Biomass Conversion and Biorefinery
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Module 05
Lecture-13
Physical Processes

Good morning students, today is lecture 1 under module 5. And under module 5 we will be discussing about the physical and thermal conversion processes. In today's lecture, we will discuss about the physical conversion of biomass. So, let us begin.

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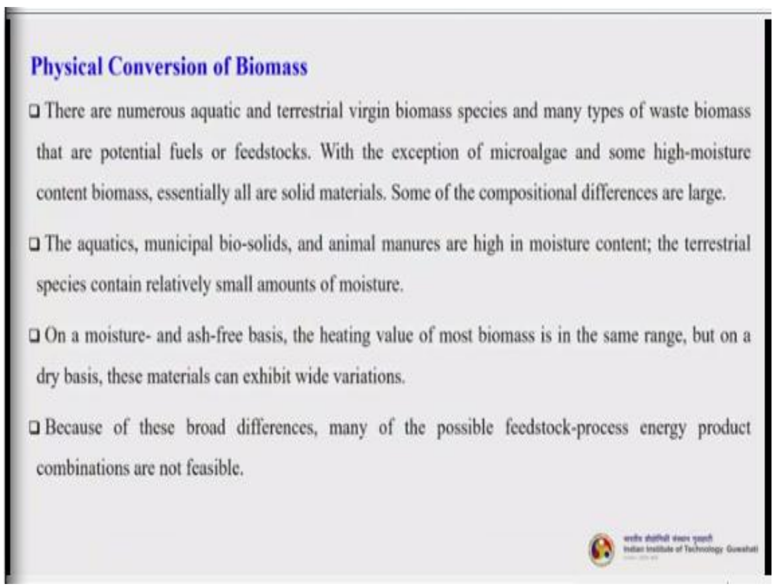

There are numerous aquatic and terrestrial virgin biomass species and many types of waste biomass that are potential fuels or feedstocks. With the exception of microalgae and some high moisture content biomass, essentially all are solid materials. Now some of the compositional differences already exist and we have discussed that also in some of our earlier classes.

So, the aquatics, municipal bio-solids, and animal manures are high in moisture content. The terrestrial species contain relatively small amounts of moisture. On a moisture and ash free basis the heating value of most biomass is in the same range, but on a dry basis, these materials can exhibit wide variation. Because of these broad differences, many of the possible feedstock process energy product combinations are not feasible.

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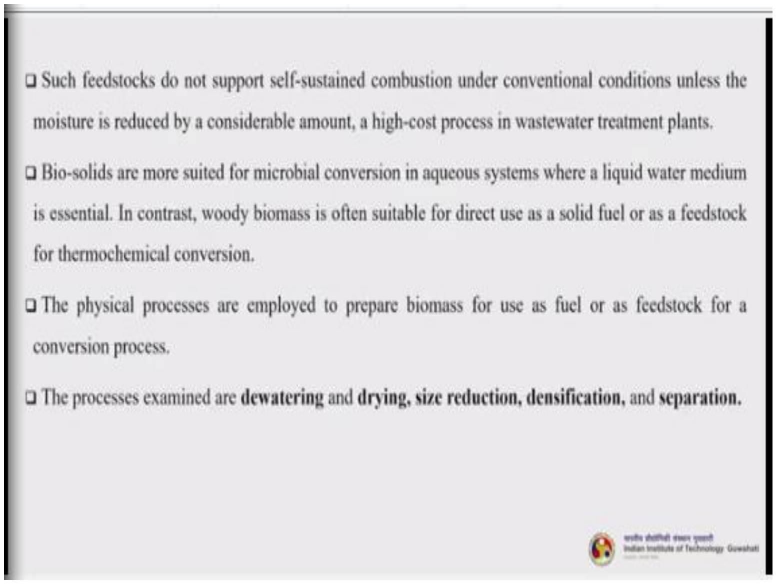

So, such feedstocks do not support self sustained combustion under conventional conditions unless the moisture is reduced by a considerable amount, a high cost process in wastewater treatment plants. Bio-solids are more suited for microbial conversion in aqueous systems, where a liquid water medium is essential. In contrast, woody biomass is often suitable for direct use as a solid fuel or as a feedstock for thermochemical conversion (such as pyrolysis, gasification which we are going to discuss under this module). The physical processes are employed to prepare biomass for use as a fuel or as feedstock for a conversion process. The processes examined are dewatering and drying, size reduction, densification and separation. So, these are the things which we are going to discuss under the physical conversion of biomass today.

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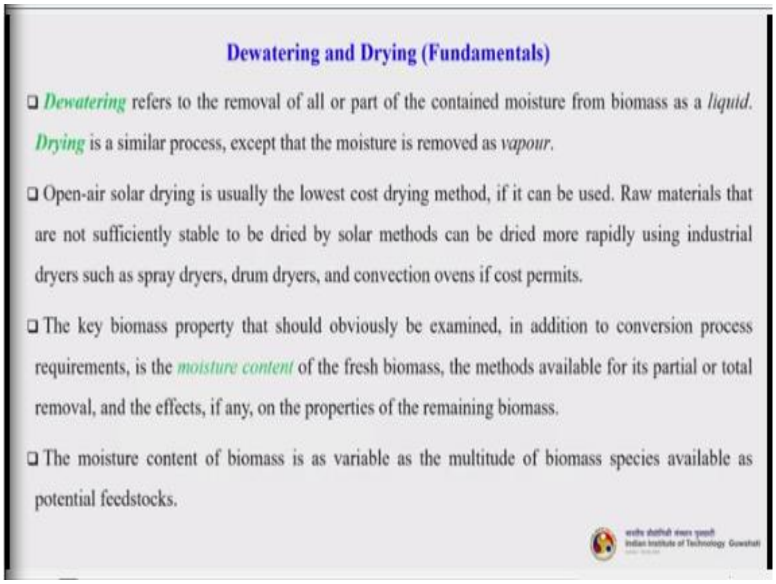

So, first let us understand about the dewatering and drying. So, dewatering and drying the basic difference between these 2 is that in the first case that is in dewatering, it is basically the removal of all or part of the contained moisture from biomass as a liquid. And while drying, it is the same thing except that the moisture that is getting removed is removed as vapour. So, open air solar drying is the one which is very much in practice in most of the countries to process biomass.

So, that is the low cost drying method and can be used. So, raw materials that are not sufficiently stable to be dried by solar methods can be dried more rapidly using industrial dryers, such as spray dryers, drum dryers and convection ovens if cost permits**.** Here the cost is basically the equipments are not so costly, the cost is the energy costs**.** The key biomass property that should be obviously examined in addition to conversion process requirement is the moisture content of the fresh biomass.

The method available for its partial or total removal and the effects, if any on the properties of the remaining biomass. So, moisture content, the amount of moisture present in the initial phase of the biomass when it is getting procured is of utmost important. Because that is finally going to decide about which conversion process you are going to use, and what will be the resultant product.

So, the moisture content of biomass is as variable as the multitude of biomass species available as potential feedstocks.

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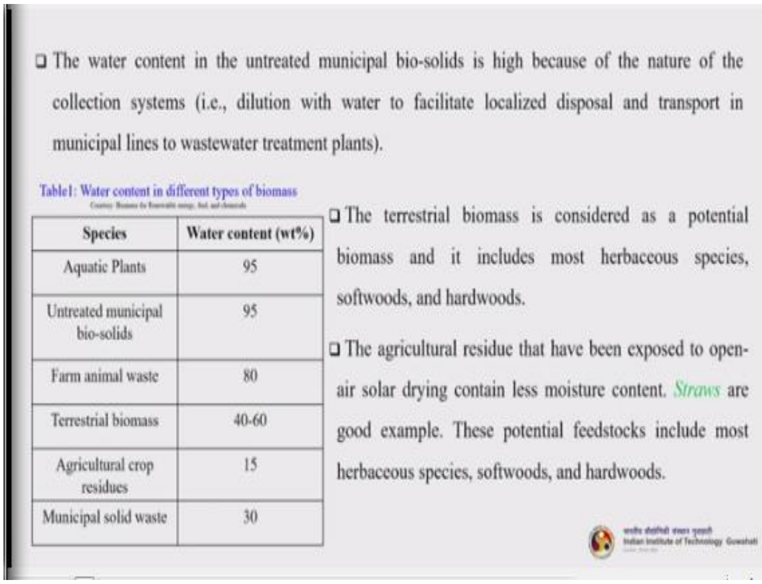

The water content in the untreated municipal bio-solids is high because of the nature of the collection system. That is dilution with water to facilitate localized disposal and transport in municipal lines to wastewater treatment plants that is what is being practiced in all municipalities across the world. So, in the table 1, some of the species are mentioned along with their water content.

Aquatic plants, you can see almost 95%, untreated municipal bio-solids also 95, farm animal waste 80%, terrestrial biomass 40 to 60%, agricultural crop residues 15%, municipal solid waste 30%. The terrestrial biomass is considered as a potential biomass and it includes most herbaceous species, softwoods and hardwoods. The agricultural residue that have been exposed to open air solar drying contain less moisture content. Straws are good example of this particular process. These potential feedstocks include most herbaceous species, softwoods as well as hardwoods.

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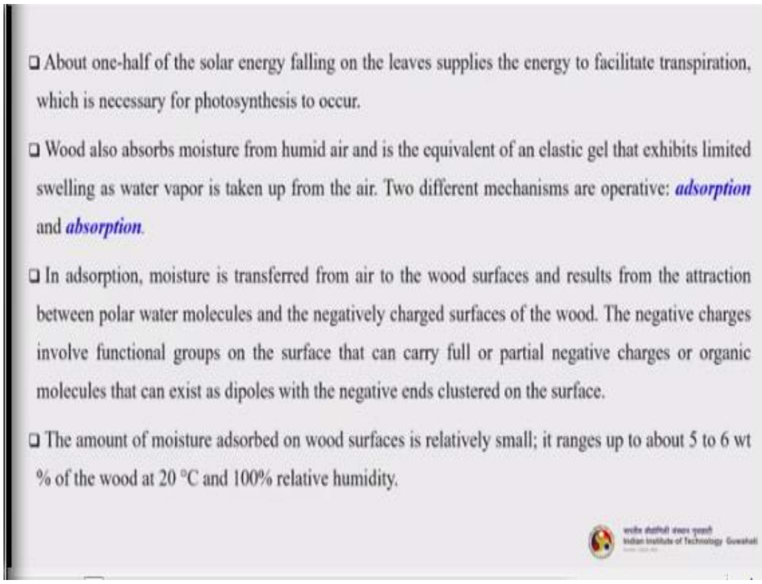

About one half of the solar energy falling on the leaves supplies the energy to facilitate transpiration which is necessary for the photosynthesis to occur. Wood also absorbs moisture from humid air and is equivalent of an elastic gel that exhibits limited swelling as water vapor is taken up from the air. Two different mechanisms are operative: one is adsorption; another is absorption.

In adsorption moisture is transferred from air to the wood surfaces and results from the attraction between polar water molecules and the negatively charged surfaces of the wood. The negative charges involve functional groups on the surface that can carry full or partial negative charges or organic molecules that can exist as dipoles with the negative ends clustered on the surface. The amount of moisture adsorbed on wood surface is relatively small, it ranges up to about 5 to 6 weight percentage of that wood at 20 degrees centigrade and 100% relative humidity.

So, I was talking about this here you can see that functional groups. Now functional groups are a certain type of groups that are present on any surface. So, any material you can say whether it is a living material, nonliving material and in most of the applications. Now I can tell you a classical example of a membrane or even a catalyst. So, I can make a membrane - tailor make basically - So, that means for a particular intended application, so let us say I want to remove some cations or anions from a particular aqueous stream. So, I will use a membrane which is doped with or let us say which is fused or topped with certain functional groups of negatively charged ions. So, if I want to remove cations, I can have anions, if I want to remove anions I can have cations, in that way.

So, basically it will attract negative charges attracts and then it will be retained on the surface of the membrane, other low molecular weight compounds and solvents will pass through it. Similarly, to make a intended and a particular synthesis, chemical reaction or a better yield we can sometimes dope different functional groups on the surface of a catalyst, so as to increase its catalytic activity.

So, functional groups can be easily found out by FTIR technique - the Fourier transform infrared techniques**,** spectroscopic technique and there are many other analytical techniques also available.

