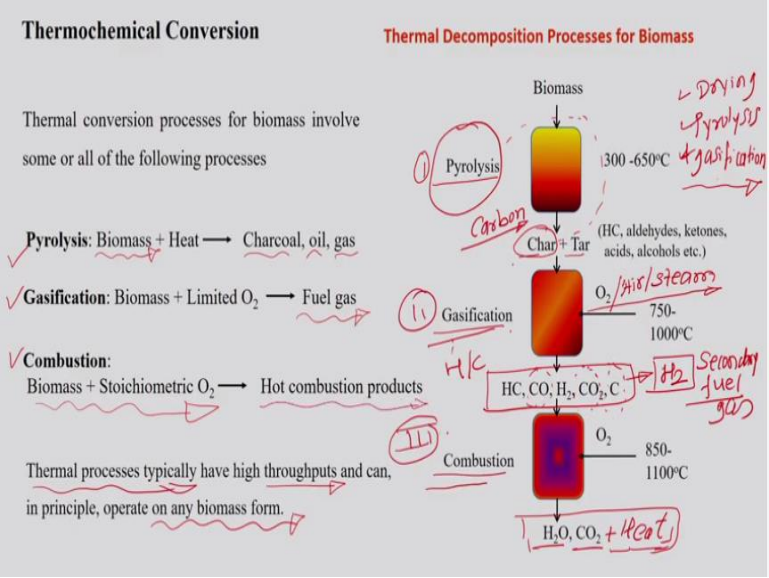

So, in the thermochemical conversion processes, the biomass undergoes decomposition and the fuel which undergoes decomposition also oxidized to produce the product. So, it is more important to know how this kind of products are formed during the thermal decomposition process. The drying pyrolysis and gasification are the first steps in the solid decomposition process.

So, the relative importance of these particular processes it depends on the technology which is adopted for the conversion purpose. Apart from that, it also depends on the raw material properties as well as the process condition which are used for the conversion purpose. For example, biomass combustion, it is a very complex process than pyrolysis and the gasification.

Since, the biomass need to be first pyrolyzed and then need to be partially combusted before it is fully combusted into the combustion chamber. So, during the combustion processes, it has to pass through both the pyrolysis and the gasification step to oxidize the entire fuel gas to achieve a significant amount of heat along with the stable compound that is CO 2 and H 2 O.

So, when this particular conversion is happening in the processes, what happens is like it has to pass through a sequence of energy transformation step. Though these steps that is pyrolysis, gasification and the combustion are frequently model in series, there is no sharp boundary between these particular processes and often these particular processes are overlap with each other.

So, if you talk about the pyrolysis, gasification and the combustion processes, these are often overlap with each other, which you can also see in this schematic. So, during this particular process, as we mentioned, the first biomass need to be dried before it undergoes the thermal decomposition as well as the pyrolysis. So, in case of pyrolysis, it is a thermal decomposition process that partially removes the carbon from the feedstock.

But it does not add hydrogen to it. So, if you see the composition of the product obtained from the pyrolysis process, it is a gas, then non condensable gases, condensable vapors as a liquid, tar as I mentioned the gas as well as the solid char as a product. So, these are the product which can be obtained from the pyrolysis process. Gasification on the other hand is carried out using a gasifying medium.

So, either it can be a oxygen, air or steam. In this particular gasifying medium is used for the gasification purpose, the product of the pyrolysis reacts among themselves as well as with the gasifying medium to produce the final product as a gas. And in this particular composition of the product gas, if you see it can add hydrogen to the product whereas, in case of pyrolysis, if you see here, the hydrogen does not added to the product.

So, that is the difference between these 2 particular processes. And based on this we can also see that the gasification is of pyrolysis adopted to produce a maximum amount of secondary fuels from the biomass. So, if you see here now, the gasification and the combustion, these 2

technologies are closely related with each other. However, there is an important difference between the gasification and the combustion process.

The gasification process, it adds hydrogen to the product as I mentioned earlier, and it strips carbon away from the feedstock. So, what happened in this case, if you see here, the carbon is strips away from the feedstock to produce a gas with higher hydrogen to carbon ratio, whereas, in case of combustion, what happens is like it oxidizes the hydrogen and carbon to produce H 2 O and CO 2 as a stable product along with the significant amount of heat as the product.

