Biomass Conversion and Biorefinery
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Module-02
Lecture-04
Biomass Conversion and Biorefinery

Good morning students. This is lecture 2 of module 2.

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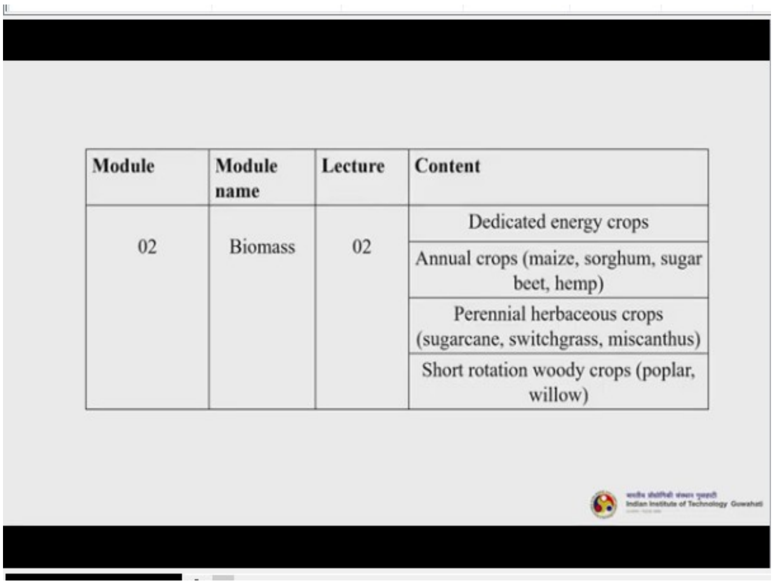

Module	Module name	Lecture	Content
02	Biomass	02	Dedicated energy crops
			Annual crops (maize, sorghum, sugar beet, hemp)
			Perennial herbaceous crops (sugarcane, switchgrass, miscanthus)
			Short rotation woody crops (poplar, willow)

And in today's lecture we will be discussing about dedicated energy crops, including some of the annual crops like maize, sorghum, sugar, beet, hemp, etc. And then perennial herbaceous crops like sugarcane, switchgrass, miscanthus and short rotation woody crops, like poplar, willow, etc. Basically how they can be grown for bioenergy purposes and what is their potential, the land availability, the energy content, all these things we will discuss.

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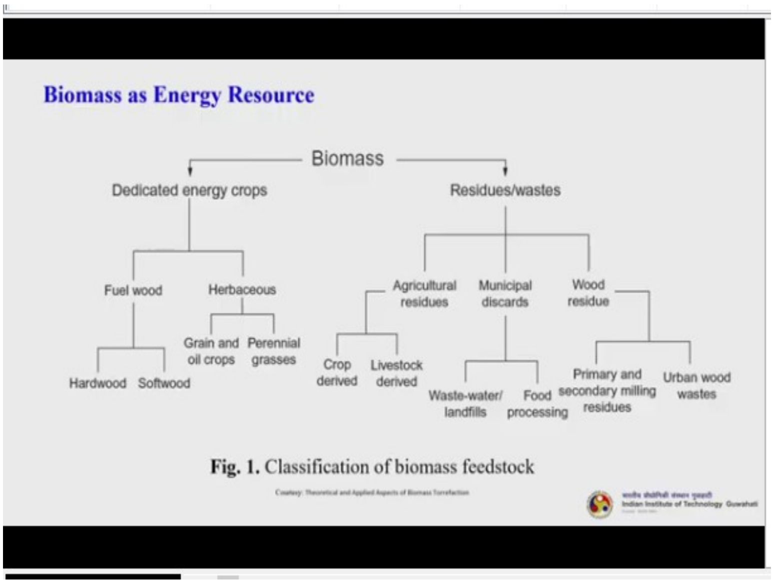

So, let us see this particular slide. You can see that biomass have been basically categorized into two groups; Dedicated energy crops and Residues/Wastes. So, under dedicated energy crops, we have the fuel wood which is basically hardwood and softwood (different traditional fuel woods) and then herbaceous. So, there (under herbaceous) we have grain and oil crops, and perennial grasses.

So, under residue and wastes (this we have discussed in one of our classes, this is a very large scale quantity) we have agricultural residues, we have municipal discards, we have wood residues. So a crop & livestock derived (under agricultural residues), wastewater/landfill and food processing waste (under municipal discards), then urban wood waste (and primary and secondary milling residues) (under wood residue category). So, we will discuss a few of these.

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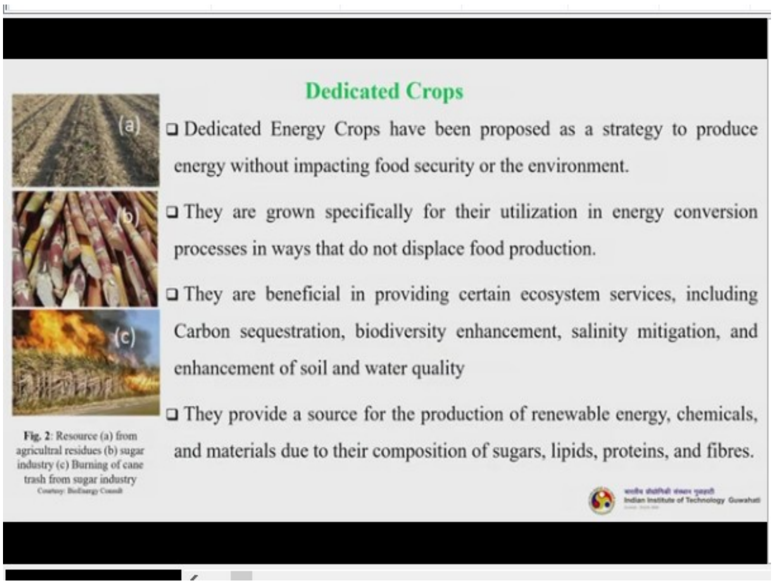

So, coming to the dedicated crops. Dedicated energy crops have been proposed as a strategy to produce energy without impacting food security or the environment. As I told you in one of the classes, one of the aims of the biofuel production is to depend on such crops or waste materials which will not interfere, the food versus feed problem. So, it should be outside of the food chain. Otherwise in a country like India, having huge population and huge food demand, we are not supposed to use sugarcane directly, or let us say beet roots (sugar beet), sorghum, corn for the bio ethanol or biofuel production. We cannot afford to do that, whereas the same is being done in some of the developed Western countries.

So, they are grown specifically for their utilization in energy conversion processes in ways that do not displace food production. So, they are beneficial in providing certain ecosystem services, including carbon sequestration, biodiversity enhancement, salinity mitigation, and enhancement of soil and water quality. So, they provide a source for the production of renewable energy, chemicals and materials due to their composition of sugars, lipids, proteins and fibers.

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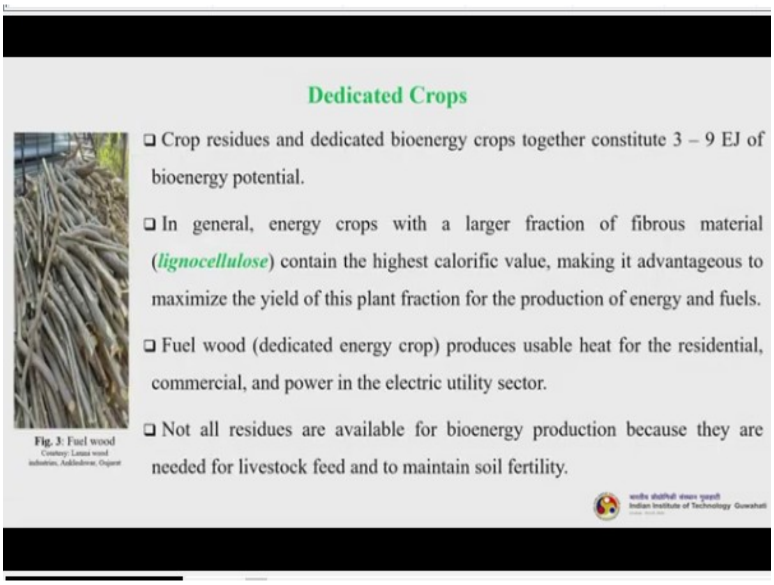

So, crop residues and dedicated bioenergy crops together constitute 3 to 9 Exajoule of the bioenergy potential. In general, energy crops with a larger fraction of fibrous material (the lignocellulosic part) contain the highest calorific value making it advantageous to maximize the yield of this plant fraction for the production of energy and fuels.

That is why I already mentioned in our previous lecture, that currently lignocellulosic biomass are being utilized for the biofuel or bioenergy production, because of the huge energy content in them. So, fuel wood (dedicated energy crop) produces usable heat for the residential, commercial and power in the electric utility sector. Not all residues are available for bioenergy production because they are needed for livestock feed and to maintain soil fertility. So, everything cannot be converted to biofuels.

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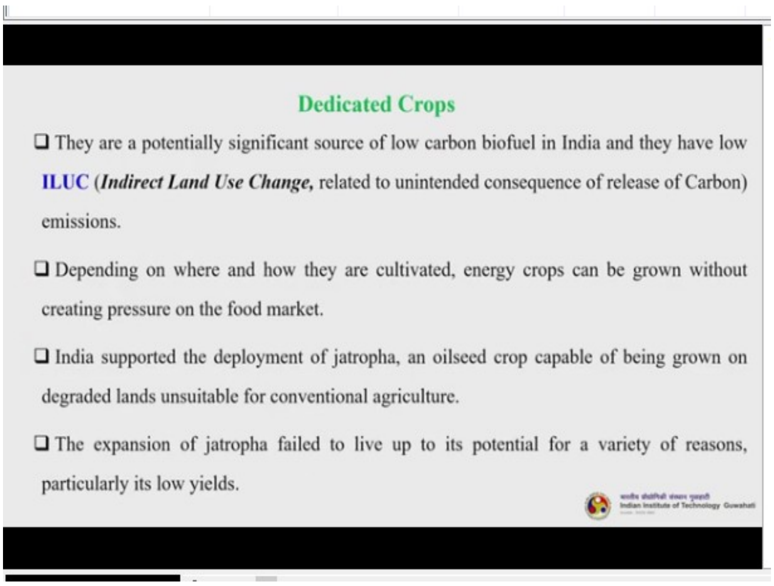

So, they (dedicated crops) are a potentially significant source of low carbon biofuel in India. And they have low ILUC (which is called indirect land use change, basically related to unintended consequence of release of carbon) emissions. So, depending on where and how they are cultivated, energy crops can be grown without creating pressure on the food market. India supported the deployment of Jatropha, an oilseed crop, capable of being grown on degraded lands unsuitable for conventional agriculture. The expansion of Jatropha failed to live up to its potential for a variety of reasons, particularly its low yields.

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So, I will show you this Jatropha cycle. You see these are the seeds, then they are being made to seedlings. Then it is planted that is a (to grow into a) mature plant; then you can see plant bearing fruits; then fruit getting dried up or ripened, and then you collect the seeds. Now from the seed we get Jatropha oil, which is being converted to biodiesel. Now please understand that why the Jatropha failed; it is because of this life cycle.

When you start with this seed and seedling, you plant it and you keep waiting for years together for the Jatropha to bear fruits and ripen; then you will harvest. This is one of the things – it is a huge time that you need to spend or you need to wait, before you get these Jatropha seeds. And then, as I already mentioned in the previous slide, the low oil yield is one of the major reasons why Jatropha has failed. Now nobody's talking about Jatropha anymore.