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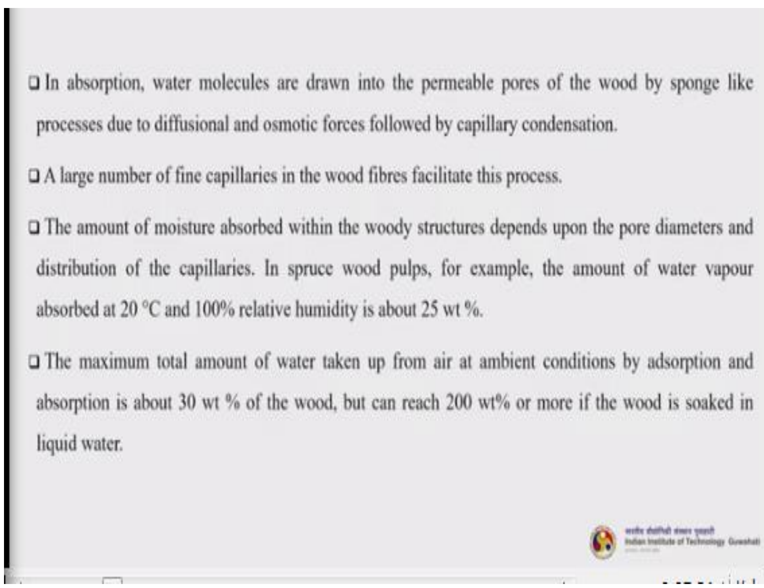

So, in absorption, water molecules are drawn into the permeable pores of the wood by sponge like processes due to diffusional and osmotic forces followed by capillary condensation. So, a large number of fine capillaries in the wood fibres facilitate this. So, you can read a little more about capillary condensation. So, I can say in a nutshell that how and what happens? So, it is very predominant when you talk about porous materials - it can be catalyst, it can be membrane, it can be similar type of materials which contains distinct pores.

So, let us say, something is getting, adsorbent basically, here we are talking about adsorption and absorption. So what is happening? Suppose, you are adsorbing some gaseous component on the surface of the adsorbent let us say, I am just giving an example to understand capillary condensation. So, it will adsorb on the surface then when you decrease the pressure it can go inside the pore of the catalyst or adsorbent whatever it is.

So, after the adsorption, you do desorption the reverse of the process, so you decrease the pressure. Once you decrease the pressure what will happen whatever the material or gaseous molecules are inside the pore they will try to move out. So, when they will try to move out, so they will form a meniscus on the surface of the pore, something like this and that is due to resultant capillary condensation or capillary forces.

So, due to this the rate of adsorption and rate of desorption are quite different, they do not fall on the same line though ideally they should have; and this is due to capillary condensation phenomena, so and this process in adsorption is called hysteresis. And so you can read little more about capillary condensation if you are more interested from any mass transfers books.

So, the amount of moisture absorbed within the woody structure depends upon the pore diameters and distribution of the capillaries. In spruce wood pulps, for example, the amount of water vapor absorbed at 20 degrees centigrade and 100% relative humidity is almost about 25 weight percentage. The maximum total amount of water taken up from air at ambient conditions by absorption and adsorption is about 30 wt% of the wood but can reach almost 200 weight percentage if the woody is soaked liquid water.

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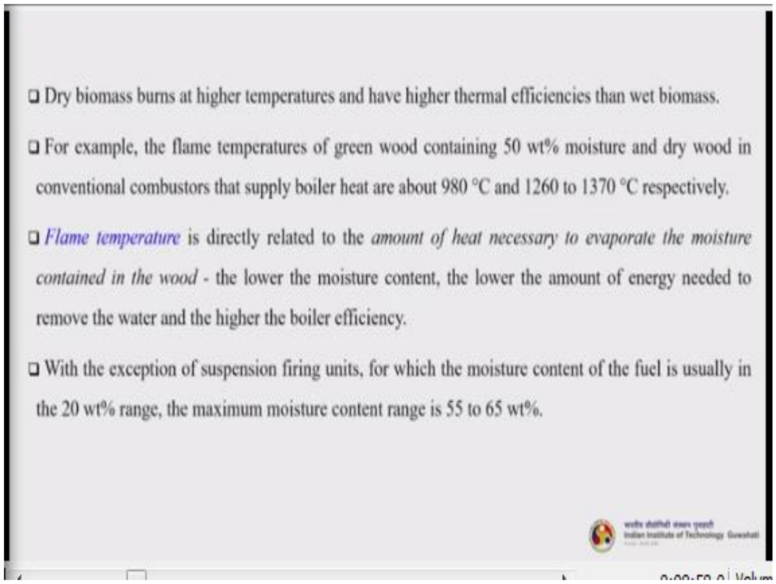

Dry biomass burns at higher temperatures and have higher thermal efficiencies than wet biomass. For example, the flame temperatures of greenwood containing 50 weight percentage moisture and dry wood in conventional combustor that supply boiler heat are about 980 degrees centigrade and 1260 to 1370 degrees centigrade respectively. Flame temperature is directly related to the amount of heat necessary to evaporate the moisture content in the wood.

The lower the moisture content, the lower the amount of energy needed to remove the water and the higher the boiler efficiency. With the exception of suspension firing units for which the moisture content of the fuel is usually in the 20 weight percentage range, the maximum moisture content range is 55 to 65 weight percentage.

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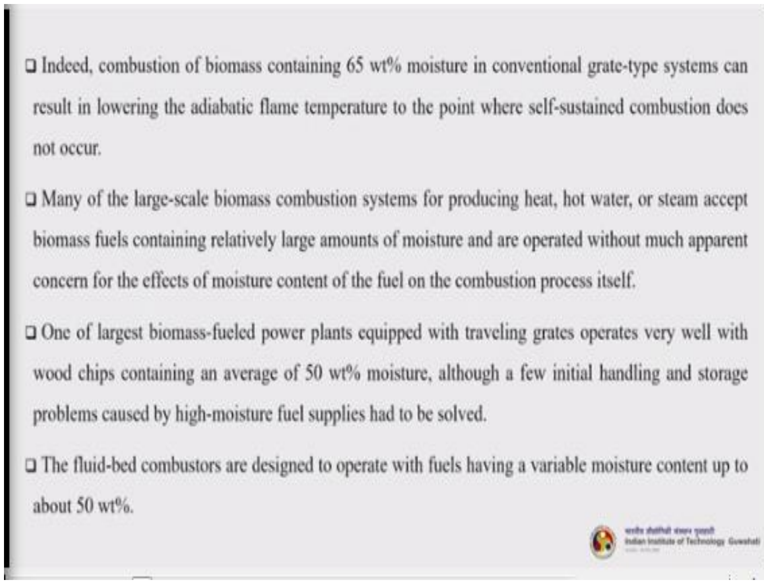

Indeed, combustion of biomass containing 65 weight percentage moisture in conventional grate type systems can result in lowering the adiabatic flame temperature to the point where self sustained combustion does not occur. Many of the large scale biomass combustion systems for producing heat, hot water or steam accept biomass fuels containing relatively large amount of moisture and are operated without much apparent concern for the effects of moisture content of the fuel on the combustion process itself.

One of the largest biomass fuel power plants equipped with travelling grates operates very well with the wood chips containing an average of 50 weight percentage moisture. Although a few initial handling and storage problems caused by high moisture fuel supplies had to be solved. The fluid bed combustors are excellent systems which are designed to operate with the fuel having a variable moisture content up to about 50 weight percentage, so they are excellent. So, they are fluidized bed combustors basically.

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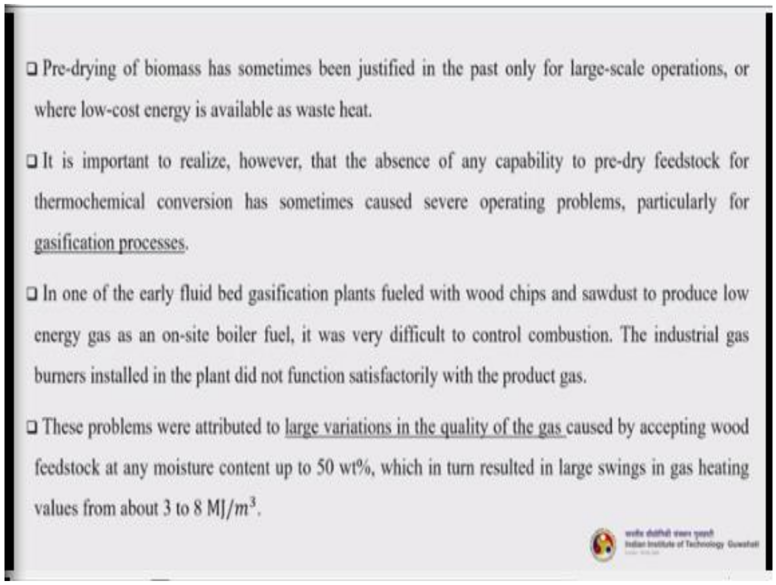

So pre-drying of biomass has sometimes been justified in the past only for the large scale operations, or where low cost energy is available as waste heat. It is important to realize however, that the absence of any capability to pre dry feedstock for thermochemical conversion has sometimes caused severe operating problems, particularly for gasification processes. In one of the early fluid bed gasification plants fueled with wood chips and sawdust to produce low energy gas as an onsite boiler fuel, it was very difficult to control combustion.

The industrial gas burners installed in the plant did not function satisfactorily with the product gas. These problems were attributed to large variations in the quality of the gas caused by accepting wood feedstock at any moisture content up to 50 weight percentage which in turn resulted in large swings in gas heating values from about 3 to 8 mega joule per meter cube.

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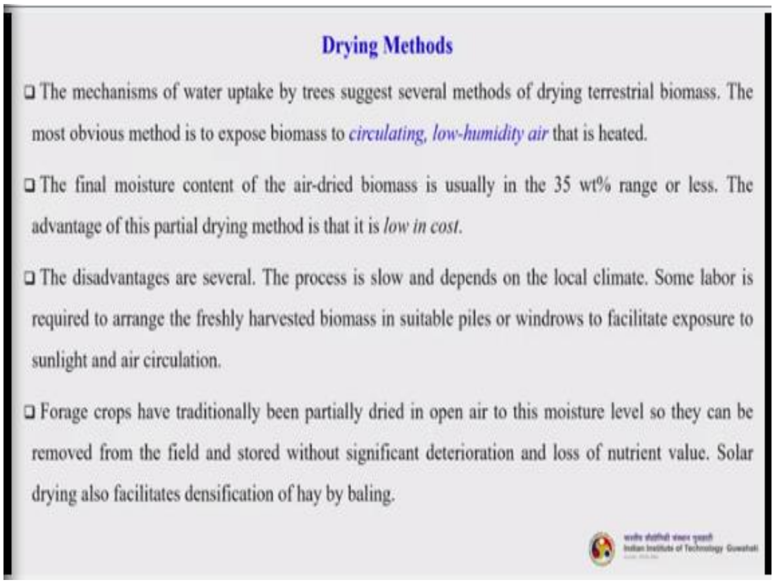

So, let us now understand the drying methods. The mechanism of water uptake by trees suggests several methods of drying terrestrial biomass. The most obvious method is to expose biomass to circulating low humidity air that is heated. So, the final moisture content of the air dried biomass is usually in the 35 weight percentage range or less. The advantage of this partial drying method is that it is low in cost, so mostly it is adopted even in commercial scale.

So, that disadvantages are however several, the process is slow and it depends on the local climate. Some labor is required to arrange the freshly harvested biomass in suitable piles or windrows to facilitate exposure to sunlight and air circulation and then if there is rain then there is a big problem. So, forage crops have traditionally been partially dried in open air to this moisture level. So, they can be removed from the field and stored without significant deterioration and loss of nutrient value. Solar drying also facilitates densification of hay by baling.

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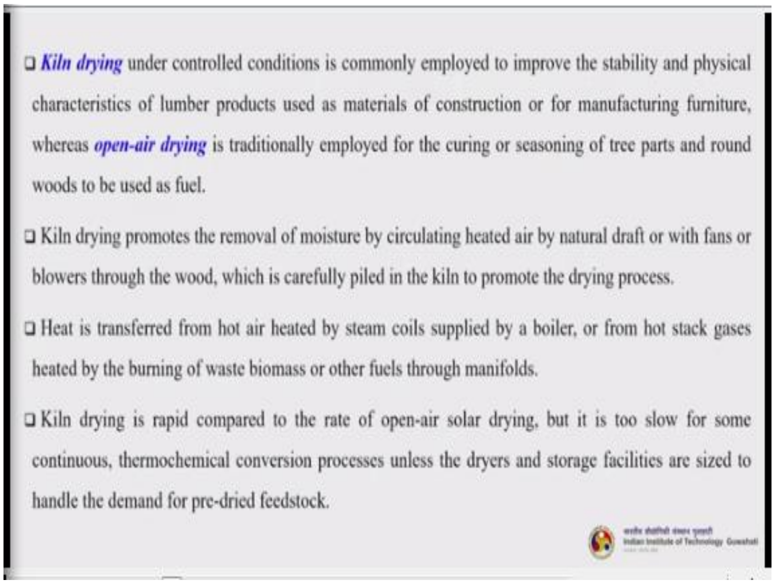

There is another technology which is also adopted in large scale in industry, it is called Kiln drying. So, under this kiln drying controlled conditions is commonly employed to improve the stability and physical characteristics of lumber products used as materials of construction or for manufacturing furniture, whereas open air drying is traditionally employed for the curing or seasoning of tree parts and round woods to be used as fuel.