Respectively, if you see in this case, when the amount of oxygen it exceeds the certain value, then the process moves from the gasification to the combustion process and then the product is flue gas instead of the fuel gas. So, that is what is the difference between the gasification and the combustion process, because when you say the gasification, it is also partial combustion of the biomass whereas, combustion is a complete oxidation of the fuel gas produced during the process.

So, this is what is the important difference between the 2 processes. That is gasification and the combustion. So, if you see here again, the thermal processes as I mentioned, typically have higher throughput and this kind of processes in principle can operate on any biomass form. So, whether it is a wet or whether it is a dry biomass. So, that is what is the advantage of the thermochemical process that it can operate on any biomass form.

And these 3 reaction represents the reaction carried out in the pyrolysis gasification and the combustion process. So, in case of pyrolysis, the biomass is heated in absence of oxygen. So, there is no oxygen supply to this particular process. In the other word, I would say there is no external source of oxygen is supplied to this particular process. And hence it releases charcoal, oil and gas as a product.

Whereas, if you talk about the gasification process, it requires the gasifying medium either it can be in terms of oxygen, air or steam. But partial amount of oxygen is need to be supplied externally in the gasification process. And hence it releases the fuel gas as a product. Whereas, in the combustion process, it is a complete oxidation of the biomass that means the stoichiometric amount of oxygen is required for the complete combustion of the biomass.

And it releases hot combustion product as a output. So, this talks about the thermochemical conversion of the biomass. So, now, let us discuss about these particular processes one by one. So, first is the combustion process.

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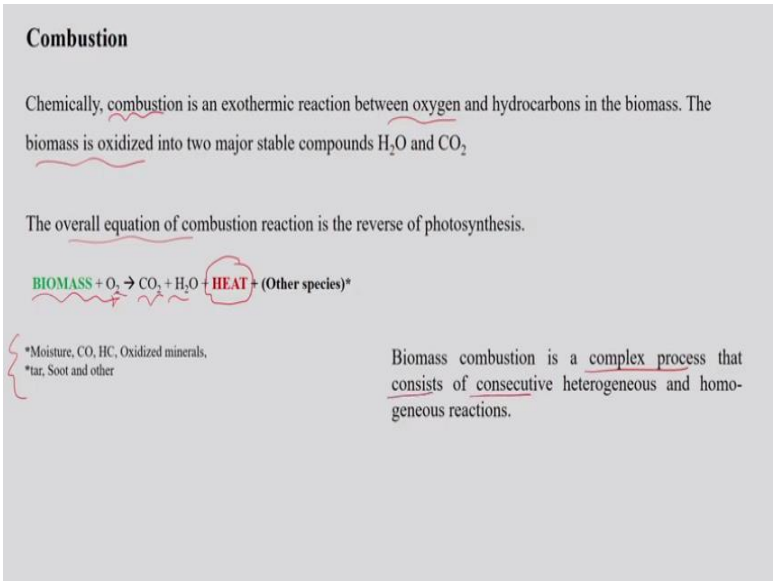

Chemically, combustion is an exothermic reaction between the oxygen and hydrocarbon in the biomass. And the biomass is oxidized into 2 stable product during this process that is CO 2 and the H 2 O. So, if you see the overall equation of the combustion reaction of the biomass, it is just reverse of the photosynthesis process. That means the biomass is oxidized in presence of oxygen.

Or you can say in presence of stoichiometric amount of oxygen to release CO 2, water and heat as the product along with some other species, so, other species which are already mentioned here. Biomass combustion, it is a complex process and that consists of consecutive heterogeneous and homogeneous reaction. So, if we talk about the stages in the combustion processes.

So, this particular schematic it represents the number of stages involved in the combustion process. So, before we discuss about the combustion processes, let us discuss about the combustibles of the solid carbon. So, the combustibles of the solid carbons are shared into 2 groups.