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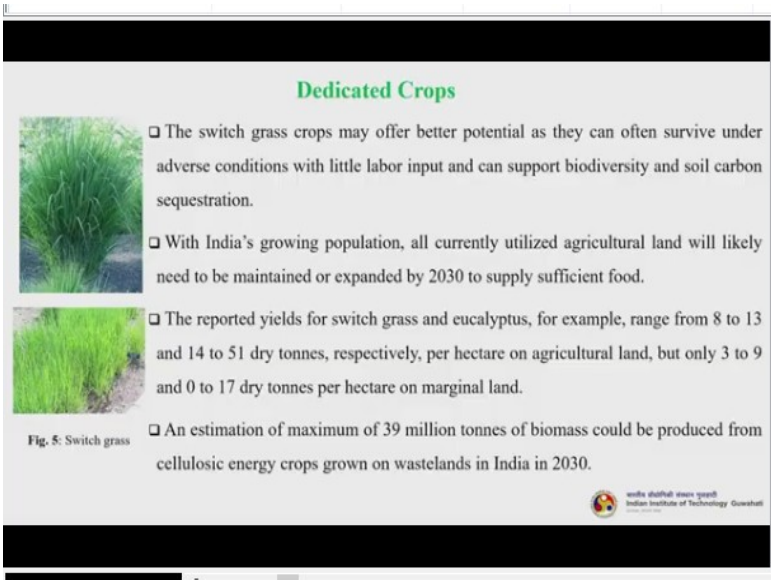

So, the switch grass is another one (which) may offer better potential as they can often survive under adverse conditions with little labor input and can support biodiversity and soil carbon sequestration. With India's growing population, all currently utilized agricultural land will likely need to be maintained or expanded by 2030 to supply sufficient food. That means in a nutshell, we can understand that, India is no more in a position to provide its prime land or the agricultural land for such bioenergy dedicated crops.

So, the need is to look for lands which are not cultivable. The reported yields for switch grass and Eucalyptus, for example, range from 8 to 13 and 14 to 51 dry tonnes, respectively, per hectare on agricultural land, but only 3 to 9 and 0 to 17 dry tonnes per hectare on marginal land. Of course, in agricultural land the production will be very high, but the aim is not to use the agricultural land, because that will be utilized for growing the crops. So, an estimation of maximum of 39 million tonnes of biomass could be produced from cellulosic energy crops grown on wastelands in India in 2030. This is a projection.

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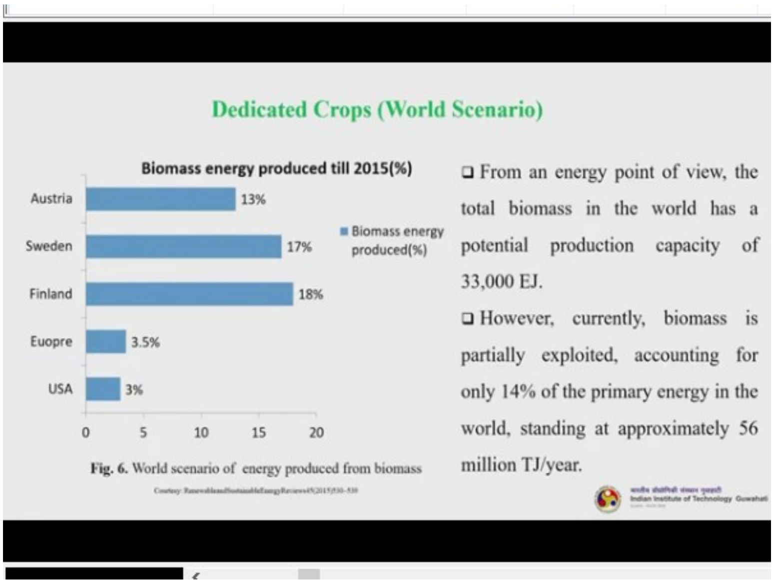

So, if you see the biomass energy produced till 2015 percentagewise, you will see that Finland, followed by Sweden, Austria is there, then Europe then United States. So, in the Asian countries actually it is very less. From an energy point of view that total biomass in the world has a potential production capacity of 33,000 Exajoule. However, currently, biomass is partially exploited, accounting for only 14% of the primary energy in the world, standing at approximately 56 million Terra joule per year.

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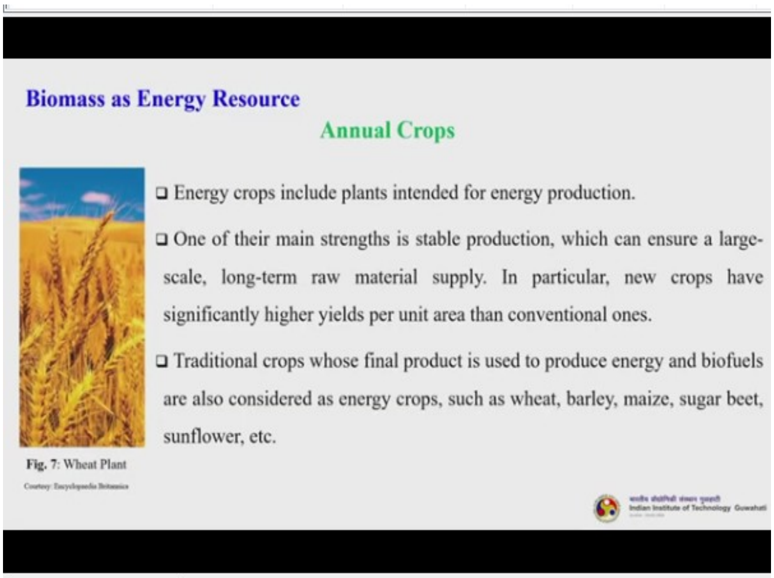

Now we will discuss about the annual crops. Energy crops include plants intended for energy production. One of their main strengths is stable production, which can ensure a large scale long term raw material supply. In particular, new crops have significantly higher yields per unit area than conventional ones. Now traditional crops whose final product is used to produce energy and biofuels are also considered as energy crops such as wheat, barley, maize, sugar beet, sunflower, etc.

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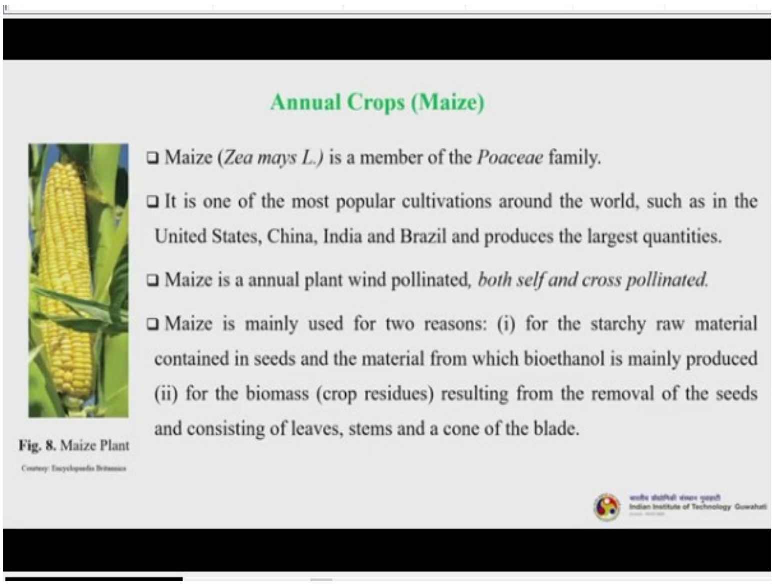

Let us understand maize. So, maize is a member of the *Poaceae* family. It is one of the most popular cultivations around the world, such as in the United States, China, India and Brazil and these 4 countries produces the largest quantities. Maize is the annual plant, wind pollinated, both self and cross pollinated. Maize is mainly used for two reasons: (i) for the starchy raw material content in the seeds and the material from which bio ethanol is mainly produced; (ii) for the biomass (the crop residues) resulting from the removal of the seeds and consisting of leaf, stems and cone of the blade.

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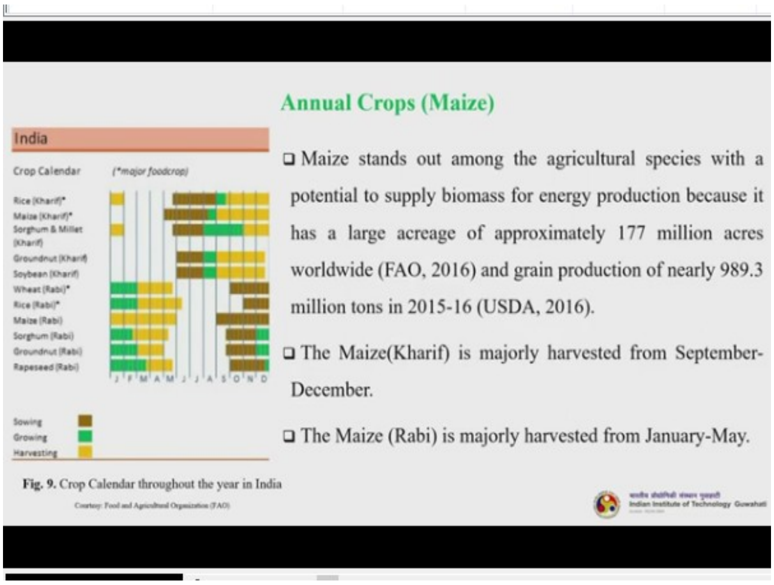

Maize stands out among the agricultural species with the potential to supply biomass for energy production because it has a large acreage of approximately 177 million acres worldwide and grain production of nearly 989.3 million tons in 2015 and 16. Now the maize is a kharif crop and is majorly harvested from September to December. The maize Rabi is majorly harvested in January and May.

So, in India we do twice and in other places also. So, here you can see in the left side is the crop calendar. This is about India and in which month it is being actually planted and harvested. So, it gives an idea about that. So, it is sowing, growing and harvesting, three things, three phases are being shown here.

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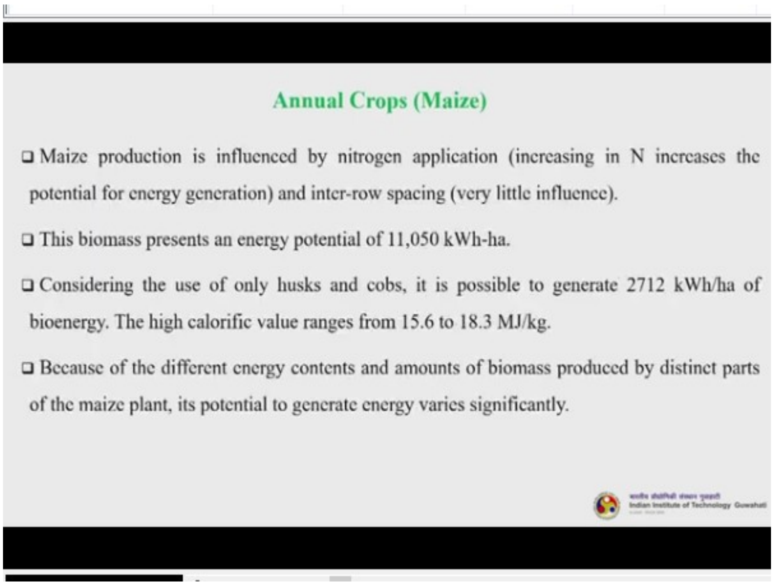

So, maize production is influenced by nitrogen application (increasing in nitrogen increases the potential for energy generation) and inter-row spacing (very little influence). So, this biomass presents an energy potential of 11,050 kilowatt hour per hectare. So, considering the use of only husks and cobs it is possible to generate 2712 kilowatt hour per hectare bioenergy. The high calorific value ranges from 15.6 to 18.3 mega joule per kg. Because of the different energy contents and amounts of biomass produced by distinct parts of the maize plant its potential to generate energy varies significantly.