A kiln drying promotes the removal of moisture by circulating heated air by natural draft or with fans or blowers through the wood, which is carefully piled in the kiln to promote the drying process. Heat is transferred from hot air, heated by steam coil supplied by a boiler or from hot stack gases heated by the burning of waste biomass or other fuels through manifolds. Kiln drying is rapid compared to the rate of open air solar drying, but it is too slow for some continuous thermo chemical conversion processes, unless the dryers and storage facilities are sized to handle the demand for pre dried feedstock. So, essentially the meaning is that when we are preparing a feedstock for a thermo chemical conversion like biomass pyrolysis, which are large in scale. So, unless until we have such a similar scale kiln drying, so you cannot supply a biomass to thermochemical conversion process, the quantity it is required using the Kiln dryer.

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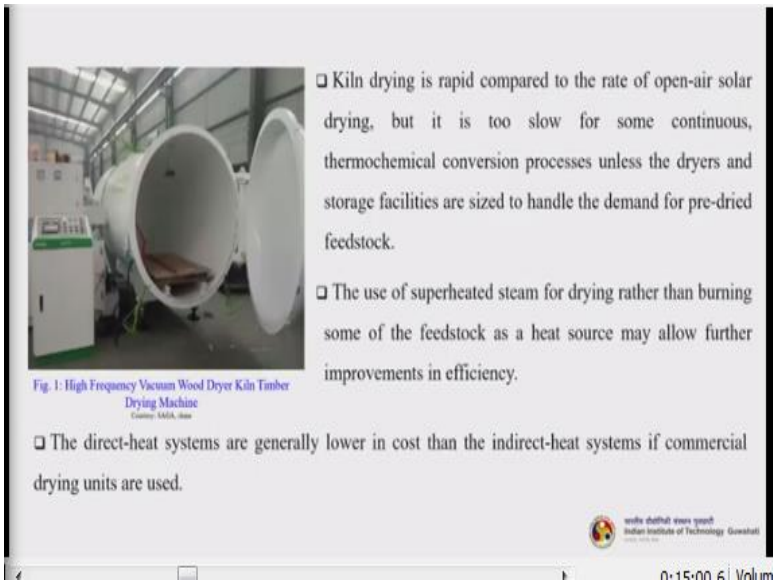

So, this is one image of the kiln drying system or dryer. So, it is rapid compared to the rate of open air solar drying but too slow for some continuous processes. So, the use of superheated steam for drying other than burning of some of feedstock as heat source may allow further improvement in efficiency. The direct heat systems are generally lower in cost than the indirect heat systems, if commercial drying units are used and these are not very expensive systems also.

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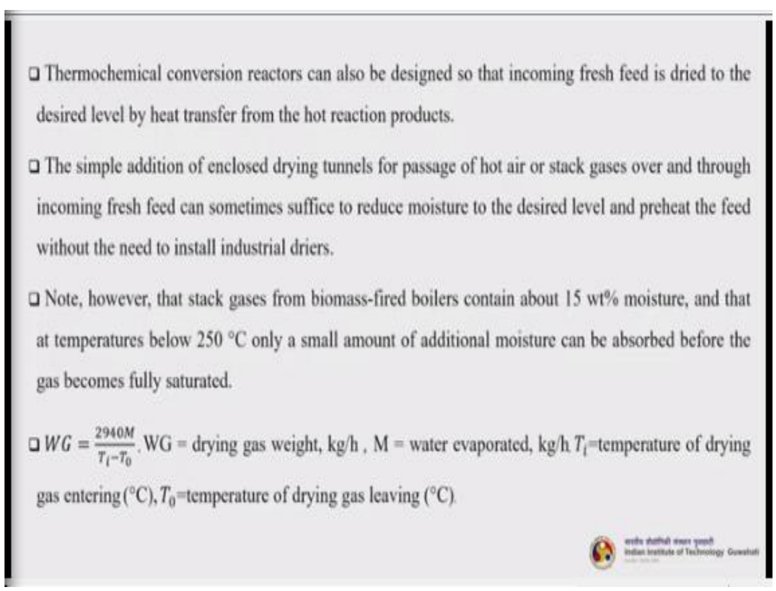

So, thermochemical conversion reactors can also be designed, so that incoming fresh feed is dried to the desired level by heat transfer from the hot reaction products. So, that means this is essentially talking about the heat that is getting generated from the thermochemical conversion processes and are basically getting wasted, so some sort of waste heat recovery.

So, that heat can be used to dry the feedstock which is going to be used in the thermochemical conversion systems. The simple addition of enclosed drying tunnels for passages of hot air or stack gases over and through incoming fresh feed can sometimes suffice to reduce moisture to the desired level and preheat the feed without the need to install the industrial driers.

Note, however, that stack gases from biomass fired boilers contain about 15 weight percentage of moisture and that temperatures below 250 degrees centigrade only a small amount of additional moisture can be absorbed before the gas becomes fully saturated. So, this is the equation WG equals to 2940M by T i minus T 0, where WG is the drying gas weight in kilograms per hour, M is the water evaporated in kilograms per hour, T i is the temperature of drying gas that is entering in degrees centigrade and T 0 is the temperature of the drying gas leaving in degrees centigrade.

$$WG = \frac{2940M}{T_i - T_0}$$

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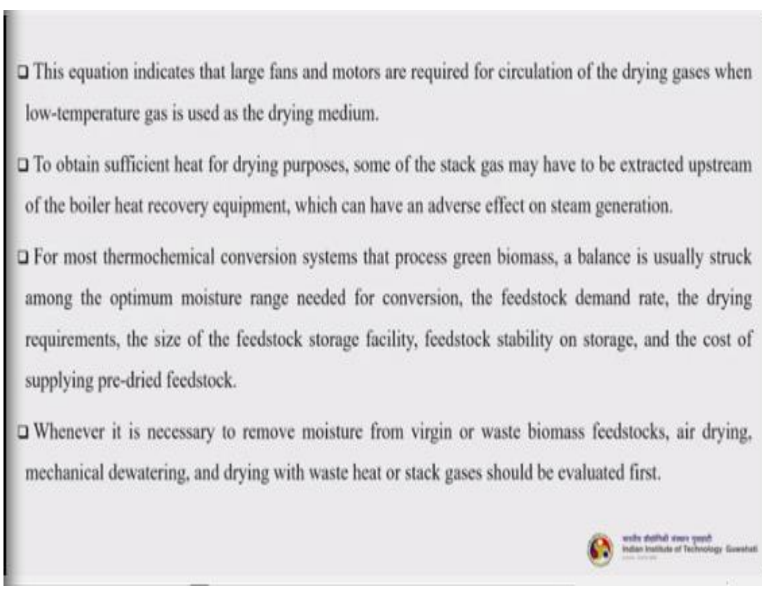

Now this equation indicates that large fans and motors are required for circulation of the drying gases when low temperature gas is used as the drying medium. To obtain sufficient heat for drying purposes, some of the stack gas may have to be extracted upstream of the boiler heat recovery equipment, which can have an adverse effect on the steam generation. For most thermochemical conversion system that process green biomass, a balance is usually struck among the optimum moisture range that is needed for the conversion, the feedstock demand rate, the drying requirements, the size of the feedstock storage facility, feedstock stability on storage and the cost of supplying pre dried feedstock. Whenever it is necessary to remove moisture from virgin or waste biomass feedstocks, air drying, mechanical dewatering and drying with waste heat or stack gases should be evaluated first.

So, the entire idea of this discussion is that when you talk about a sustainable bio refinery perspective, basically whatever the heat that is getting generated from one or the other processes and are being wasted. So, should not be wasted basically that is what is the message. So, you need to go for the waste heat recovery systems. There are excellent waste heat recovery systems that are being designed and are being implemented in most of the petroleum refineries, where the process streams that comes out is at very elevated temperature and we basically use some selective heat exchanger type of units to recover the heat. And that heat can again be used for drying purposes or for something else where the heat and/or energy is being required. Energy is very important in any process industries that takes the major amount of the cost, one of the major amount of the cost. So, it is always important that energy whatever it is being getting into wastes should be recovered and reused.

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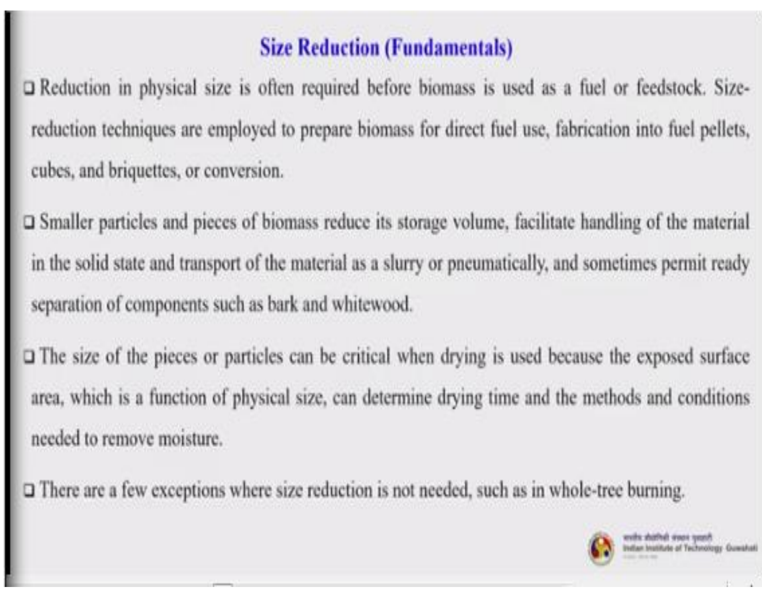

So, now let us discuss about size reduction. So, we have understood little about size reduction during in some of our earlier classes, that we need to reduce size to increase it is surface area and all. So, let us just quickly glance through the same thing once again in a little elaborate manner. So, reduction in physical size is often required before biomass is used as a fuel or feedstock.

Size reduction techniques are employed to prepare biomass for direct fuel use, fabrication into fuel pellets, cubes, briquettes and/or conversion. Now smaller particles and pieces of biomass, reduce its storage volume, facilitate handling of the material in the solid state and transport of the material as a slurry or pneumatically and sometimes permit ready separation of components such as bark and whitewood.

The size of the pieces or particles can be critical when drying is used. Because the exposed surface area which is a function of physical size, can determine drying time and the methods and conditions needed to remove moisture. There are a few exceptions where size reduction is not needed, such as in whole tree burning, but nobody is doing all these things nowadays so, because that takes more amount of energy to start the burning.

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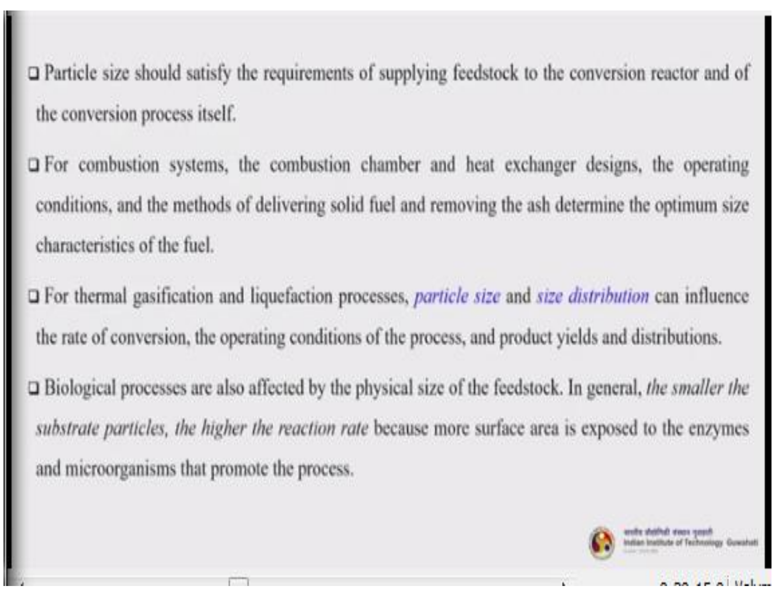

So, particle size should satisfy the requirements of supplying feedstocks to the conversion reactor and of the conversion process itself. For combustion systems, the combustion chamber and heat exchanger designs, the operating conditions and the methods of delivering solid fuel and removing the ash, determine the optimum size characteristics of the fuel. For thermal gasification and liquefaction processes, particle size and size reduction can influence the rate of conversion, the operating conditions of the process and product yields and distributions. Biological processes are also affected by the physical size of the feedstock. In general, the smaller the substrate particles the higher the reaction rate because more surface area is exposed to the enzymes and microorganisms that promote the process.

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So, this is one of the application size reduction machine basically, so it is the hammer mill. So, dry shredders are commercially used for reducing the size of biomass. The most common types of machines are vertical and horizontal shaft hammer mills. Metal hammers on rotating shafts or drums reduced particle size by impacting the feed material until the particles are small enough to drop through the grate openings.

So, hammer mills are commonly used in the MSW, MSW means here municipal solid waste, MSW processing systems to reduce the size of the components before separation of RDF, RDF is the refuse-derived fuel or you can say that combustible fraction of the municipal solid waste.