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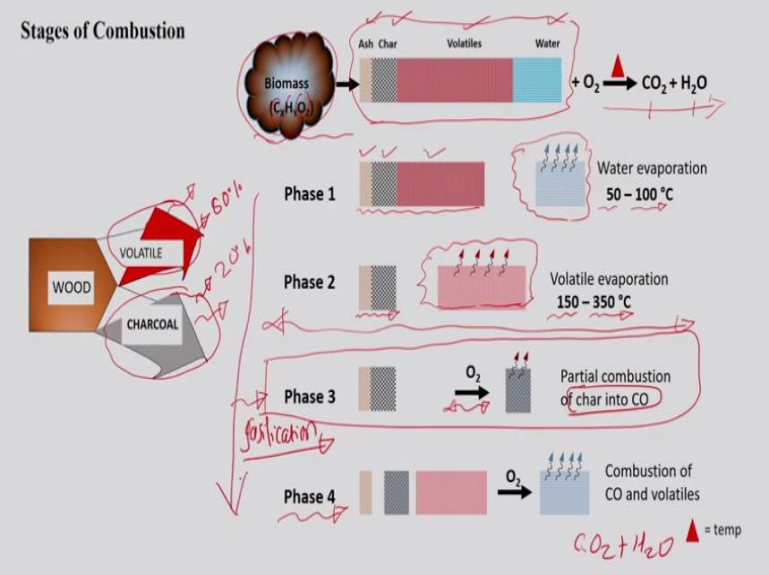

First one is the volatile matter and the second one is the charcoal matter of the solid carbon. So, share of the volatile matter component in the woody biomass is around 80% whereas, share of the solid carbon in the woody biomass is around only 20%. So, 80% of the energy it generally originates from the combustion of the volatile matter of the wood material, whereas, 20% of the combustion energy it originate from the burning of solid carbon in the biomass.

So, this is what is the difference between the volatile matter combustion and the solid carbon combustion in the process. So, the representative image of the biomass composition which is shown here, where the biomass in the form of C, H and O. It is represented as ash, char contain, volatile matter and the water. This under complete combustion process converted into CO 2 and H 2 O as a product.

Along with that, it also releases significant amount of the heat. So, during these combustion processes, the biomass has to pass through a these sequence of the phases. So, as I mentioned, drying, pyrolysis, gasification are the first steps in the thermochemical decomposition process. However, the relative importance of these processes, it depends on the conversion technology which is adopted for the conversion of biomass to a fuel or the chemical.

So, in this case, as I mentioned, the drying is the first step in the combustion process, where the moisture content in the biomass will evaporate in the temperature range of say 50 to 100 degree C. So, as a result, once the moisture is removed from the biomass, so, remaining component left out in the biomass are ash, char and the volatile matter.

So, once this particular moisture evaporation step is done that is in terms of drying, once the moisture is removed, then the material undergoes thermal decomposition that is also called as a devolatilization of the biomass. So, in this case, the volatile matter present in the biomass undergoes the decomposition in the temperature range of say 150 to 350 degree C.

So, as a result, all the volatile matter present in the biomass undergoes the devolatilization process and the left out component in the biomass now are ash and the char. So, this devolatilization of the material, it start at around 200 degrees C and the rate of the devolatilization of the material it increases with increasing the temperature of the process. So, if it goes beyond 200 degree C, the rate of volatilization of the material is increases.

And this entire process is carried out in absence of externally supplied oxygen. So, that is why this is also termed as a kind of a pyrolysis process. So, once the products are formed during this devolatilization of the biomass, so, it undergoes the partial combustion in presence of either oxygen, steam and the air. So, during this partial combustion process, what happens is like the char present in the product, it also get oxidized to CO 2 and H 2 O.

Because, in case of pyrolysis process, the attempt is to maximize the char and the (()) (39:24) whereas in case of gasification process, the attempt is to maximize the gaseous form of the product so that it can be used as a fuel gas. So, here as we mentioned this as a partial combustion process, this is also called as a gasification of a biomass because this is termed as a partial combustion process as well.

So, in this case, what happens is like the char will react with the CO as well as along with the certain gases present in the composition and then it releases CO 2 and the H2 as a product. So, when it reaches to a last phase of the combustion process where it is called as a complete oxidation of the produced gases. So, in that case the entire gas as well as char is getting converted into a CO 2 and water.

Along with that, it releases significant amount of heat from the system. And this is how the combustion process it takes place in the combustion chamber. So, this all talks about how the combustion process happens in the combustion chamber. Now, let us discuss about the biomass combustion in detail.