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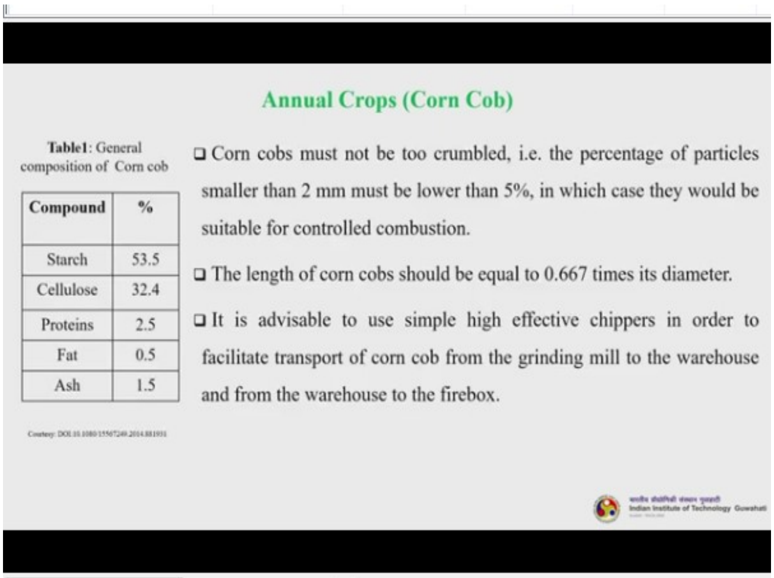

Then corn cobs. So, corn cobs must not be too crumbled, that is, the percentage of particles smaller than 2 mm must be lower than 5% in which case they would be suitable for controlled combustion. The length of corncob should be equal to 0.667 times its diameter. It is advisable to use simple high effective chippers in order to facilitate transport of corncob from the grinding mill to the warehouse and from the warehouse to the firebox.

You can see here; the general composition of the corn cob given in table 1; starch, cellulose, proteins, fat and ash. You can see the starch is the highest followed by cellulose. So, this cellulose can be basically exploited for bioenergy purposes.

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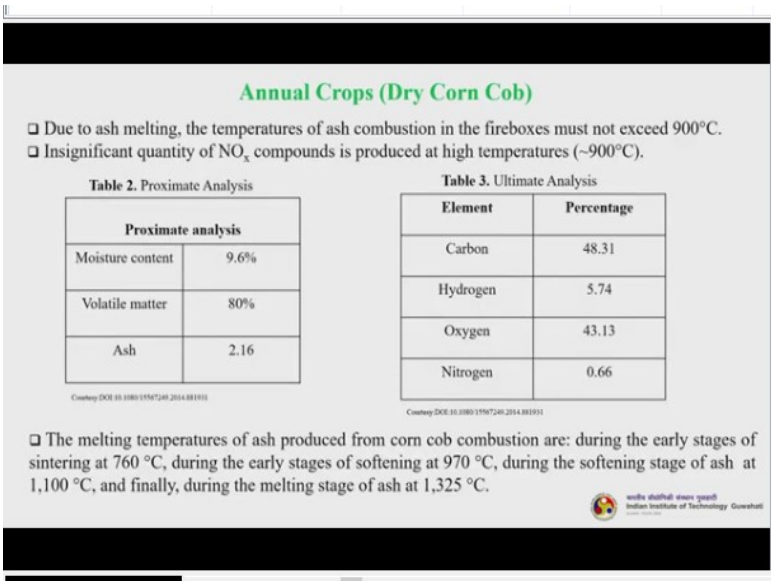

Then dry corn cob. So, due to ash melting, the temperatures of ash combustion in the fireboxes must not exceed 900 degrees centigrade. Insignificant quantity of NO_X compounds is produced at high temperatures. You can see the proximate and ultimate analysis. So, the moisture content is around 9.6%, the volatile matter is 80% and remaining is ash 2.16. And in the element analysis you can see the carbon content is very high; it is almost close to 50%.

Now, the melting temperatures of ash produced from corncob combustion are: during the early stages of sintering at 760 degrees centigrade, during the early stages of softening at 970 degrees centigrade, during the softening stage of ash at 1100 degrees centigrade, and finally, during the melting stage of ash at 1325 degrees centigrade. So, these parameters, are very important when somebody is going to design a particular bioenergy unit or a system or a process.

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Fig. 10. Corn stalk to lignocellulosic ethanol

Now, let us understand how corn is being converted to ethanol. You can see here. So, the corn stock gets separated into flower, stem, cob and husk and leaf. All these are having excellent bioenergy potential as it is. So, we can combine them and see what is their bioenergy potential (that also can be done). So what you do basically, once you take it out, of course, remove the corn, all other parts will remain. So, then you go for different pretreatment technologies to break the recalcitrant nature of the materials. So, you can go for dilute acid (there are many technologies), dilute acid is very common. And it is less costly, less time consuming also. So, let us assume that we go for dilute acid pretreatment. Then once it is done, solid residues are left. So, then you can go for the enzymatic hydrolysis, then whatever sugar you got, it goes for the fermentation.

So, (next is) ethanol fermentation and you get that lignocellulosic ethanol or bioethanol. Here, in a nutshell, you can understand about the schematic of the ethanol production from the corn stock.

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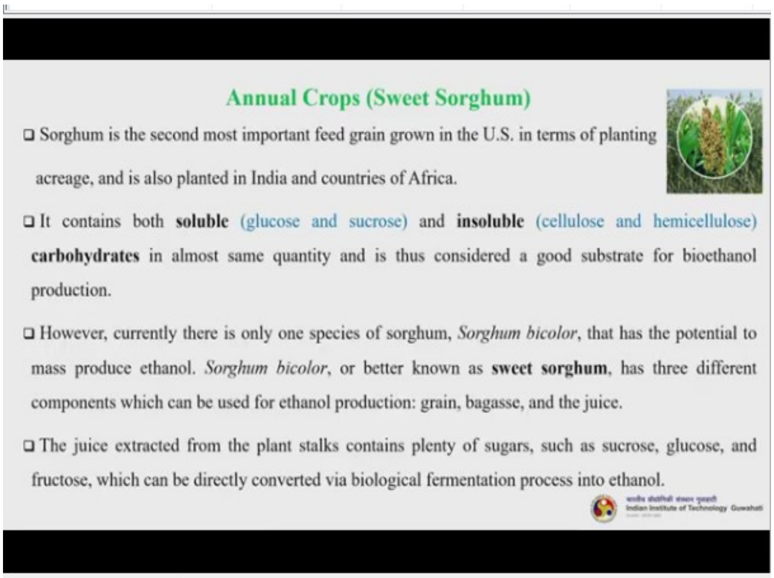

Let us understand about another annual crop which is sweet sorghum. So, sorghum is the second most important feed grain grown in the United States in terms of planting acreage, and is also planted in India and countries of Africa. So, it contains two things, both soluble and insoluble carbohydrate. So, in soluble we have glucose and sucrose and in insoluble we have cellulose and hemicellulose, in almost the same quantity (soluble and insoluble in almost same quantity) and is thus considered a good substrate for bioethanol production. However, currently, there is only one species of sorghum that is called *Sorghum bicolour*, that has the potential to mass produce ethanol. *Sorghum bicolour*, better known as the sweet sorghum, has three different components which can be used for ethanol production, the grain, the bagasse and the juice.

Now the juice extracted from plant stalks contains plenty of sugar such as sucrose, glucose and fructose, which can be directly converted via biological fermentation process into ethanol.

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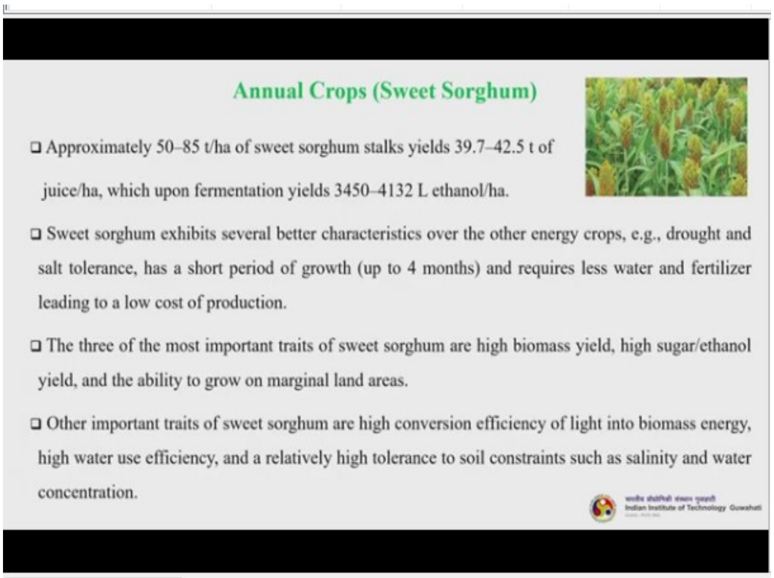

So, approximately 50 to 85 tons per hectare of sweet sorghum stalks yields 39.7 to 42.5 ton of juice per hectare, which upon fermentation yield 3450 to 4132 litres of ethanol per hectare. Please note that it is a very good yield. And sweet sorghum exhibits several better characteristics over the other energy crops. For example, drought and salt tolerance, has a short period of growth (almost within 4 months you can take it out) and requires less water and fertilizer leading to a low cost of production.

So, these are all very interesting features when we are thinking of growing sweet sorghum with an aim for bio energy potential or bioenergy purposes. Now the three of the most important traits of sweet sorghum are high biomass yield, high sugar to ethanol yield and the ability to grow on marginal land areas. Other important traits of sweet sorghum are high conversion efficiency of light into biomass energy, high water use efficiency and a relatively high tolerance to soil constraints, such as salinity and water concentration.

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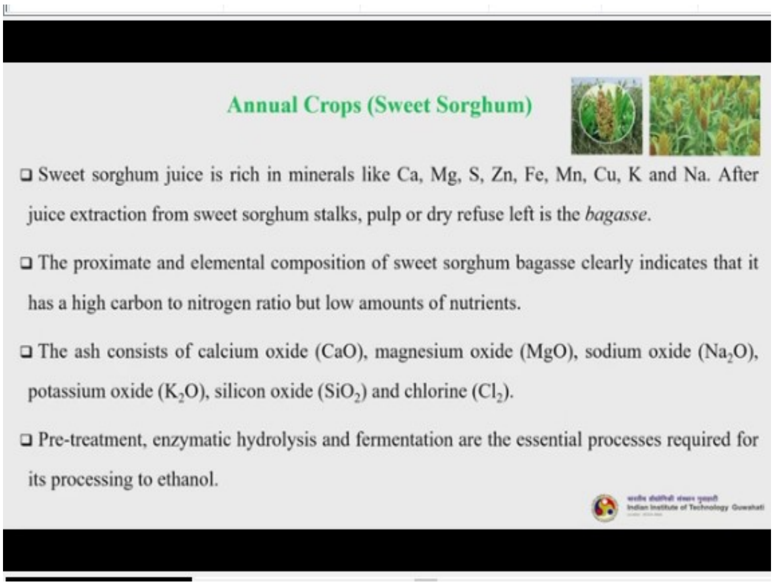

Sweet sorghum juice is rich in minerals, like calcium, magnesium, zinc, iron etc. After juice extraction from sweet sorghum stalks, pulp or dry refuse left is the bagasse; and that has also enormous potential towards bioenergy or biofuel production. So, the proximate and elemental composition of sweet sorghum bagasse clearly indicates that it has a high carbon to nitrogen ratio, but low amounts of nutrients.

Now, the ash consists of calcium oxide, magnesium oxide, sodium oxide, potassium oxide, silicon oxide as well as traces of chlorine. Pretreatment, enzymatic hydrolysis and fermentation are the essential processes (required for its) processing to ethanol.