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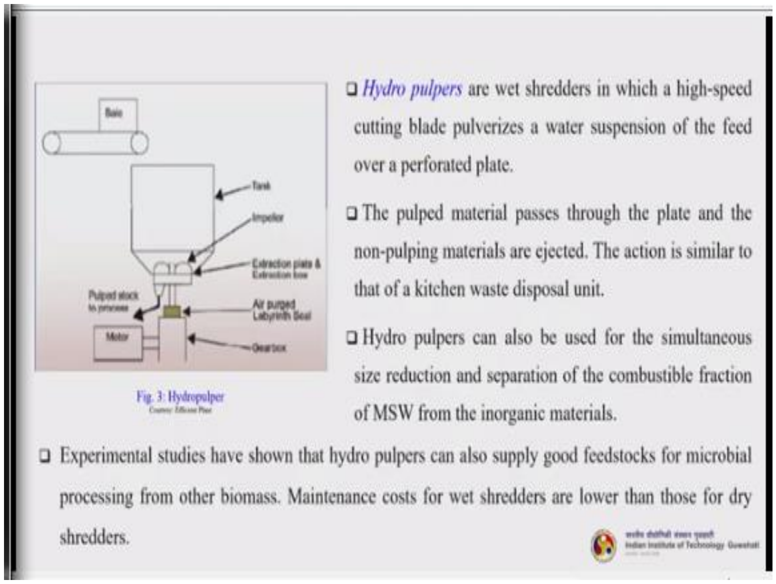

So, there is another machine which is called a hydro pulper. So, hydro pulpers are wet shredders in which a high speed cutting blade pulverizes a water suspension of the feed over a perforated plate. So, you can see this is a tank and which is holding this, this is the extraction plate and extraction box here, then air plunged seal here, there is a gearbox motor that is rotating actually.

So, the pulped material passes through the plate and then non pulping materials are rejected. Anything that is mostly you can say that semi-solid form or in a paste form or basically the pulp that will pass through smoothly through that extraction plate and rest everything will be retained on the surface of the plate and will be rejected. The action is similar to that of a kitchen waste disposal unit.

So, the hydro pulpers can also be used for the simultaneous size reduction and separation of the combustible fraction of the municipal solid waste from the inorganic materials. Experimental studies have shown that hydro pulpers can also supply good feedstocks for microbial processing from other biomass. Maintenance cost wet shredders are lower than those for the dry shredders.

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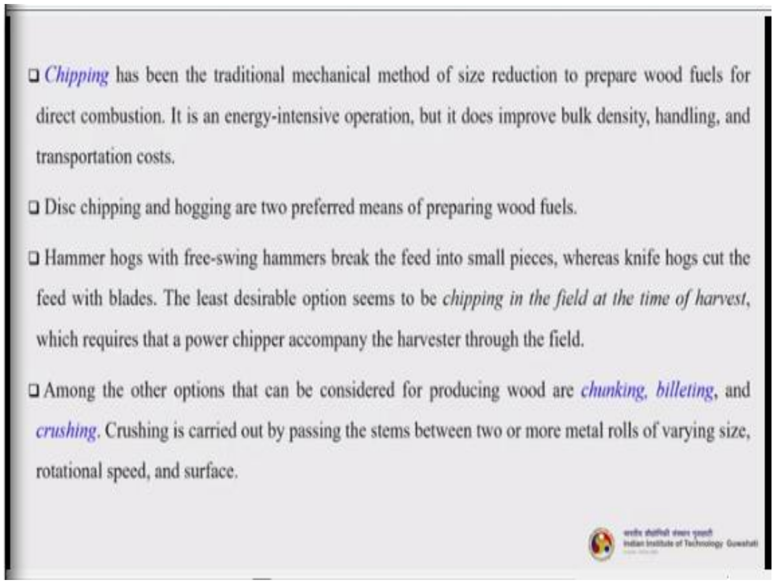

Chipping has been the traditional mechanical method of size reduction to prepare wood fuels for direct combustion. It is an energy intensive operation, but it does improve bulk density, handling and transportation cost. So, it is a good technique, now also being widely used. Disc chipping and hogging at the 2 preferred means of preparing the wood fuels. A hammer hogs with free swing hammers break the feed into small pieces, whereas knife hogs cut the feed with blades.

So, the 2 way basically either you cut it otherwise you just hammer it. So, the least desirable option seems to be chipping in the field at the time of harvest, which requires that a power chipper accompanying the harvester through the field. So, this particular thing is very interesting, we have discussed this when we discussed about this bio refinery details. So it is always important that whatever processing of the biomass you are doing you please do at the source, it is always not possible but it is important for more sustainability. If you do the processing in the field, then the transportation cost also reduces significantly. Among the other options that can be considered for producing wood or chunking, billeting and crushing. Crushing is carried out by passing the stems between 2 or more metal rolls of varying size, at different rotational speed and the different types of surfaces.

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So, the crushing and brunching of wood may offer significant advantages over chipping, this is a biomass crusher grinder. So, this technique is flexible and is able to process lengthy stems to yield bolts of crushed wood that exhibit relatively rapid drying. For reactor feeding purposes, however further size reduction would be necessary. The feedstock characteristics required for the combustion or conversion process used determine which of these methods of size reduction maybe applicable.

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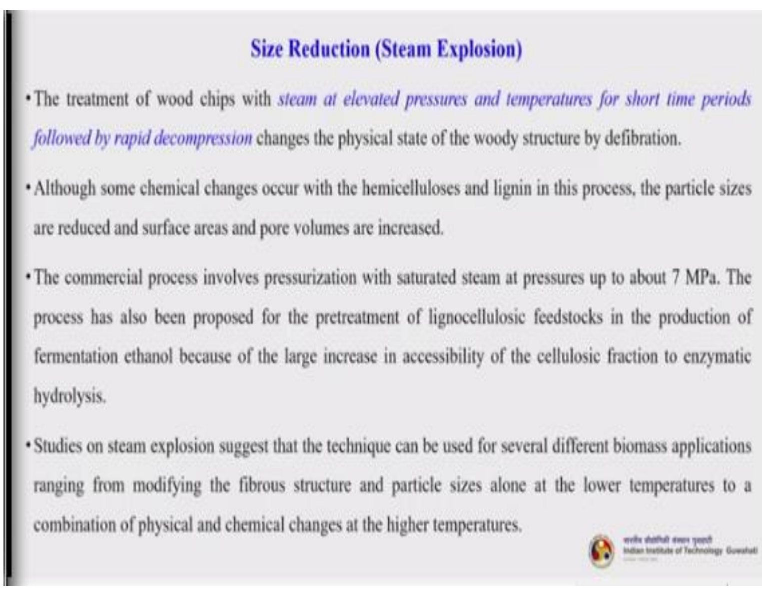

Next is the size reduction in using steam explosion. See, we have understood steam explosion in detail in our one of the last module classes when we discussed pretreatment processes physiochemical pretreatment processes. So, the treatment of wood chips with steam at elevated pressures and temperatures for shorter time periods followed by rapid decompression, this is what is the principle of steam explosion, changes the physical state of the woody structure by defibration.

Although some chemical changes occur with the hemicelluloses and lignin in this process, the particle sizes are reduced and surface areas and pore volume is increased. The commercial process involves pressurization with saturated steam at pressure to about 7 megapascals. The process has also been proposed for the pretreatment of lignocellulosic feedstock in the production of fermentation ethanol because of the large increase in accessibility of the cellulosic fraction to enzymatic hydrolysis. So, studies on steam explosion suggests that the technique can be used for several different biomass applications, ranging from modifying the fibrous structure and particle sizes alone at the low temperatures to a combination of physical and chemical changes at the higher temperatures.

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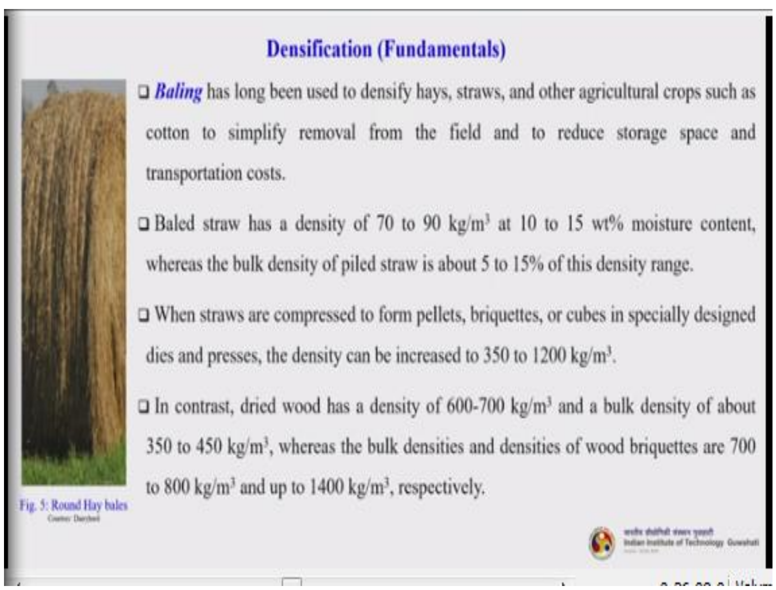

Next is densification, so baling has long been used to densify hays, straws and other agricultural crops such as cotton to simplify removal from the field and to reduce storage space and transportation costs. Baled straw has a density of 70 to 90 kilograms per meter cube at 10 to 50 weight percent moisture content, whereas bulk density of piled straw is about 5 to 15% of this density range.

When straws are compressed to form pellets, briquettes or cubes in specially designed dies and presses the density can be increased to 350 to 1200 kilograms per meter cube. In contrast, dried wood has a density of 600 to 700 kg per meter cube and a bulk density of about 350 to 450 kg per meter cube, whereas the bulk densities and densities of wood briquettes are 700 to 800 kilograms per meter cube and up to 1400 kilograms per meter cube respectively.

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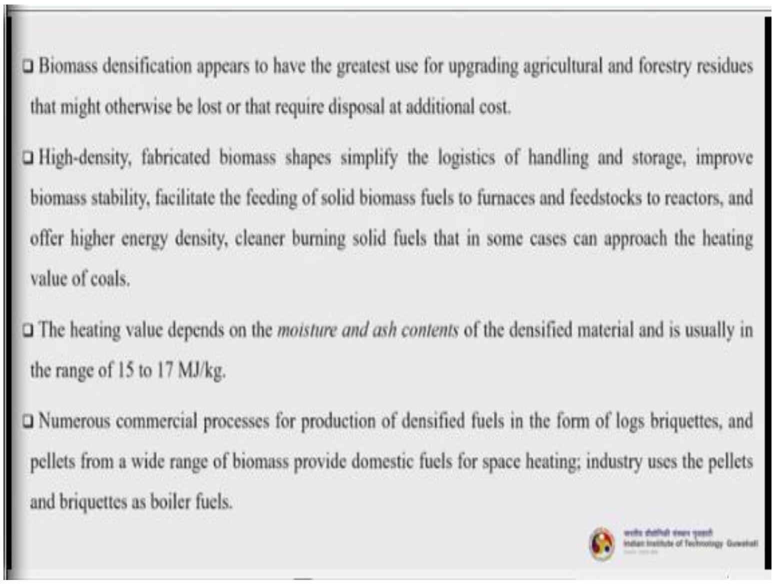

Biomass densification appears to have the greatest use for upgrading agricultural and forestry residues that might otherwise be lost, or that require disposal at additional cost. High Density fabricated biomass shapes simplify the logistics of handling and storage, improve biomass stability, facilitate the feeding of solid biomass fuels to furnaces, and feedstocks to reactors, and offer higher energy density, cleaner burning solid fuels that in some cases can approach the heating value of coals.

The heating value depends on the moisture and ash contents of the densified material, and is usually in the range of 15 to 17 mega joules per kg. Numerous commercial processes for production of densified fuels in the form of logs, briquettes, and pellets from a wide range of biomass provide domestic fuels for space heating, industry uses the pellets and briquettes as boiler fuels.

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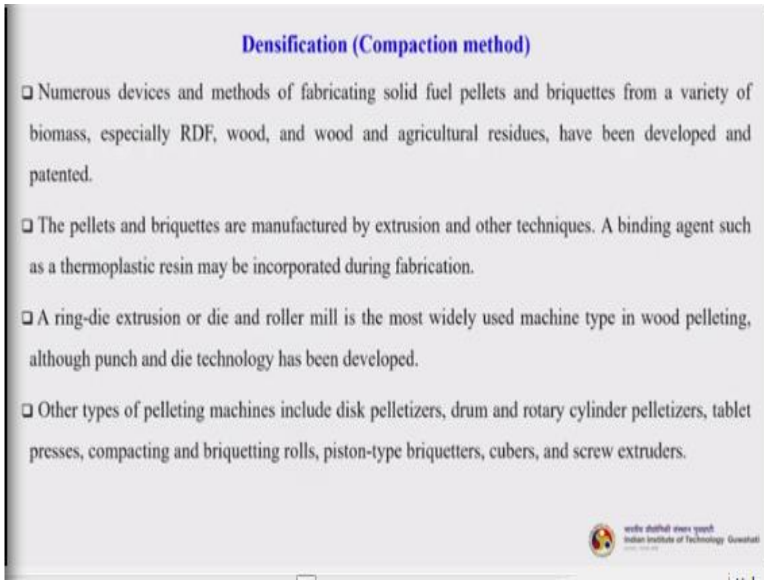

Numerous devices and methods of fabricating solid fuel pellets and briquettes from a variety of biomass, especially RDF, wood and wood and agricultural residues have been developed and patented. The pellets and briquettes are manufactured by extrusion and other techniques. A binding agent such as a thermoplastic resin may sometimes be incorporated during the fabrication.