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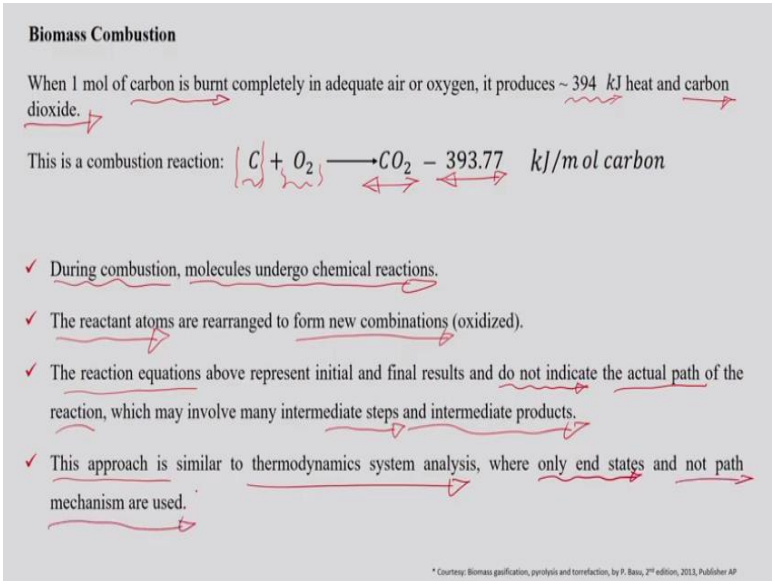

So, when one mole of carbon is burned completely in adequate air or the oxygen supply, it produces around 394 kilojoule of heat and carbon dioxide as a product. So, this reaction it is shown here, this is the carbon content in the biomass. It undergoes complete combustion it produces CO 2 and significant amount of the heat. During the combustion process molecules undergoes the chemical reaction.

Because as I mentioned, biomass combustion, it is a very complex process, because, it involves (()) (41:15) heterogeneous as well as the homogeneous reaction. The reactants atoms are rearranged to form new combinations of the oxidized product. Apart from that, the reaction equations above it represent only the final and initial steps, whereas, do not talk about the actual path of the reaction, which may involve many intermediate steps or intermediate product.

And this conversion approach which is shown here in the form of the reaction. This approach is similar to thermodynamics system analysis, where only end states are mentioned and no path mechanisms are used. However, if you talk about the combustion of the fuel, so, the combustion of the fuel is also more complex than the above process that is the combustion of the biomass.

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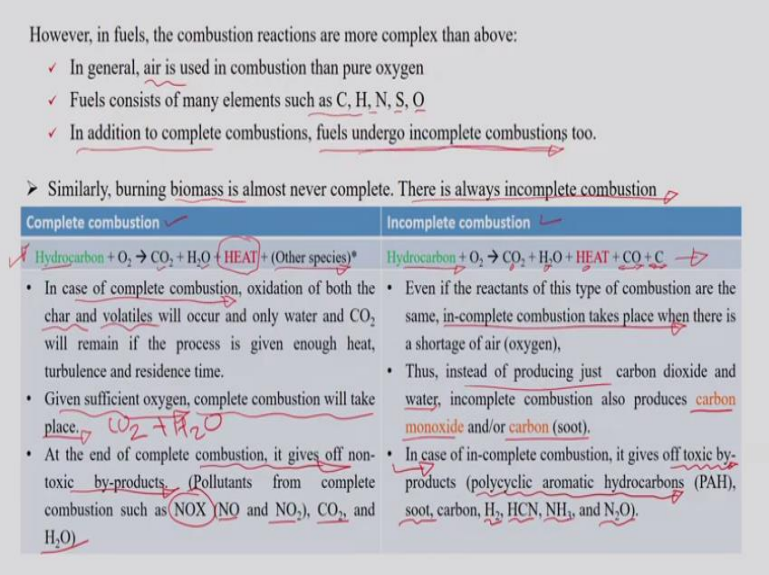

Because, in general, air is used as a combustion medium than oxygen in the combustion of the fuel. Also the element of the fuel it consists of C, H, N, S and O, which indicates carbon, hydrogen, nitrogen, sulphur and oxygen content in the fuel. Apart from that, in addition to complete combustion, the fuel also undergo incomplete combustion as well. And this is also similar with the biomass.