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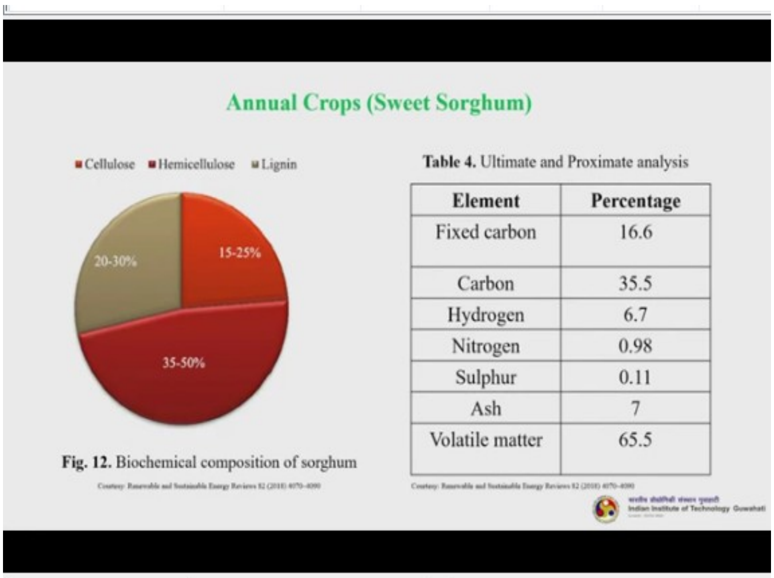

So, you can see the composition. Basically, this is the biochemical composition of the sorghum. You can see 35 to 50% is cellulose, 15 to 25% is hemicellulose and then rest is lignin. So, here the ultimate and proximate analysis is given. Fixed carbon is 16.6%, carbon is 35.5%, hydrogen, nitrogen sulfur ash is very less and volatile matter is 65.5% (huge volatile matter content basically).

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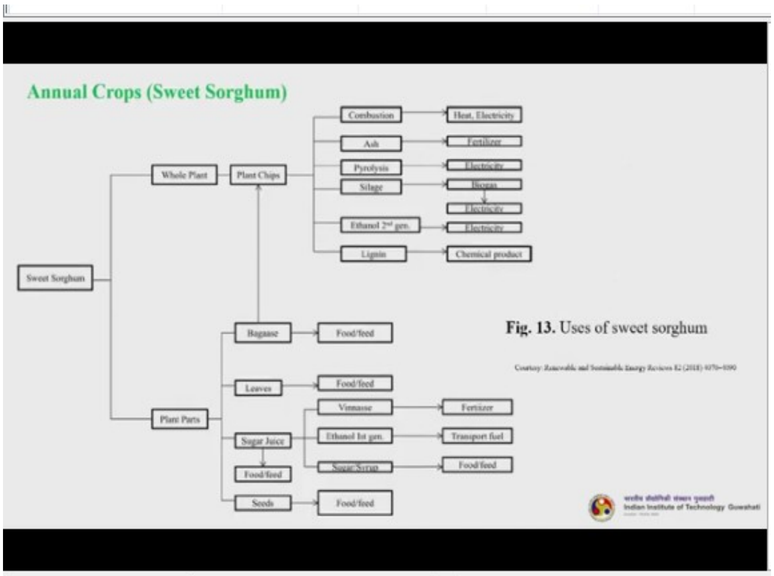

So, this scheme will make you understand, how sweet sorghum can be made into various value added products. So, if you look about the whole plant, and then here is the plant parts; if you look at the whole plant → make into chips; then you go for combustion, and then you get ash for fertilizer, then you go for the pyrolysis (another thermochemical conversion process), silage, ethanol second generation, lignin.

So, you get so many different types of products. It can be converted further into electricity and fertilizer, some platform chemicals also. Then bagasse, leaves, sugar juice (of course, it will go to the food and feed purposes), then the seeds will be there (that also goes for food and feed purposes), other than that parts of juice, leaves will be converted to fertilizer and transport fuel. So, this will make us understand about the different uses of the sweet sorghum. And you can see that apart from other uses, it has enormous energy potential or bioenergy potential.

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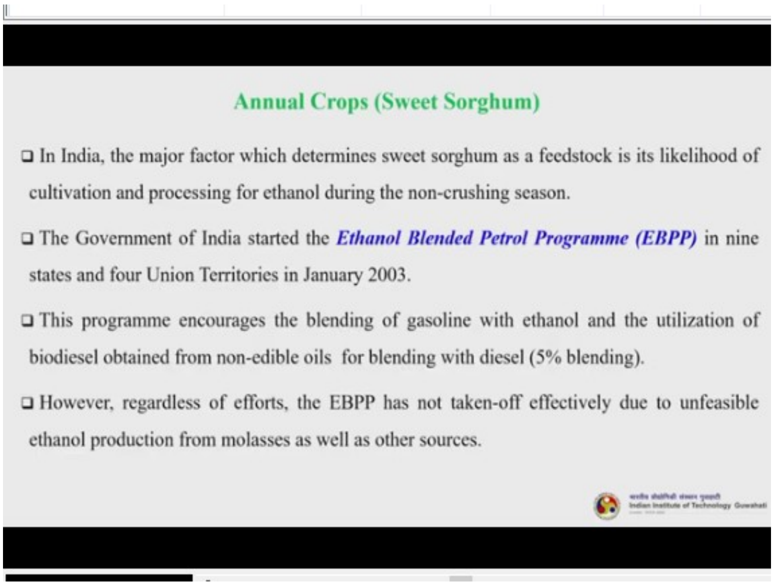

So, in India, the major factor which determines sweet sorghum as a feedstock is its likelihood of cultivation and processing for ethanol during the non-crushing season. The Government of India has started the Ethanol Blended Petrol Program (EBPP) in 9 states and 4 union territories in January 2003. Now, this program encourages the blending of gasoline with ethanol and the utilization of biodiesel obtained from non edible oils for blending with diesel (5% blending).

Now, however, regardless of efforts, the EBPP has not taken off effectively due to unfeasible ethanol production from molasses as well as other sources. So, though the government is mandating that we should have almost 10% ethanol blending, however, it is not happening due to inadequate supply, because we do not have such plants as it is. And I am happy to tell you that Numaligarh refinery Ltd. located in Numaligarh, Assam (Indian Oil Corporation), is basically establishing a state-of-the-art bioethanol plant. So, within 2 years, the production will start, it is under the process now.

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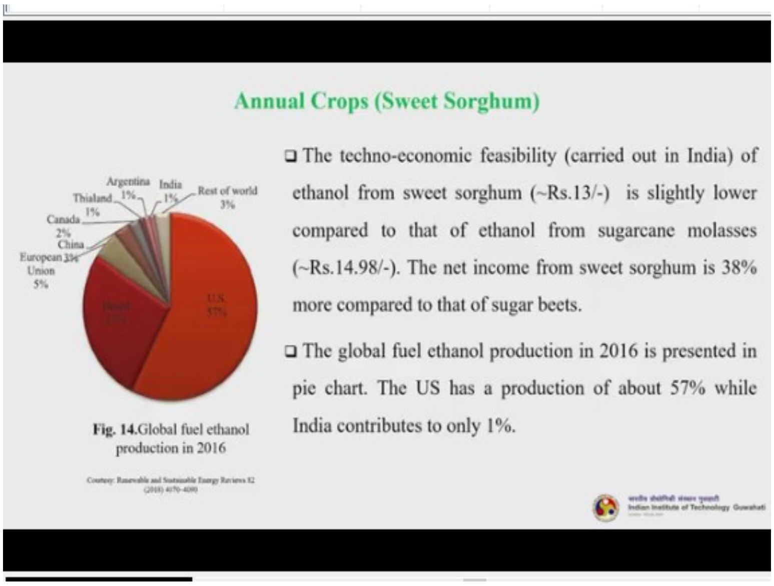

So, the techno economic feasibility (carried out in India) of ethanol from sweet sorghum is slightly lower compared to that of ethanol (from sugarcane molasses). So, sweet sorghum is around 13 rupees, sugar cane molasses is close to 15 rupees. So, the net income from sweet sorghum is 38% more compared to that of the sugar beets. Now, the global fuel ethanol production in 2016 is presented in this pie chart. You can see that United States is the huge amount (has a production of about) 57% and India is contributing only 1%. But please note that, India is working on this particular crop and soon within three to four years or maybe down 5 years, we will most likely double our bioethanol capacity or production capacity.

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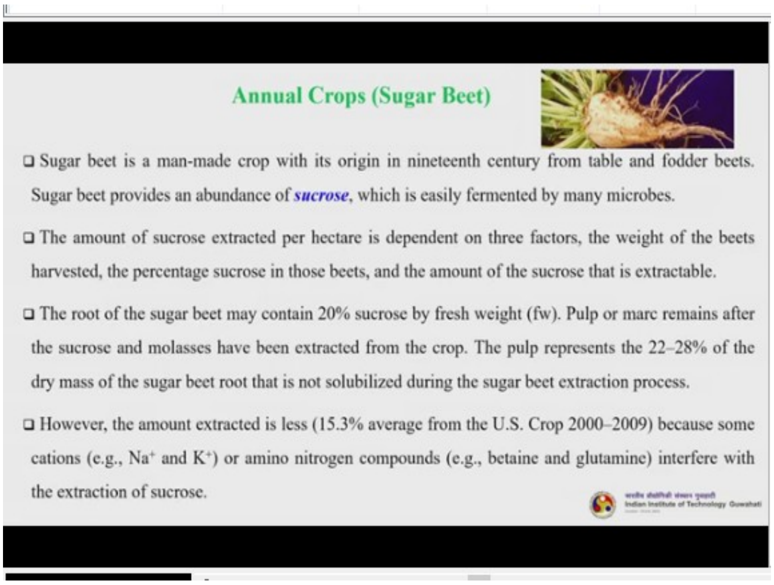

So, now understand about the sugar beet as a bioenergy crop. Now sugar beet is a man made crop with its origin in the 19th century from table and fodder beets. Sugar beet provides an abundance of sucrose which is easily fermented by many microbes. The amount of sucrose extracted per hectare is dependent on three factors. The weight of the beets harvested, the percentage sucrose in these beets, and the amount of sucrose that is extractable.

The root of the sugar beet may contain almost 20% sucrose by fresh weight. Pulp or marc remains after the sucrose and molasses have been extracted from the crop. The pulp represents the 22 to 28% of the dry mass of the sugar beet root that is not solubilized during the sugar beet extraction process. However, the amount extracted is less (if you compare that is almost 15.3% average from the United States crop data) because some cations like sodium and potassium or some amino nitrogen compounds like betaine and glutamine, interfere with the extraction of the sucrose. So, thereby making the sucrose extraction a bit complicated.

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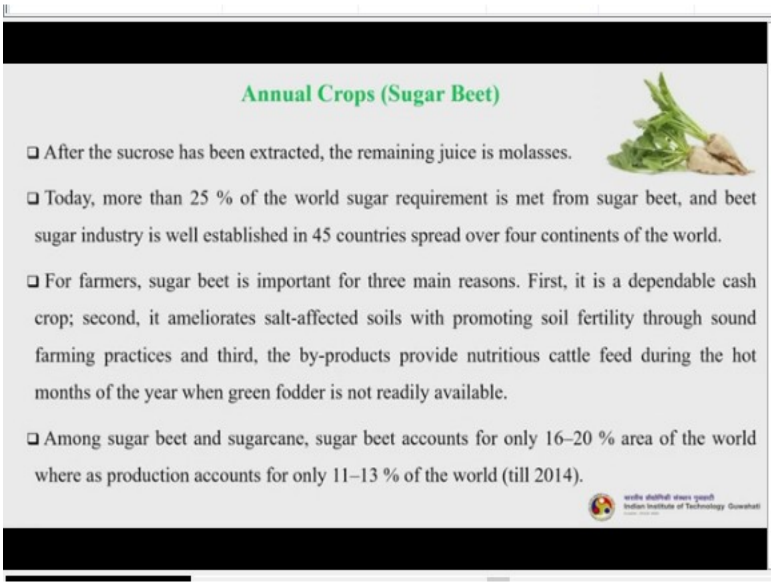

So, after the sucrose has been extracted, the remaining juice is the molasses. Today, more than 25% of the world's sugar requirement is made from sugar beet and beet sugar industry is now well established in 45 countries spread over 4 continents of the world. For farmers, sugar beet is important for three main reasons. First, it is a dependable cash crop. Second, it ameliorates salt affected soils with promoting soil fertility through sound farming practices.