A ring die extrusion or a die and roller mill is the most widely used machine type in wood pelleting, although punch and die technology has been developed. Other types of pelleting machines include disk pelletizers, drum and rotary cylindrical pelletizers, tablet presses, compacting and briquetting rolls, piston type briquetters, cubers and screw extruders. There are so many different types of units are available for doing this densification.

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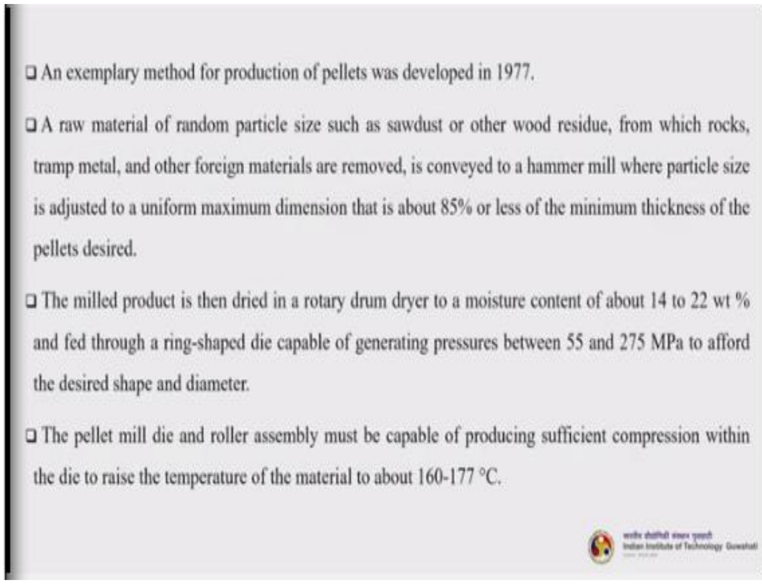

An exemplary method for production of pellets was developed in 1977. A raw material of random particle size such as sawdust or wood residue from which rocks, tramp metal and other foreign materials are removed is conveyed to a hammer mill where particle sizes is adjusted to a uniform maximum dimension that is about 85% or less of the minimum thickness of the pellets desired.

The milled product is then dried in a rotary drum dryer to a moisture content of about 14 to 22 weight percent and fed through a ring shaped die capable of generating pressure between 55 to 275 megapascals to afford the desired shape and diameter. The pellet mill die and roller assembly must be capable of producing sufficient compression within the die to raise the temperature of the material to about 162 to 177 degree centigrade.

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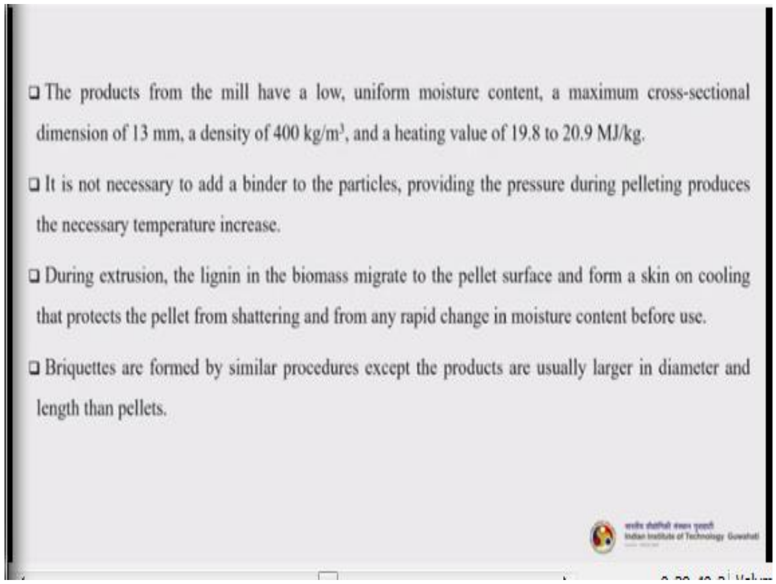

The products from the mill have a low uniform moisture content, a maximum cross sectional dimension of 13 mm, a density of 400 kilograms per meter cube and a heating of 19.8 to 20.9 mega joules per kg. It is not necessary to add a binder to the particles, providing the pressure during the pelleting produces the necessary temperature increase. During extrusion, the lignin in biomass migrate to the pellet surface and form a skin on cooling that protects the pellet from shattering and from any rapid change in the moisture content before use. Briquettes are formed by similar procedures, except the products are usually larger in diameter and length then the pellets.

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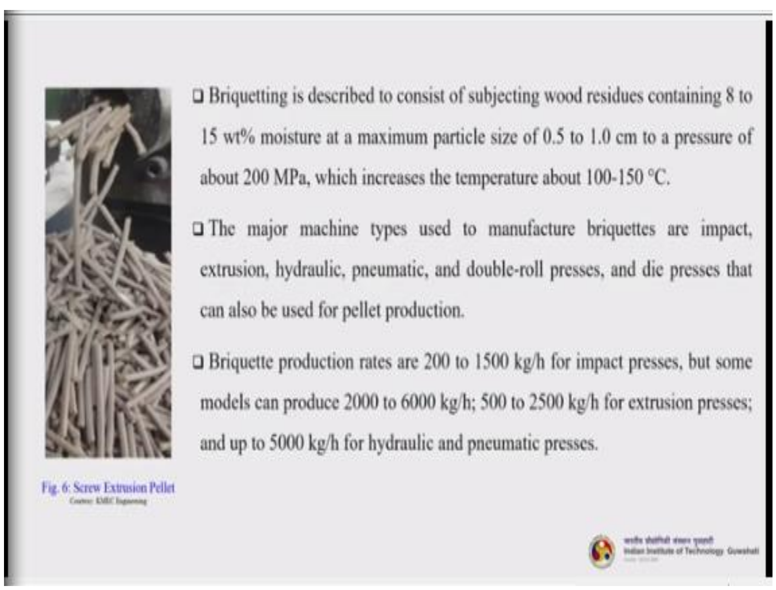

These are images of some of the briquettes. So briquetting is described to consist of subjecting wood residues containing 8 to 15 weight percent of moisture at a maximum particle size of 0.5 to 1 centimeter to a pressure of about 200 megapascals, which increases the temperature about 100 to 150 degrees centigrade. The major machine types used to manufacture briquettes are impact, extrusion, hydraulic, pneumatic and double roll presses and die presses that can also be used for pellet production.

Briquette production rates are 200 to 1500 kilograms per hour for impact presses, but some models can produce 2000 to 6000 kilograms per hour, 500 to 2500 kilograms per hour for extrusion presses and up to 5000 kilograms per hour for hydraulic and pneumatic presses.

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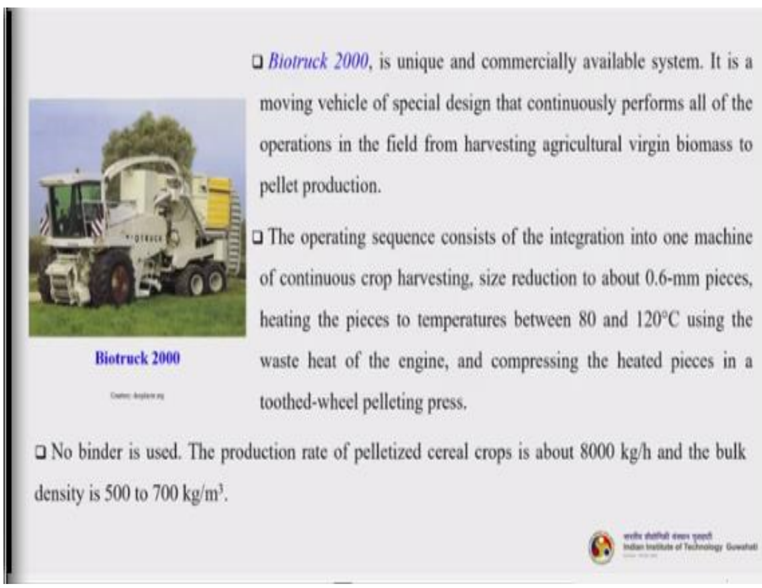

There is something called a *Biotruck 2000*, so this is the image of biotruck 2000, so what is this? This is a unique commercially available system, it is a truck , transportation vehicle, so what it does? So, it is a moving vehicle of special design, so that continuously perform all the operations in the field, so it has to be taken to the field. So, from harvesting agricultural virgin biomass to pellet production.

So, what it will do is that, it will do the harvesting of the agricultural crops as well as at the same time after harvesting of the cereals and grains whatever the left out biomass straw or whatever it is , it will convert on the field itself to pellets. So, the operating sequence consists of the integration into one machine of continuous crop harvesting, size reduction of about 0.6 mm pieces, heating the pieces to a temperature between 80 to 120 degrees centigrade using the waste heat of the engine, and compressing the heated pieces in a toothed wheel pelleting press.

Now this is again very interesting, you can see this using the waste heat of the engine, what about the heat that is getting generated when the engine is running, that heat is being captured to do the process. So, no binder is used. The production rate of the pelletized cereal crops is about 8000 kilograms per hour, it is a huge amount. And the bulk density is about 500 to 700 kilograms per meter cube, so the transportation becomes easy.

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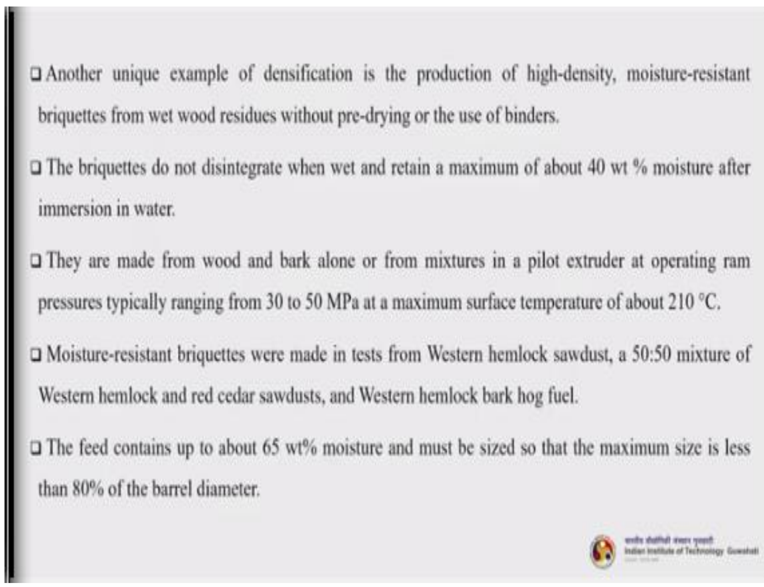

So, another unique example of densification is the production of high density, moisture resistant briquettes from wet wood residues without pre drying or the use of binders. The briquettes do not disintegrate when wet and retain a maximum of about 40 weight percent moisture after immersion in water. They are made from wood and bark alone and from mixtures in the pilot extruder at operating pressures typically ranging from 30 to 50 megapascals at a maximum surface temperature about around 210 degrees centigrade.

Moisture resistant briquettes were made in tests from the Western hemlock sawdust, a mixture of 50:50 Western hemlock and red cedar sawdust and Western hemlock bark hog fuel**,** this is just an example. So, the feed contains up to about 65 weight percent moisture and must be sized, so that maximum size is less than 80% of the barrel diameter.

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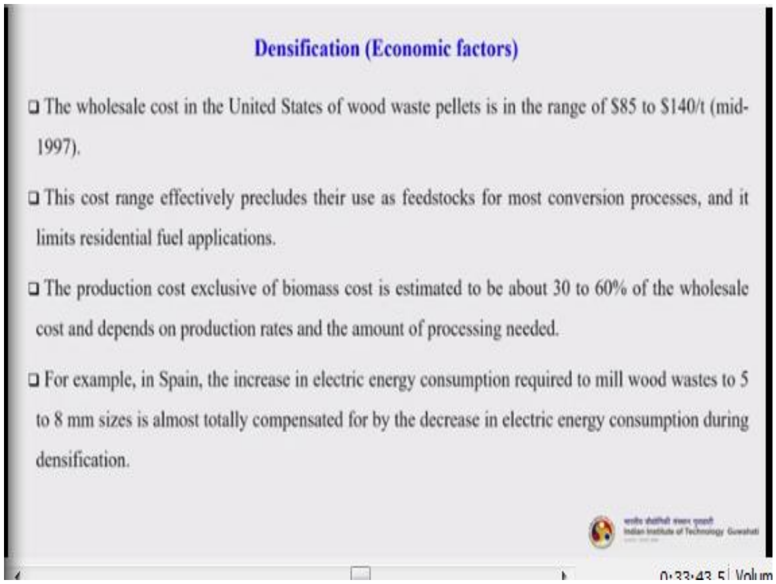

So, let us understand the economical factors or economic factors of the densification process. The wholesale cost in the United States of wood waste pellets is in the range of 85 to 140 dollars per ton, so that was in mid 1997. Now this cost range effectively precludes their use as a feedstock for most conversion processes, and it limits residential fuel applications. The production cost exclusive of biomass cost is estimated to be about 30 to 60% of the wholesale cost, and depends on production rates and the amount of processing needed.