Because the biomass is almost never complete, and there is always an incomplete combustion in the biomass combustion process as well. Let us discuss the concept of the complete and incomplete combustion in more detail. So, if you see this particular table here, it represents the overall reaction of the complete combustion process as well as the overall reaction of the incomplete combustion process.

So, in case of complete combustion process, the product (()) (43:08) are CO 2, H 2 O and it raises significant amount of heat along with some other species as well. While in case of incomplete combustion, the product (()) (43:22) are similar like CO 2, H 2 O, heat, and along with this product, it also produces carbon monoxide and carbon soot particle.

Because in case of complete combustion, oxidation of both char and the volatiles will occur and only heat, CO 2 and the water is produced as a product along with some traces of other species. Whereas in case of incomplete combustion, because of insufficient amount of oxygen or the oxidizing medium in the chamber, it produces CO 2, H 2 O, heat along with the some unwanted byproduct.

So, thus instead of just producing the CO 2 and water it also produces the carbon monoxide and carbon soot particle during the incomplete combustion process. But that is not the case in case of complete combustion, because in case of complete combustion, if the sufficient oxygen is allowed to enter in the combustion chamber, then the complete combustion will take place.

And it will release mostly CO 2 and H 2 O as a product along with a significant amount of heat. In case of incomplete combustion, if you see here it gives off toxic byproduct in the form of polycyclic aromatic hydrocarbons that is also called as a PAAH, soot particles, hydrogen, HCN, NH3 and N2O. If you just try to see the complete combustion process, in case of complete combustion, the process gives off nontoxic byproducts in the form of NOX.

That is NO and NO2 along with CO 2 and the water. So, this is what is the difference between the incomplete and complete combustion. But as we have discussed earlier, the fuel combustion is a more complex process than the biomass combustion. And it always undergoes incomplete combustion. As a result is bound to form certain byproduct which are toxic also. Now, if you see the application of the combustion processes.

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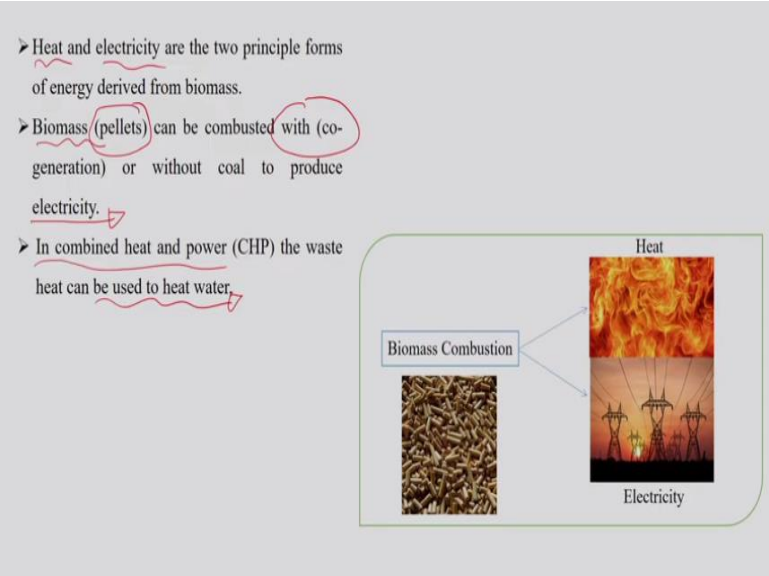

So, the heat and electricity are the 2 principle forms of energy which can be derived from the combustion of the biomass. Moreover, the biomass, which is in the form of pellets or the briquettes can be combusted with coal or without coal to produce the electricity that is also possible in the combustion of the biomass.

Apart from that, in combined heat and power cycle, the waste heat which is generated during the processes can be used to heat water in the process itself. And this is what is the advantage of this particular combustion process as well, because the waste heat which is generated during the process, it can be again reused to heat the water in the process itself. So, that is what is more important aspect of the combustion process.

So, up to this point, it all discusses about the combustion of the biomass, which is also one of the thermochemical conversion process. So, in the next lecture, we will discuss about the another thermochemical conversion process that is pyrolysis and the gasification. Regarding this lecture, if you have any doubt, so feel free to contact me at vvgoud@iitg.ac.in. Thank you.

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