And third, the by-products provide nutritious cattle feed during the hot months of the year, when green fodder is not readily available. So, this is a win, win situation for the farmers basically. So, among sugar beet and sugar cane sugar beet accounts for only 16 to 20% area of the world, whereas production accounts for only 11 to 13% of the world. This is a 2014 data.

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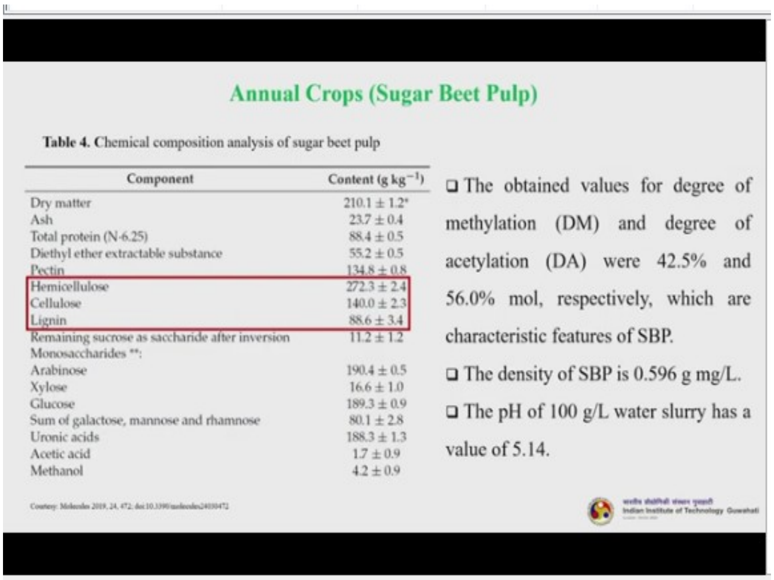

You can see this table 4, the chemical composition analysis of the sugar beet pulp. You can see that the lignocellulosic part, that is basically hemicellulose, cellulose and lignin; they are the highest. And when you go for sugar analysis you will see that glucose is the highest and followed by arabinose and xylose and very minor quantity of galactose, mannose and rhamnose.

So, the obtained values for the degree of methylation and degree of acetylation were 42.5% and 56% respectively, which are characteristics features of the SBP (that sugar beet pulp). The density of the sugar beet pulp is 0.596 grams per liter and the pH of 100 grams per liter water slurry has a value of 5.14.

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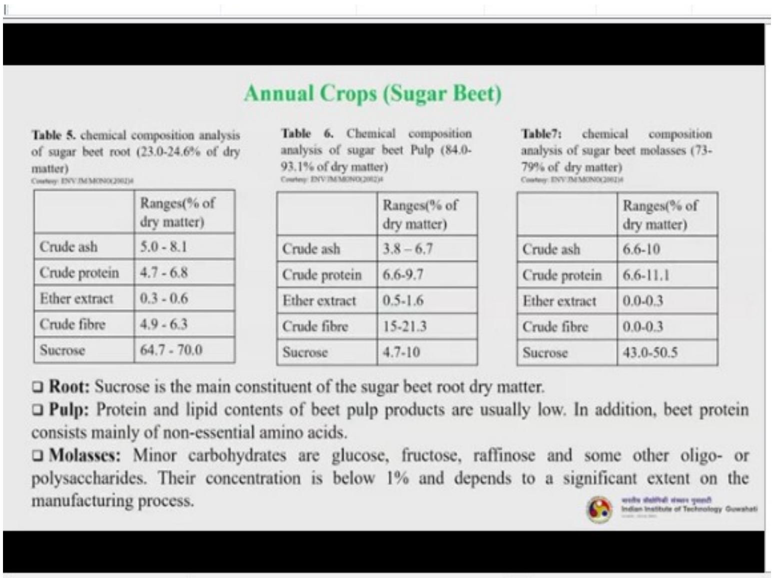

So, we can further discuss little about this chemical composition analysis. The first one, table 5, tells you the chemical composition analysis of sugar beet root (dry matter basically). Then table 6 will give you the same for sugar beet pulp and table 7 will give you that of the sugar beet molasses. So, you can see the ash, protein, ether extracts, crude fiber and sucrose content. You can see that the root is having the highest sucrose content, almost close to 70%.

So, sucrose is the main constituent of the sugar beet root dry matter. Protein and lipid contents of beet pulp products are usually low. In addition, beet protein contains mainly non essential amino acids. So, then minor carbohydrates are glucose, fructose, raffinose and some other oligo or polysaccharides, their concentration is below 1% and it depends to a significant extent on the manufacturing process.

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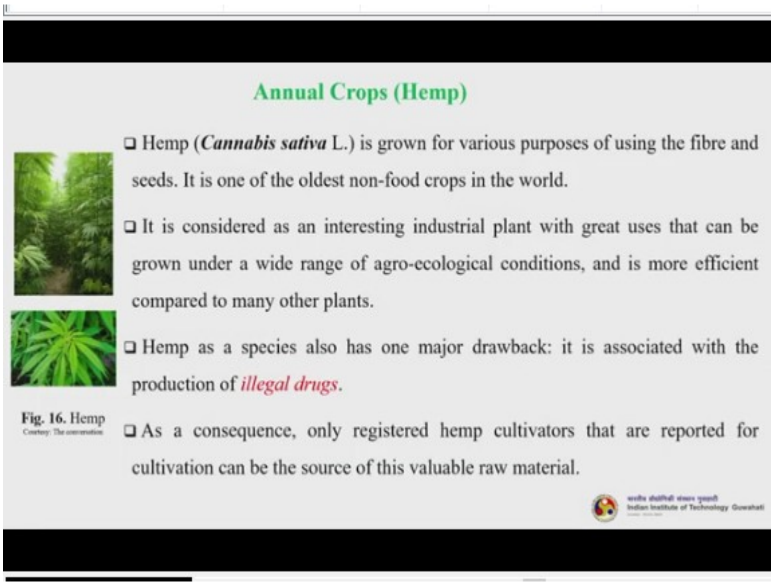

And now let us understand another annual crop which is known as hemp. Hemp is *Cannabis sativa*. So, there are many other species also. It is grown for various purposes of using the fibre and seeds. It is one of the oldest non food crops in the world. Now, it is considered as an interesting industrial plant with great uses that can be grown under a wide range of agro ecological conditions and is more efficient compared to many other plants.

Hemp as a species also has one major drawback. It is associated with the production of illegal drugs. So, that means you can understand that there is a controlled growing basically. So, as a consequence, only registered hemp cultivators that are reported for the cultivation can be the source of this valuable raw material.

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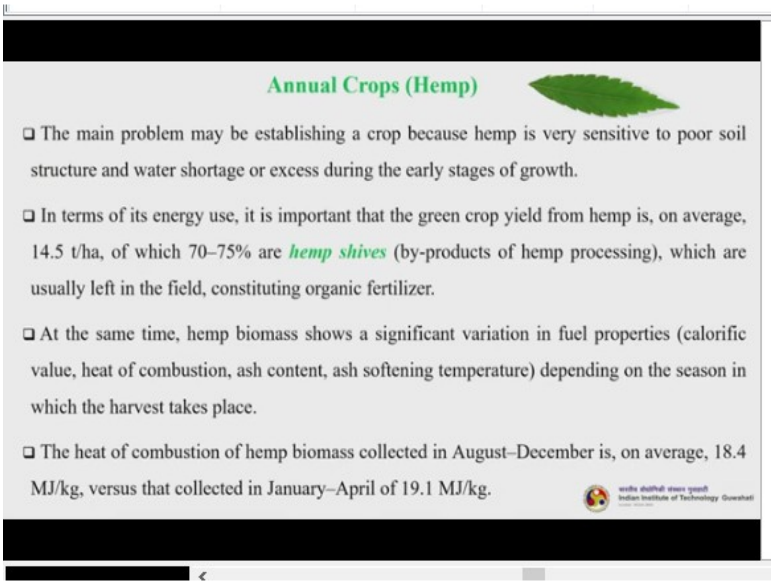

So, the main problem may be establishing a crop, because hemp is very sensitive to poor soil structure and water shortage or excess during the early stages of growth. In terms of its energy use, it is important that the green crop yield from hemp is on average 14.5 ton per hectare of which 70 to 75% are hemp shives (the byproduct of the hemp processing), which are usually left in the field constituting organic fertilizer.

Now at the same time, hemp biomass shows a significant variation in fuel properties (calorific value, heat of combustion, ash content, ash softening temperature etc.) depending on the season in which the harvest takes place. The heat of combustion of hemp biomass collected in August - December is on average 18.4 mega joule per kg versus that collected in January, April is 19.1 mega joule per kg. You can say that there is no significant or very huge dip in that, but still there is a difference.

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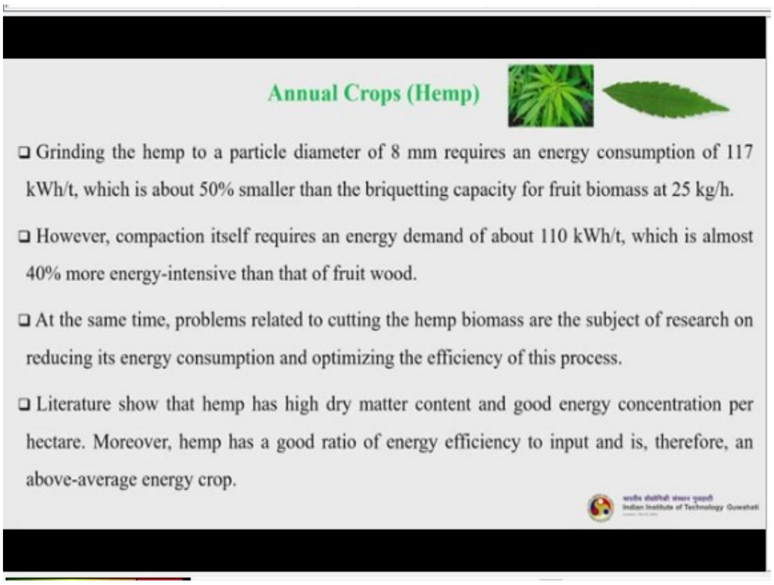

So, grinding the hemp to a particle diameter of 8 mm requires an energy consumption of 117 kilowatt hour per tonne, which is about 50% smaller than the briquetting capacity of fruit biomass at 25 kg per hour. However, compaction itself requires an energy demand of about 110 kilowatt hour per tonne, which is almost 40% more energy intensive than that of the fruit wood.

At the same time problems related to cutting the hemp biomass are the subject of research on reducing its energy consumption and optimizing the efficiency of this process. Literature show that hemp has high dry matter content and good energy concentration per hectare. Moreover, hemp is a good ratio of energy efficiency to input and is therefore an above-average energy crop.