For example, in Spain the increase in electric energy consumption required to mill wood waste to 5 to 8 mm sizes is almost totally compensated for by the decrease in electrical energy consumption during the densification process itself.

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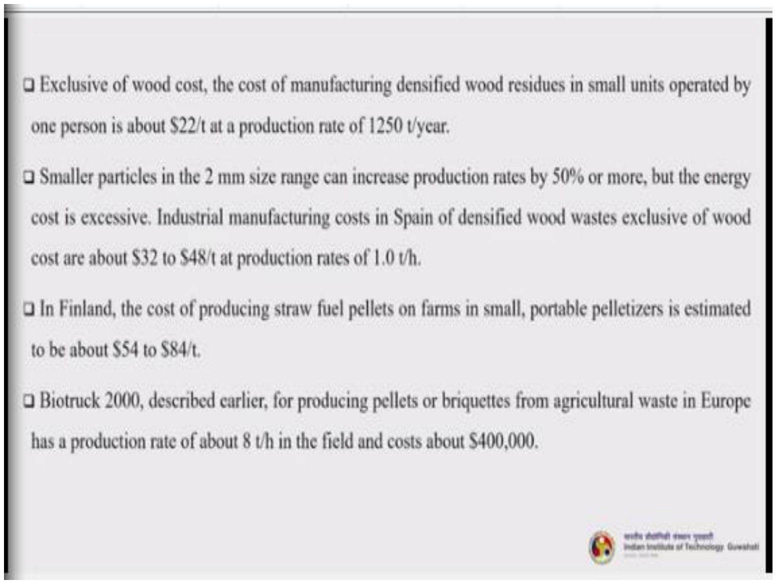

Exclusive of wood cost, the cost of manufacturing densified wood residues in small units operated by one person is about 22 dollar per ton at a production rate of 1250 tons per year. Smaller particles in the 2 mm size range can increase production rates by 50% or more, but the energy cost is excessive. Industrial manufacturing cost in Spain of densified wood wastes exclusive of wet wood costs are about 30 to 200 dollars per ton at a production rates of one ton per hour.

So, in Finland the cost of producing straw fuel pellets on farms in small portable pelletizers is estimated to be about 54 to 84 dollar per ton. Biotruck 2000, described as earlier for producing pellets or briquettes from agricultural waste in Europe has a production rate of about 8 ton per hours in the field and cost about 400,000 dollar.

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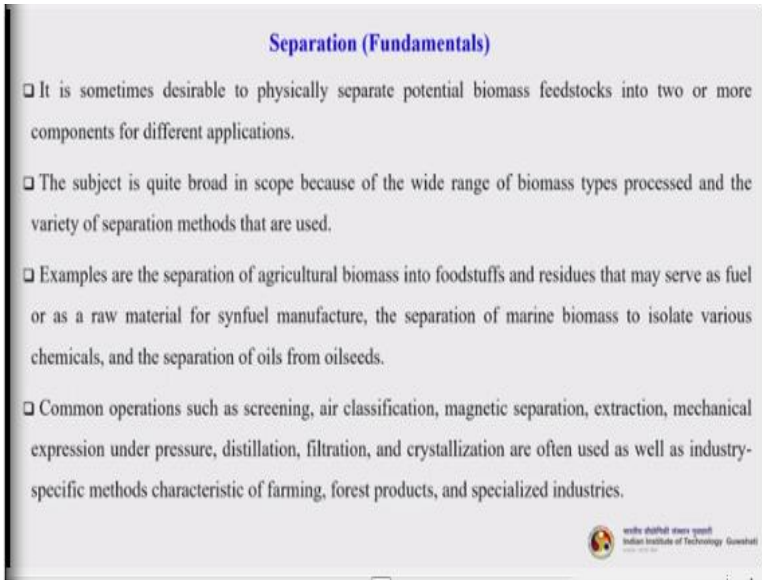

Now we will discuss about the separation. It is sometimes desirable to physically separate potential biomass feedstocks into 2 or more components of different applications. So, the subject is quite broad in scope because of the wide range of biomass types processed and the variety of separation methods that are used. Examples are the separation of agricultural biomass into foodstuffs and residues that may serve as fuel or as a raw material for synfuel manufacture.

The separation of marine biomass to isolate various chemicals and the separation of oils from oilseeds. Now common operations such as screening, air classification, magnetic separation, extraction, mechanical expression under pressure, distillation, filtration, and crystallization are often used, as well as industry specific methods characteristic of farming, forest products, and specialized industries - depending upon your biomass, you need to choose a particular separation process.

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So MSW, the municipal solid waste, is a complex mixture of inorganic and organic materials. Efficient separation and economic recovery of the RDF - the refuse derived fuel and the components that can be recycled is the ultimate challenge to engineers who specialize in designing resource recovery equipment for the large scale processing of solid waste generated by urban communities.

One of the first comprehensive resource recovery plants in the world was built in Dade County, Florida in United States. A brief description of this facility when it was in full scale operation to recover recyclables and RDF is very, very informative. You can read more by Google searching the name of the place. The plant was designed to process 2720 tons per day of MSW, but it frequently processed over more than that, close to 4000 tons per day. And it could process up to 5000 tons per day if only household garbage were received.

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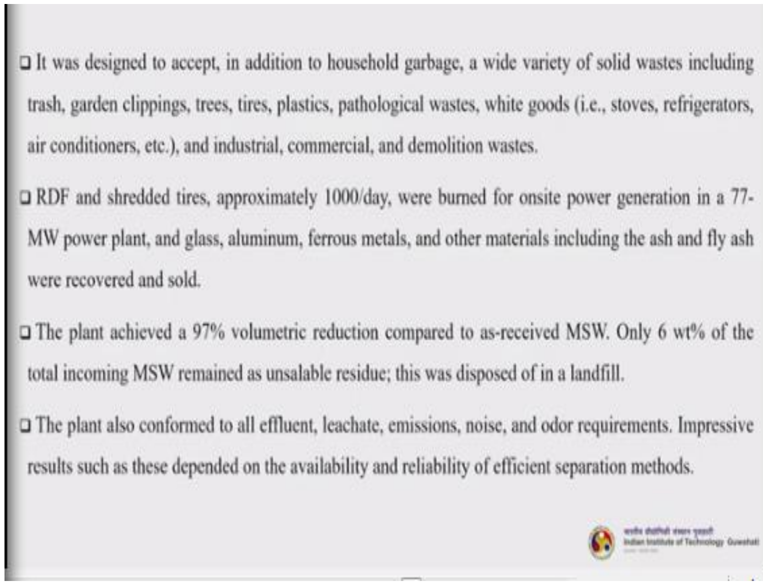

So, it was designed to accept in addition to household garbage, a wide variety of solid wastes, including trash, garden clipping, trees, tires, plastics, pathological wastes, white goods - As for example stoves, refrigerators, air conditioners, and industrial, commercial and demolition wastes. RDF and shredded tires approximately 1000 per day were burned for onsite power generation in a 77 megawatt power plant and glass, aluminum, ferrous metals as well as materials including the ash and fly ash were recovered and sold.

The plant achieved a 97% volumetric reduction compared to as received MSW. Only about 6% of the total incoming MSW remained as unsalable residue and was disposed of in a proper manner using landfill technology. The plant also conformed to all effluent, leachate, emissions, noise and odor requirements, so the environmental clearance basically from the environmental agencies. So, impressive results such as this dependent on the availability and reliability of the efficient separation methods, this is an very good, classic success story of the MSW treatment.

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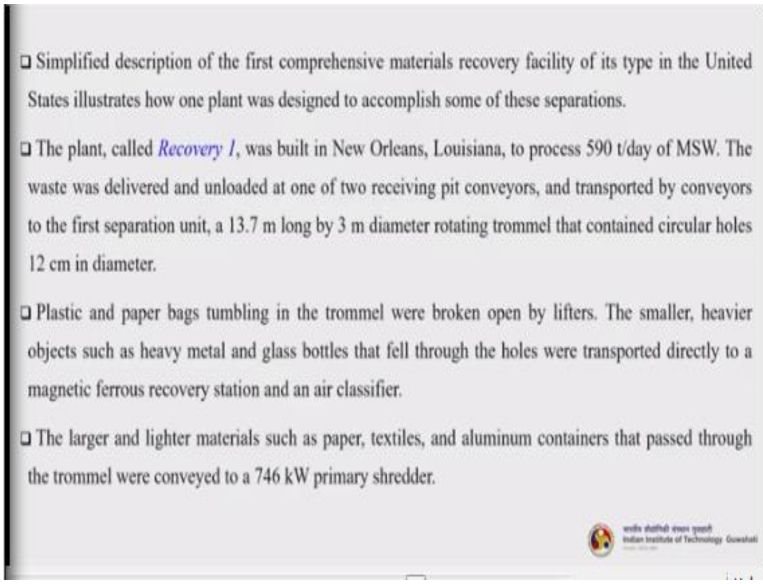

Simplified description of the first comprehensive materials recovery facility of its type in the United States illustrates how one plant was designed to accomplish some of these separations. The plant called Recovery 1 was built in New Orleans, Louisiana to process 590 tons per day of municipal solid waste.

The waste was delivered and unloaded at one of the 2 receiving pit conveyers and transported by conveyers to the first separation unit, a 13.7-meter-long by 3-meter diameter rotating trommel that contained circular holes 12 centimeter in diameter. So it is a perforated trommel, rotating trommel. So, plastic and paper bags tumbling in the trommel were broken upon by the lifters. The smaller and heavier objects such as heavy metal, glass bottles, even some of the plastics, that fell through the holes were transported directly to a magnetic ferrous recovery station and an air classifier. So, air classifier is a unit in which air is being used to fluidize the MSW. So, based upon their density, so they will be separated. The larger and light materials such as paper, textiles and aluminum containers that pass through the trommel were conveyed to a 746 kilowatt primary shredder.

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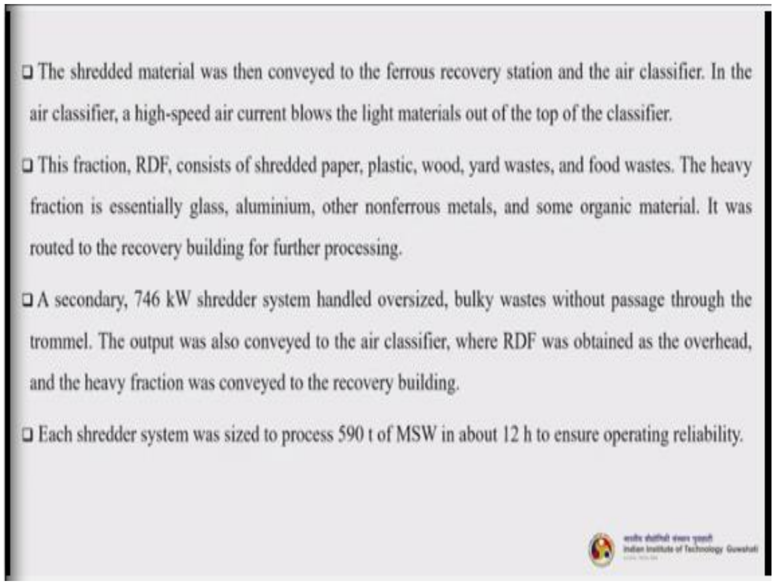

This shredded material was then conveyed to the ferrous recovery station and the air classifier. In the air classifier a high speed air current blows the light materials out of the top of the classifier. This fraction RDF which is the refuse fuel consist of shredded paper, plastic, wood, yard waste and food wastes. The heavy fraction is essentially glass, aluminum and other non-ferrous metals and some organic material, it was routed to the recovery building for further processing.

A secondary 746 kilowatt shredder system handled oversized bulky wastes without passage through the trommel. The output was also conveyed to the air classifier where RDF was obtained as the overhead and the heavy fraction was conveyed to the recovery building. Each shredder was sized to process around 590 ton of the MSW in about 12 hour to ensure operating reliability.