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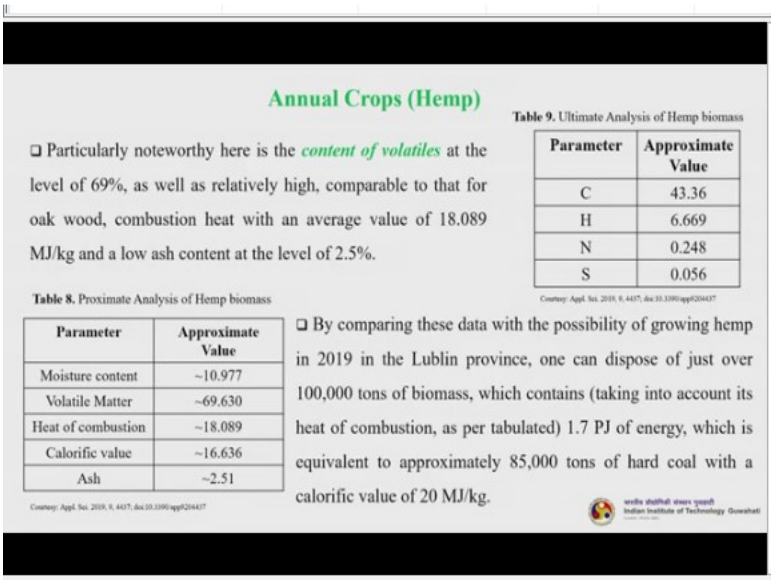

So, particularly noteworthy here is the content of volatiles at the level of 69%. Please have a look at this proximate analysis of hemp biomass, you can see that the highest constituent or component is basically the volatile matter and if you see the ultimate analysis, the carbon is 43.36% followed by hydrogen and then of course nitrogen and sulfur, sulfur is very small quantity.

So, you can see that by comparing this data with the possibility of growing hemp in 2019 in the Lublin province, one can dispose of just over 100,000 tons of biomass which contains (if you take into account its heat of combustion as per the tabulated) 1.7 PJ of energy which is equivalent to approximately 85,000 tons of hard coal with the calorific value of 20 mega joule per kg.

So, having said that the inherent meaning of this table data is saying that hemp is having huge potential for bioenergy production. So, if you compared to even the hard wood also. So, since this is outside, it is a non-food crop, and can be grown at marginal lands with little care, then we can certainly look for such a beautiful crop for a dedicated bioenergy potential or purposes.

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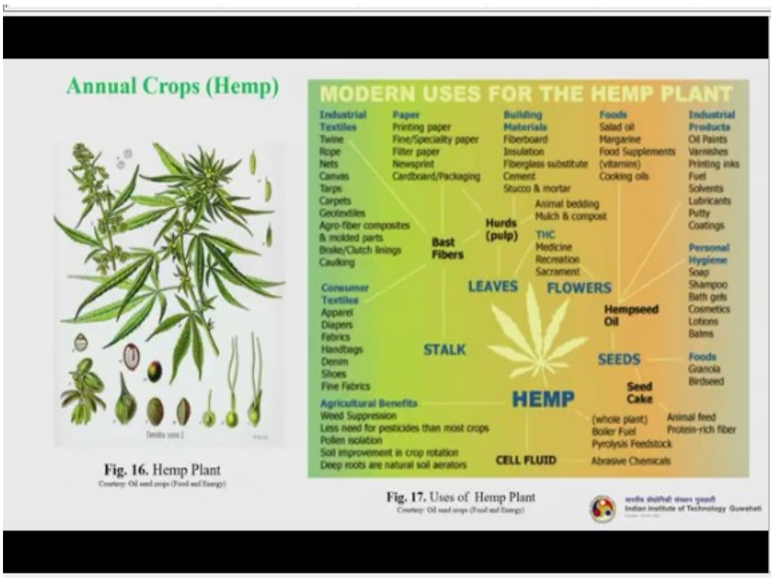

So, you can see this particular slide; it will tell you about the hemp plant basically; these are the various parts and this particular figure or the scheme will tell you what are the different usages of hemp plant. So, you can see that there are industrial textiles and consumer textiles fibers, agricultural benefits are there, then we can make paper, building materials okay THC, all these things from the leafs and the bast fibers, then the hemp seed oil.

So, seed is being used for food purposes, seed cake can go for the animal feed, the oil can go for the personal hygienic products, for industrial products, and even for the foods also. So, it is so much use.

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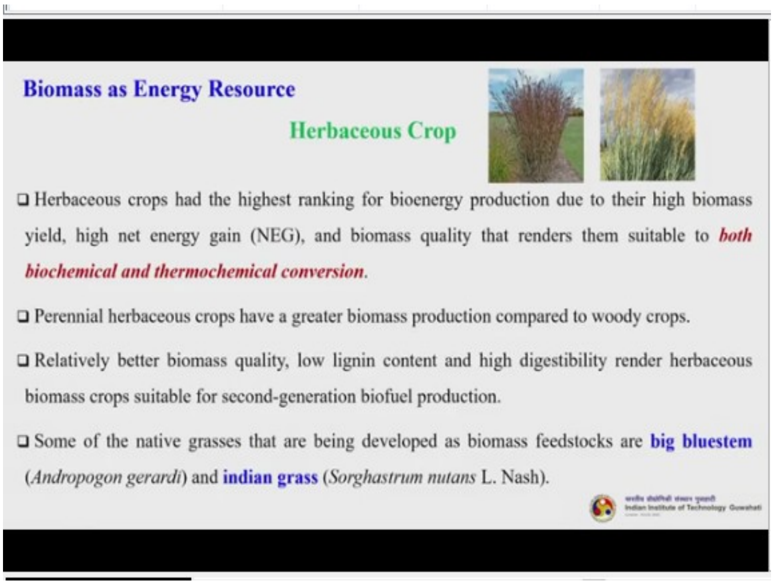

So, now let us understand another crop which is called a herbaceous crop towards this energy potential. So, herbaceous crops have the highest ranking for bioenergy production due to their high biomass yield, high net energy gain and biomass quality that renders them suitable for both biochemical and thermochemical conversion. Now, please understand one more thing, among all these, whatever we were discussing, the different biomasses; biomasses are not suitable for both biochemical and thermochemical conversion.

Some are pretty good for biochemical conversion that means fermentation to get bio alcohols, ethanol or butanol; and some are pretty good for thermo chemical conversion, for using in gasification, pyrolysis etc. However, there are only few noteworthy biomasses which can be used for both the purposes and herbaceous crops are one among them.

Perennial herbaceous crops have a greater biomass production compared to woody crops, relatively better biomass quality, low lignin content and high digestibility render herbaceous biomass crops suitable for second generation biofuel production. Some of the native grasses that are being developed as biomass feedstocks are big bluestem and Indian grass. So, the first one you can see is big bluestem and the second picture is that of the Indian grass.

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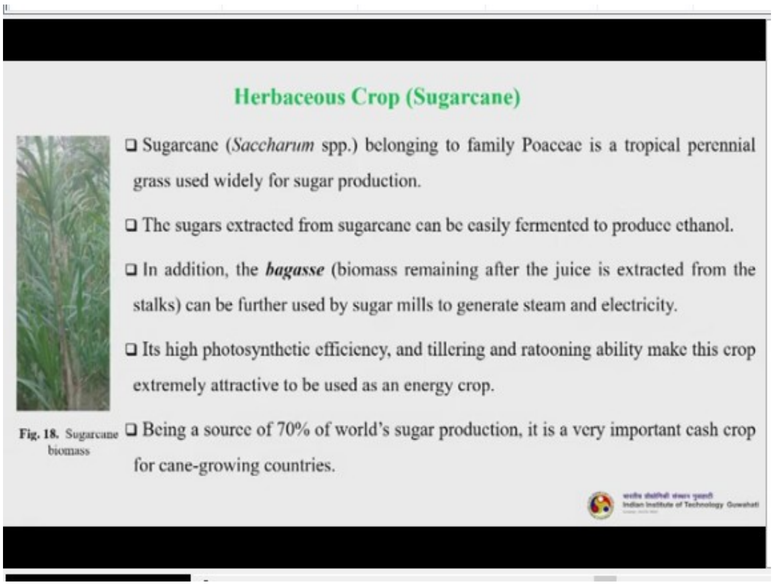

Then let us discuss one of the most important crop in India and apart from India in other countries also, i.e., sugar cane. Now sugar cane belonging to the family Poaceae is a tropical perennial grass widely used for the sugar production. Now, the sugars extracted from sugar cane can be easily fermented to produce ethanol. But having said that, please note that in India we cannot afford to do that. It can be produced that is true, but, in India we are not doing that. So, in addition the bagasse (biomass remaining after the juice is extracted from the stalks) can be further used by sugar mills to generate steam and electricity. In India, what we are doing is we are doing with the bagasse. Now, this bagasse is being traditionally utilized to produce steam. And in the boilers (basically we are burning it in the boilers). And then gasification process to generate steam and of course, feed it to the boiler and you get electricity also. In small scale also this is being implemented in various sugar producing industries. So, its high photosynthetic efficiency and tillering and ratooning ability make this crop extremely attractive to be used as an energy crop. Now being a source of 70% of world's sugar production, it is very important cash crop for cane growing countries.

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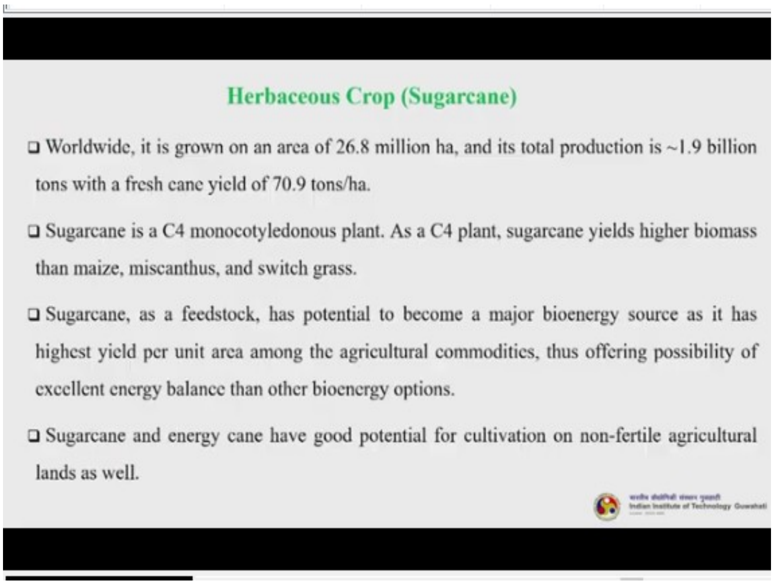

Worldwide it is grown on an area of 26.8 million hectare and its total production is 1.9 billion tons with a fresh cane yield of 70.9 tons per hectare. Sugarcane is a C4 for plant and as a C4 for plant, sugar cane yields higher biomass than maize, miscanthus and switch grass. Sugarcane as a feedstock has potential to become a major bioenergy source, as it has highest yield per unit area among the agricultural commodities, thus offering possibility of excellent energy balance than other bioenergy options.

Sugarcane and energy cane have good potential for cultivation on non fertile agricultural lands as well. Please understand, you may be wondering what is energy cane. Energy cane is nothing but a genetically modified version of the sugarcane and that is modified with an aim to increase its bioenergy potential.

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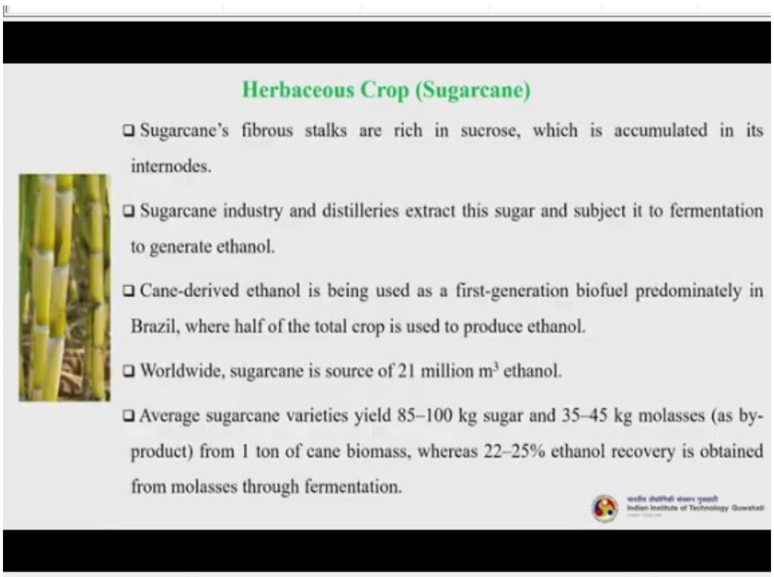

So, sugarcane's fibrous stalks are rich in sucrose, which is accumulated in its internodes. Sugarcane industry and distilleries extract this sugar and subject it to fermentation to generate ethanol. Now, cane derived ethanol is being used as a first generation biofuel predominantly in Brazil where half of the total crop is used to produce ethanol. Now in Brazil, they can afford to do so but that is not possible in India or other developing countries including most of the Asia.

So, worldwide sugarcane is source of 21 million m^3 ethanol. And average sugarcane varieties yield 85 to 100 kg sugar and 35 to 45 kg molasses (that is the byproduct) from 1 ton of cane biomass, whereas, 22 to 25% ethanol recovery is obtained from molasses through fermentation. Again, I am telling you that fermentation of molasses to produce bio-ethanol, we are not going to use the sucrose part to produce bio ethanol.

Though it is being done in Brazil and some of the developed countries, because, for them the availability is huge with respect to their consumption. But in other countries like India and Asian countries, that is not possible. So, we look for basically the bagasse and molasses.

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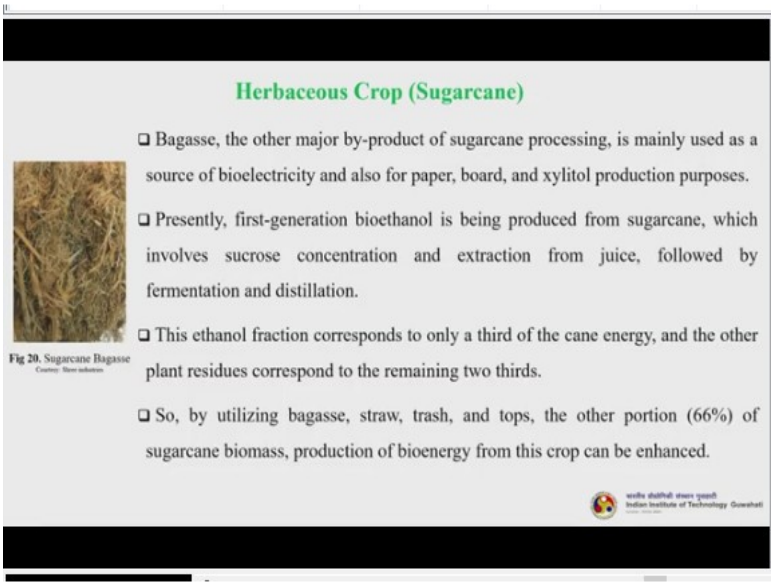

So, bagasse the other major byproduct of the sugarcane processing is mainly used as a source of bioelectricity and also for paper, board and xylitol production purposes. So, xylitol is a very high demand compound or component you can say. So, it's a sugar, which is being used mostly in the chewing gums. So, xylitol will be fermented from xylose, which is one of the sugars present in the bagasse.

So, presently, first generation, bioethanol is being produced from sugarcane, which involves sucrose concentration and extraction from juice, followed by fermentation and distillation. Now, this ethanol fraction corresponds to only a third of the cane energy and the other plant residues corresponding to the remaining two thirds. So, by utilizing bagasse, straw, trash and tops the other portion (that is 66%) of the sugarcane biomass, production of bioenergy from this group can be enhanced.

Having said that, the meaning is literally that: forget about the sucrose part, that will go basically for the production of the sugar; rest everything which is amounting to almost 66%, every part of this, whether it is bagasse, whether it is the top, trash, straw, these all can be converted into bioenergy or biofuels.

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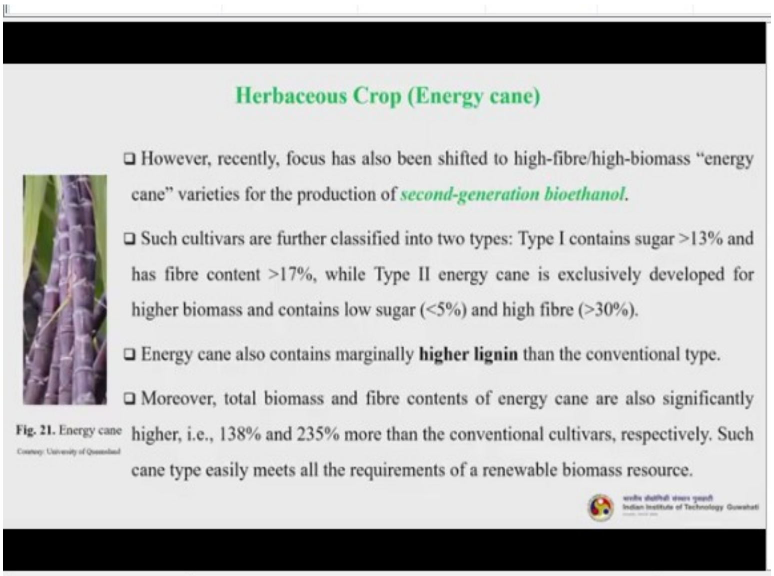

However, recently, focus has also been shifted to "high-fibre/high-biomass" energy cane varieties for the production of second generation bioethanol. These are genetically modified sugarcane which is known as energy cane. Now such cultivars are further classified into two types. So, type one contains sugar greater than 13% and has fiber content of greater than 17%.

Whereas type two energy cane is exclusively developed for higher biomass and contains low sugar and high fiber. Now, please understand that this energy cane, especially the type two, is exclusively grown for bioenergy purposes because the sugar content is very less. So, we can just use that part also as it is, if it is possible, directly to produce ethanol.

So, energy cane also contains marginally higher lignin than the conventional type. The total biomass and fiber contents of energy cane are significantly higher, almost 138% and 235% more than the conventional cultivars. Such cane type easily meets all the requirements of a renewable biomass resource.

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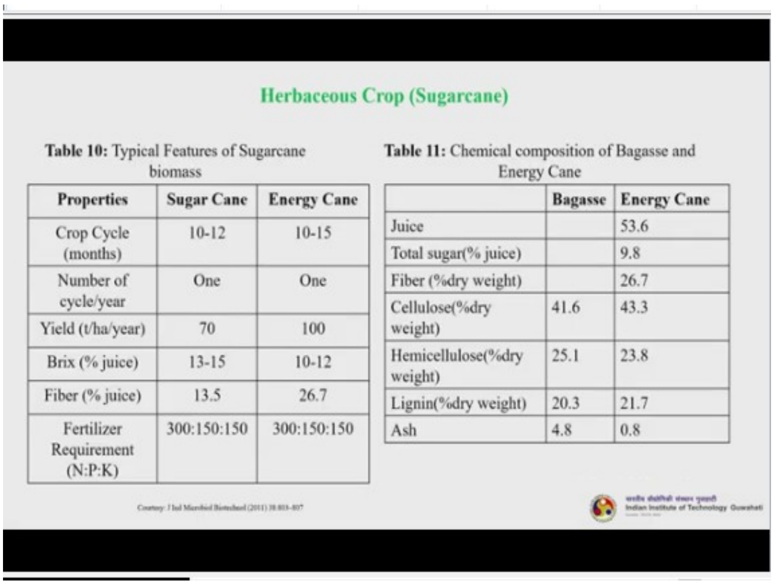

Now, if you look at the typical features of sugarcane biomass, then table 11 will tell you the chemical composition of the biomass and energy cane. So, you can see that basically the total fiber content is almost 26.7 in the energy cane, cellulose is 41.6 and 43.3 in both bagasse and energy cane. So, they are comparatively complementing each other. Lignin by percentage dry weight is also comparable (20.3 and 21.7). And table 10 will give you the typical features of the sugarcane biomass, the properties and the yield, the brix, fibre and fertilizer requirement and NPK basically.

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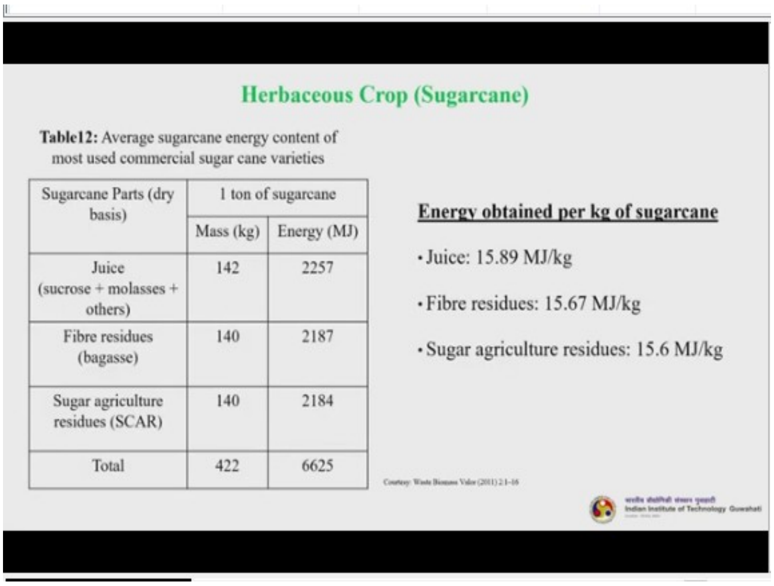

So, table 12 will tell you about the average sugarcane energy content mostly used in commercial sugarcane varieties; the juice, then fiber residues, sugar agricultural residue (which is called a SCAR); and that will tell you about their mass per 1 ton of sugarcane and the corresponding energy value.

It is very interesting; all these values they are all complementing each other. That means, whether it is juice, whether it is fiber residue bagasse or it is SCAR, every component is having huge bioenergy potential. So, you can see that juice is having almost 15.89 mega joule per kg energy obtained from the sugarcane, from fiber residues it is 15.67, from sugar agricultural residues that is SCAR, it is 15.6; all are almost complementing each other.

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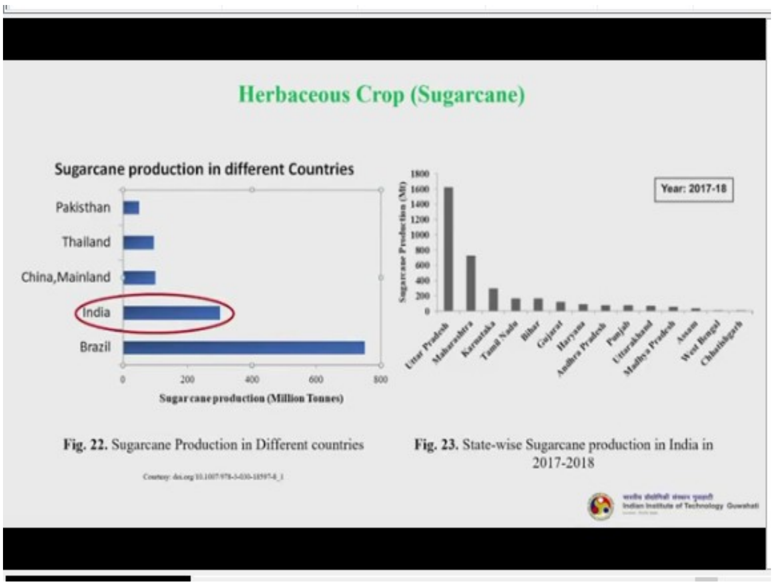

So, here you can see the sugarcane production in different countries. So, you can see that India stands here, India produces huge amount of sugarcane (a little lesser than Brazil). And far more than that of the mainland China and other Asian countries like Thailand and Pakistan.