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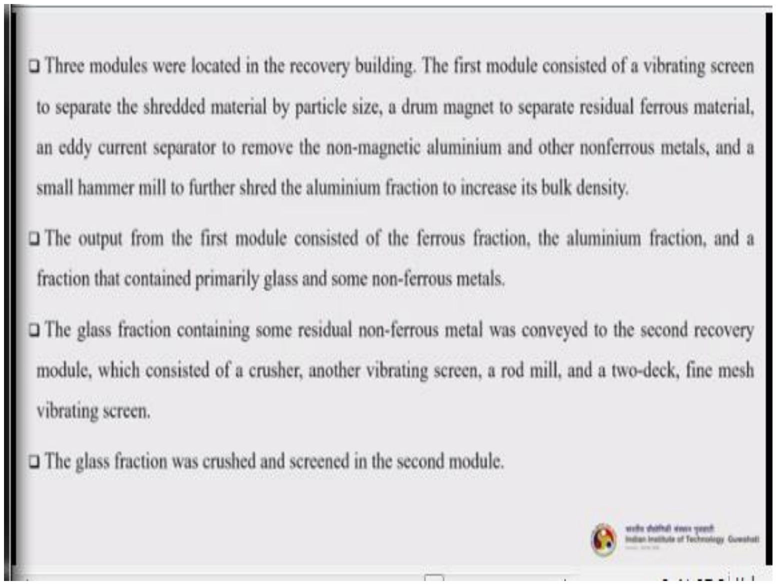

Three modules were located in the recovery building, the first module consisted of a vibrating screen to separate the shredded material by particle size, a drum magnet to separate residual ferrous material, an eddy current separator to remove the non magnetic aluminum and other nonferrous metals, and a small hammer mill to further shred the aluminum fraction to increase it is bulk density.

The output from the first module consisted of the ferrous fraction, the aluminum fraction and a fraction that contained primarily glass and some non ferrous metals. The glass fraction, containing some residual non ferrous metal was conveyed to the secondary recovery module which consisted of a crusher, another vibrating screen, a rod mill and a two-deck, fine mesh vibrating screen. The glass fraction was then crushed and screened in the second module.

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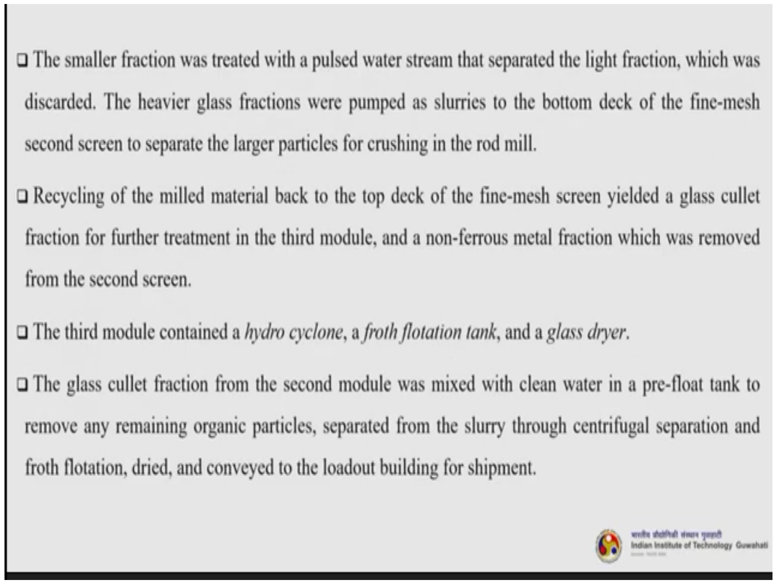

The smaller fraction was treated with a pulsed water stream that separated the light fraction which was discarded. The heavier glass fraction was pumped as slurries to the bottom deck of the fine mesh second screen to separate the larger particles for crushing in the rod mill. Recycling of the milled material back to the top deck of the fine mesh screen yielded a glass cullet fraction for further treatment in the third module, and a non ferrous metal fraction which was removed from the second screen.

In the third module contained a hydro cyclone, a froth floatation tank and a glass dryer. The glass cullet fraction from the second module was mixed with clean water in the pre float tank to remove any remaining organic particles, separated from the slurry through centrifugal separation and froth flotation and conveyed to the loadout building for shipment.

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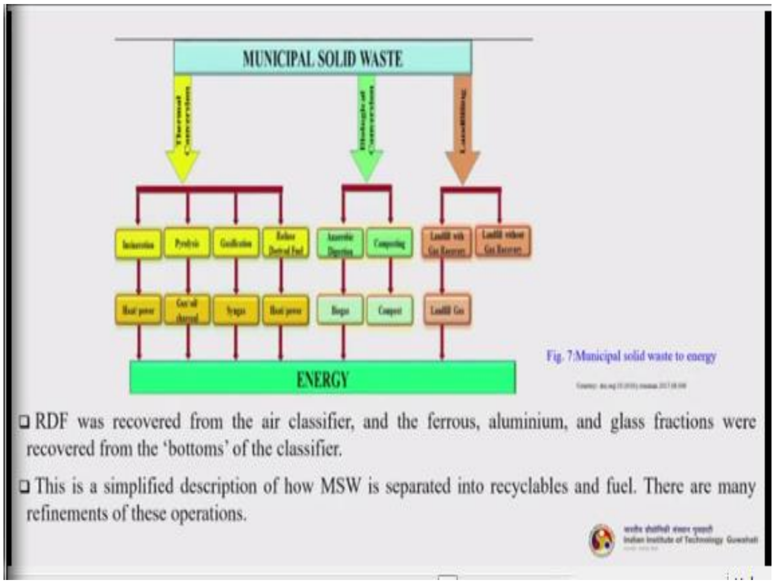

So, you can have a close look at this MSW processing. Municipal solid waste. So, three things it has been shown here, first one is the thermal conversion process, second is the biological conversion, third one is the landfilling. So, look at this thermal conversion process, this is what we are going to discuss in this module. So, different types of process, incineration, pyrolysis, gasification and RDF the refused derived fuel.

So, what it gives us, heat and power, gas, oil, charcoal, syngas, heat and power everything is energy. Then biological fractions, basically 2 things anaerobic digestion which gives us biogas, methane rich biogas maybe sometimes hydrogen also in more quantity depending upon what is the feedstock and composting, so you get compost. Again we are talking about energy, then landfill with gas recovery and that landfill gas can also be collected and can be converted to the energy systems and landfill without gas recovery.

So, RDF was recovered from the air classifier and the ferrous, aluminum and glass fractions were recovered from the bottom of the classifier, this is a simplified description of how MSW is separated into recyclables and fuel. There are many refinements of these operations, this is just a simple understanding that what processes can be used to convert municipal solid waste into energy.

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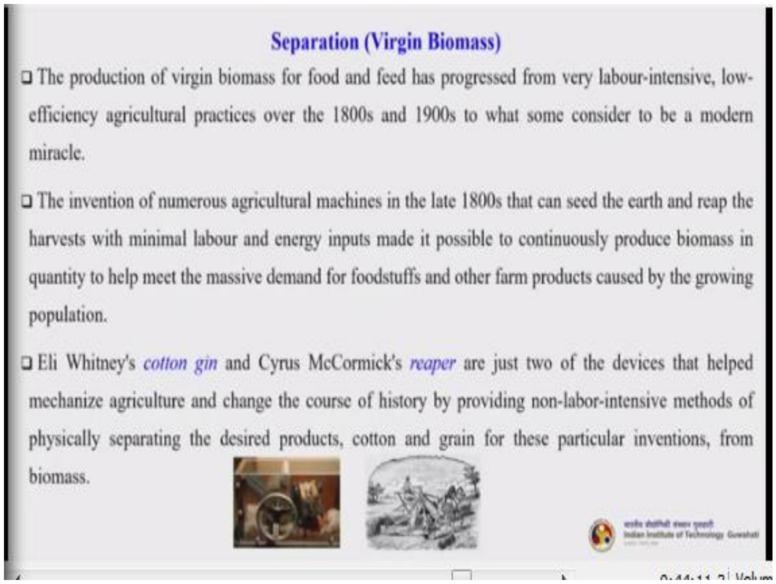

Now we will understand the separation of the virgin biomass. The production of virgin biomass for food and feed has progressed from the very labour-intensive, low-efficiency agricultural practices over the 1800s and 1900s to what some now consider to be a modern miracle. Now the invention of numerous agricultural machines in the late 1800s that can seed the earth and reap the harvest with minimum labour and energy inputs made it possible to continuously produce biomass in quantity to help meet the massive demand for foodstuffs and other farm products caused by the growing population.

Eli Whitney's cotton gin, so this is the Eli Whitney's cotton gin machine it is a classic example of this type of machine which will do the virgin biomass separation. And the Cyrus McCormick's reaper, you can see this, it is a reaper which is being used in the field. And these are the 2 devices that helped mechanize agriculture and change the course of history by providing non labour intensive methods of physically separating the desired products - cotton and grain for these particular inventions from biomass, these units actually made history. So, earlier everything was completely labour-dependent, after these discoveries less labour-dependent processing of the entire agricultural product was possible basically.

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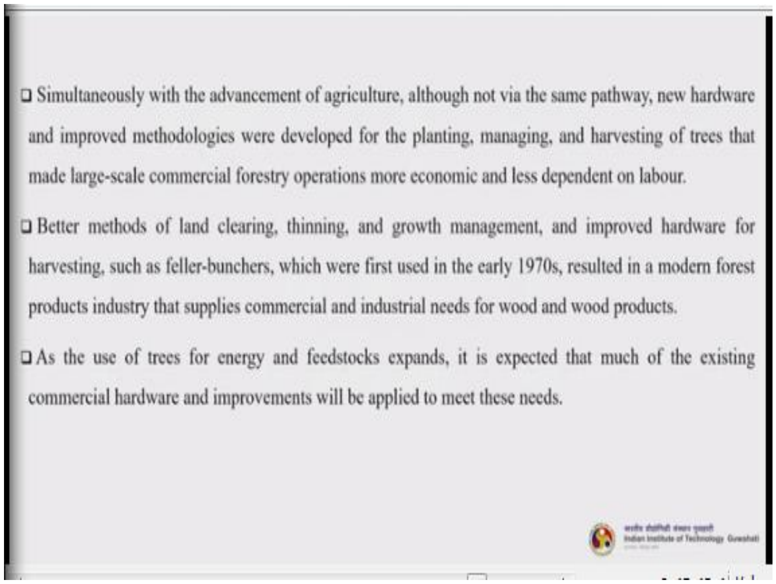

Simultaneously with the advancement of agriculture, although not via the same pathway, new hardware and improved methodologies were developed for the planting, managing and harvesting of trees that made large scale commercial forestry operations more economic and less dependent on labour. Better methods of land clearing, thinning and growth management and improved hardware for harvesting such as feller bunchers which were first used in the early 1970s, resulted in modern forest products industry that supplies commercial and industrial needs for the wood and wood products. As the use of trees for energy and feedstock expands, it is expected that much of the existing commercial hardware and improvements will be applied to meet these needs.

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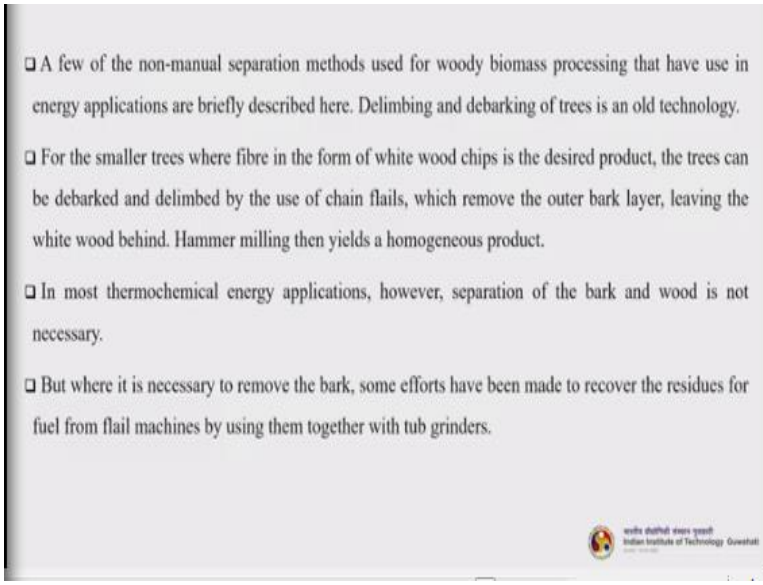

A few of the non manual separation methods used for woody biomass processing that have use in energy applications are briefly described. Delimbing and debarking of trees is an old technology. For the smaller trees where fibre in the form of white wood chips is the desired product, the trees can be debarked and delimbed by the use of chain flails which will remove the outer bark layer, leaving the white wood behind. Hammer milling then yields a homogenous product. Basically white board, white chip whatever it is.

So in most thermochemical energy applications however, separation of the bark and wood is not necessary. But where it is necessary to remove the bark, some efforts have been made to recover the residues for fuel from flail machines by using them together with tub grinders.

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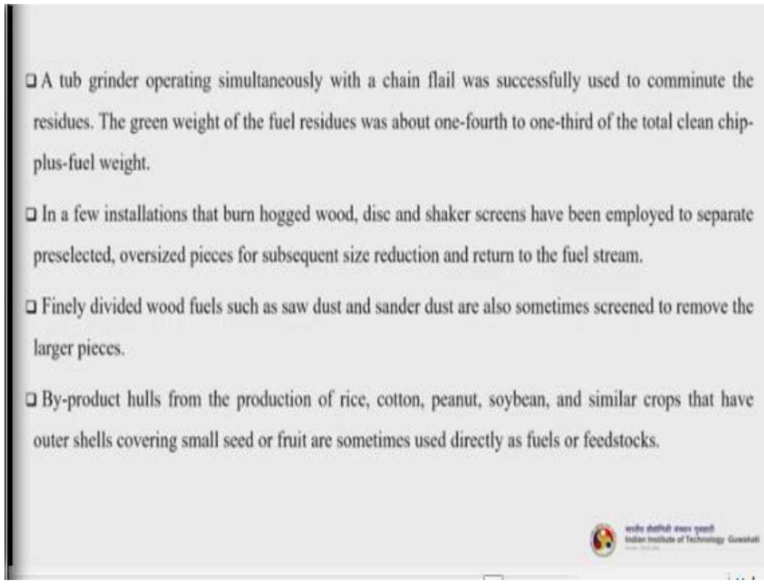

A tub grinder operating simultaneously with a chain flail was successfully used to comminute the residues. The green weight of the fuel residues was about one-fourth to one-third of the total clean chip plus fuel weight. In a few installations that burn hogged wood, disc and shaker screens have been employed to separate preselected, oversized pieces for subsequent size reduction and return to the fuel stream.

Finely divided wood fuels such as sawdust and sander dust are sometimes screened to remove the larger pieces. By-product hulls from the production of rice, cotton, peanuts, soybean and similar crops that have outer shells covering small seed of fruit are sometimes used directly as fuels or feedstocks.

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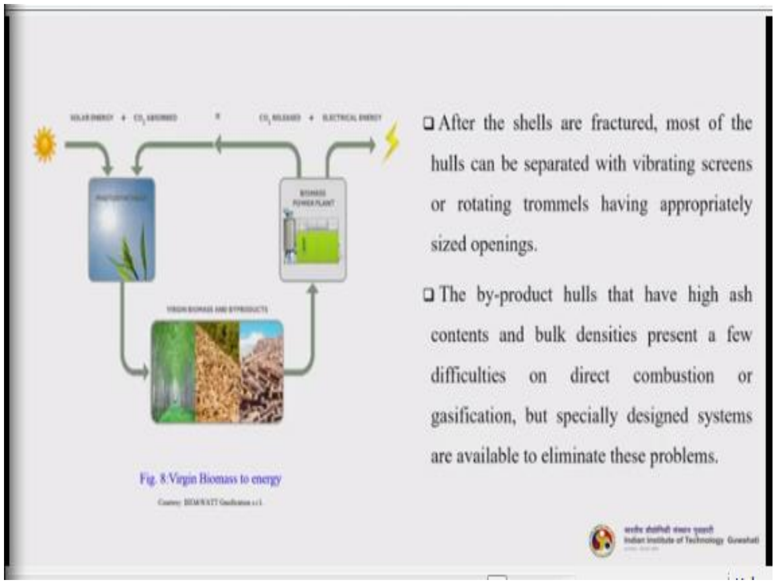

So, you can see this is the virgin biomass processing actually, so the biomass that is getting generated by the use of solar energy and the carbon dioxide that is getting used during the photosynthesis are being collected and chipped and processed into various by-products. Then it goes to the biomass power plant where it is basically converted into energy.

And after the shells are fractured most of the hulls can be separated with vibrating screens or rotating trommels having appropriately sized openings. The by-product hulls that have high ash content and bulk density present a few difficulties on direct combustion or gasification, but specially designed systems are available to eliminate these problems.

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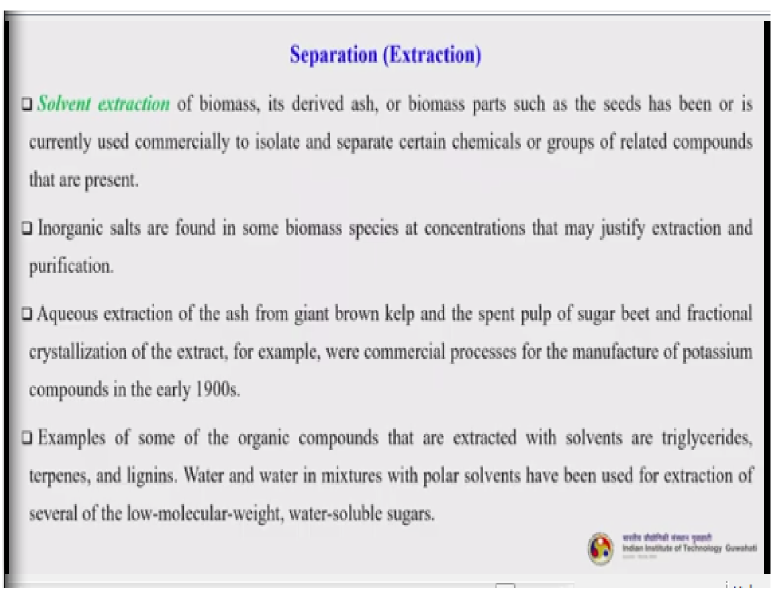

So, now we will discuss about the extraction. Solvent extraction is the age old technique and it is still in practice whether it is in the lab scale or in the commercial scale. So, solvent extraction of biomass, its derived ash or biomass parts such as the seeds has been or being currently used commercially to isolate and separate certain chemicals or group of related compounds that are present. Inorganic salts are found in some biomass species at concentrations that may justify extraction and purification.

Aqueous extraction of the ash from giant brown kelp and the spent pulp of sugar beet and fractional crystallization of the extract, for example, were commercial processes for the manufacture of potassium compounds in the early 1900s. Examples of the some of the organic compounds that are extracted with solvents are trigycerides, terpenes and lignins. Water and water in mixtures with polar solvents have been used for extraction of several of the low molecular weight water soluble sugars.

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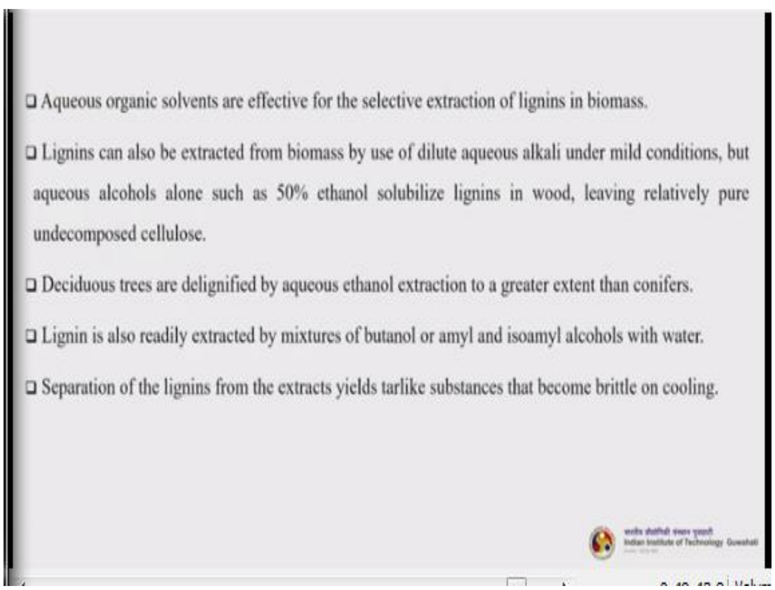

Aqueous organic solvents are effective for the selective extraction of lignins in biomass. Lignins can also be extracted from biomass by the use of dilute aqueous alkali under mild conditions but aqueous alcohols alone such as 50% ehanol solubilize lignins in wood leaving relatively pure undecomposed cellulose. Deciduous trees are delignified by aqueous ethanol extraction to a greater extent than conifers.

Lignin is also readily extracted by mixtures of butanol or amyl or isoamyl alcohols with water. Separation of the lignins from the extracts yields tarlike substances that become brittle on cooling.

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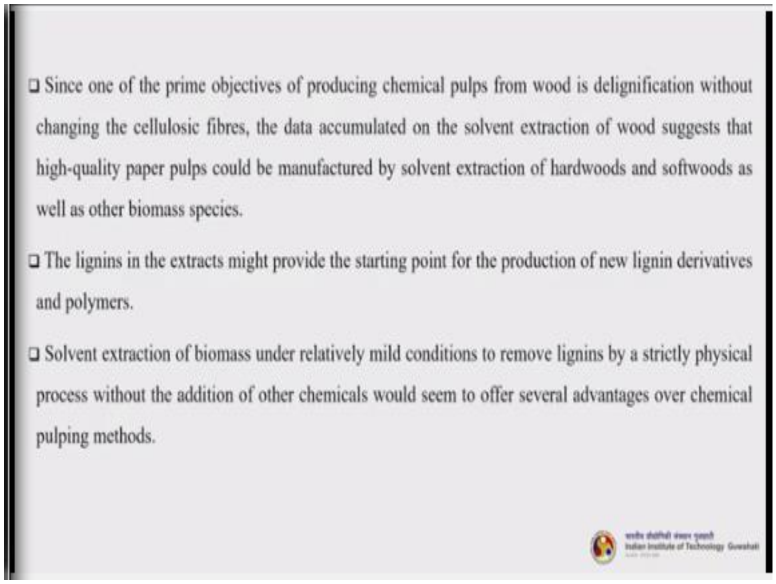

Since one of the prime objective of producing chemical pulps from wood is delignification, without changing the cellulosic fibres the data accumulated on the solvent extraction of wood suggests that high quality paper pulps could be manufactured by solvent extraction of hardwoods and softwoods as well as other biomass species. The lignins in the extracts might provide the starting point for the production of new lignin derivatives and polymers. As you have understood that lignin is a by-product and having high commercial value. Solvent extraction of biomass under relatively mild conditions to remove lignins by a strictly physical process without the addition of other chemicals would seem to offer several advantages of a chemical pulping methods.

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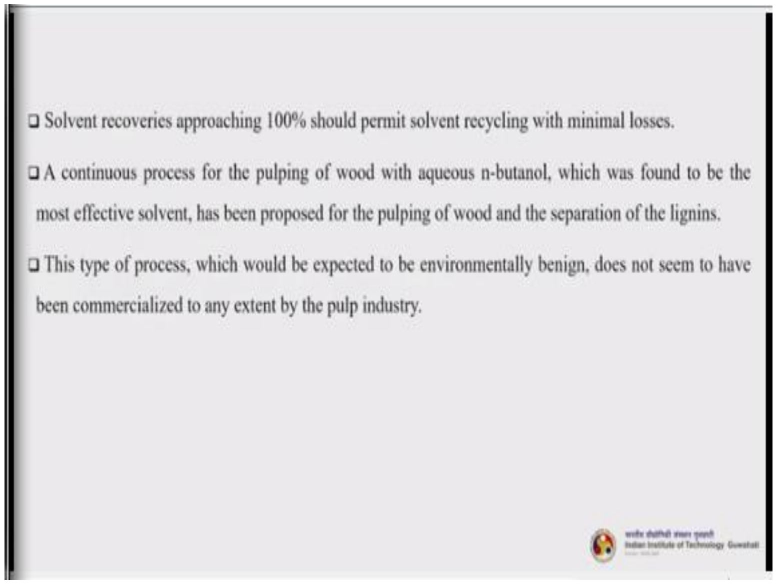

Solvent recoveries approaching 100% should permit solvent recycling with minimal losses. A continuous process for the pulping of wood with aqueous n-butanol which was found to be the most effective solvent has been proposed for the pulping of wood and the separation of lignins. So, this type of process which would be expected to be environmentally benign, does not seem to have been commercialized to any extent by the pulp industry.

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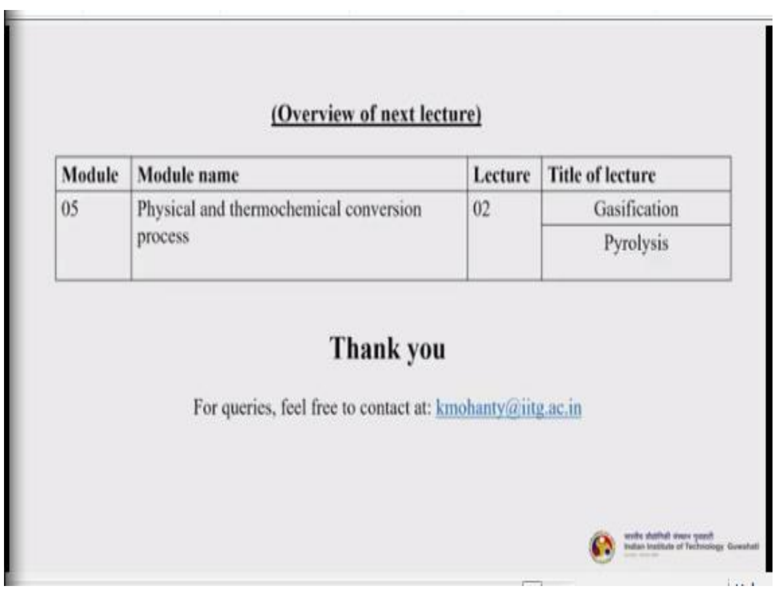

So, with this I windup today, so today we have discussed about the physical conversion of the biomasses and tried to learn how this happens basically. In the next class we will be discussing about the gasification and pyrolysis process, the fundamentals and how gasification and pyrolysis actually can be conducted. So, thank you very much, in case you have any query please submit it in the swayam portal or drop a mail to me at kmohanty@iitg.ac.in.