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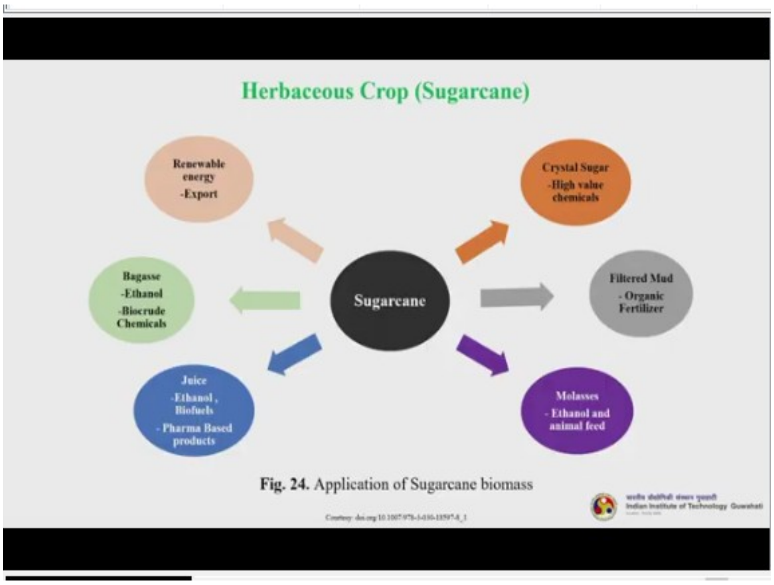

So, these are the application of sugarcane biomass. You go for sugar, then filtered mud (that is organic fertilizer), molasses (that can be converted into ethanol and animal feed), then we have the juice (that can be converted to biofuels, pharma based products), we have bagasse (that can be converted to ethanol), we have other renewable energy.

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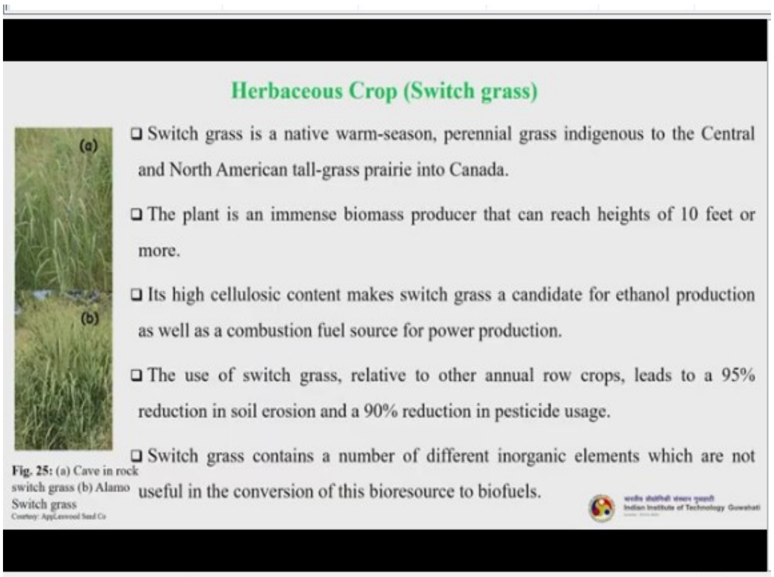

So, let us understand another interesting herbaceous crop, which is called switch grass. Now, switch grass is a native warm season perennial grass indigenous, to the central and North

American tall grass prairie into Canada. So, the plant is an immense biomass producer that can reach heights of 10 feet or more. Its high cellulosic content makes switch grass a candidate for ethanol production as well as, as a combustion fuel source for power production. The use of switch grass relative to other annual row crops leads to a 95% reduction in soil erosion and a 90% reduction in pesticide usage. So, all switch grass contains a number of different inorganic elements, which are not useful in the conversion of this bioresource to biofuels. And please also understand that there are different species of this particular switch grass. There are many different varieties that are grown in India and other countries also.

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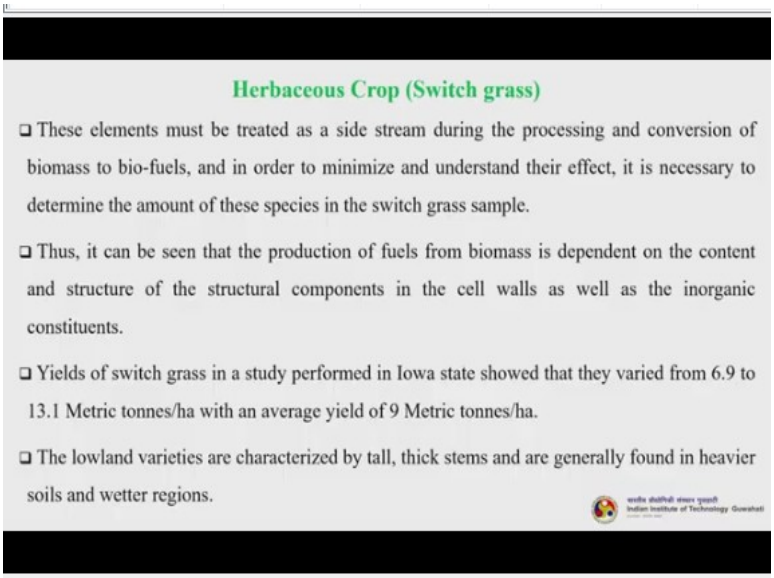

So, these elements must be treated as a side stream during the processing and conversion of biomass to biofuels, and in order to minimize and understand their effect, it is necessary to determine the amount of these species in the switch grass sample. Now, it can be seen that the production of fuels from the biomass is dependent on the content and structure of the structural components in the cell wall, as well as the inorganic constituents.

Yields of switchgrass in a study performed in Iowa state showed that they varied from 6.9 to 13.1 metric tons per hectare, with an average yield of 9 metric tons per hectare. The lowland varieties are characterized by tall, thick stems and are generally found in heavier soils and wetter regions.

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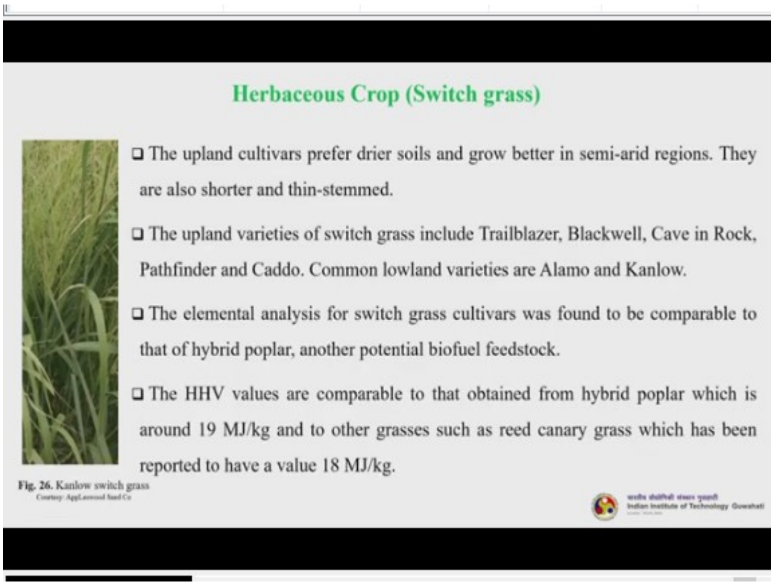

The upland cultivars preferred drier soils and grow better in semi-arid regions, they are also shorter and thin-stemmed. The upland varieties of switch grass include Trailblazer, Blackwell, Cave in Rock, Pathfinder and Caddo. These are some varieties of switch grasses. Common low land varieties are Alamo and Kanlow. Now the elemental analysis for switchgrass cultivars was found to be comparable to that of the hybrid poplar, another potential biofuel feedstock.

The HHV/ the heating values are comparable to that obtained from the hybrid poplar which is around 19 mega joules per kg and to other grasses such as the reed canary grass which has been reported to have a value of 18 mega joules per kg.

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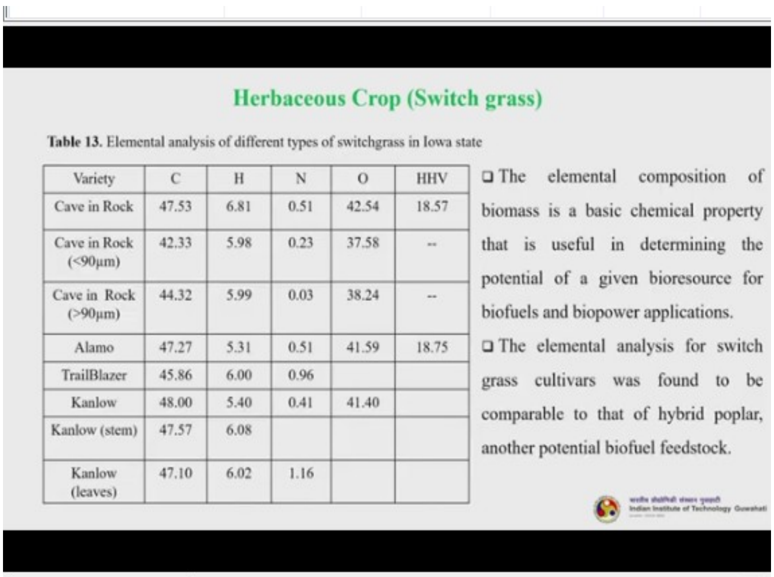

Table 13. Elemental analysis of different types of switchgrass in Iowa state

Variety	C	H	N	O	HHV
Cave in Rock	47.53	6.81	0.51	42.54	18.57
Cave in Rock (<90μm)	42.33	5.98	0.23	37.58	--
Cave in Rock (>90μm)	44.32	5.99	0.03	38.24	--
Alamo	47.27	5.31	0.51	41.59	18.75
TrailBlazer	45.86	6.00	0.96		
Kanlow	48.00	5.40	0.41	41.40	
Kanlow (stem)	47.57	6.08			
Kanlow (leaves)	47.10	6.02	1.16		

You can see the elemental analysis of different types of switchgrass grown in the Iowa state in the United States. The elemental composition of biomass is a basic chemical property that is useful in determining the potential of a given bioresource for biofuels and biopower application. Elemental analyses for switch grass cultivars were found to be comparable to that of the hybrid poplar and other potential biofuel feedstock.

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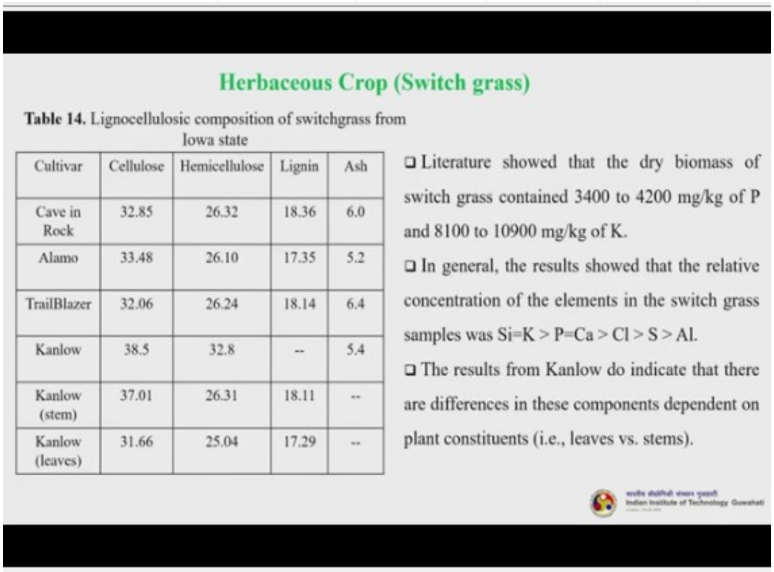

Cultivar	Cellulose	Hemicellulose	Lignin	Ash
Cave in Rock	32.85	26.32	18.36	6.0
Alamo	33.48	26.10	17.35	5.2
TrailBlazer	32.06	26.24	18.14	6.4
Kanlow	38.5	32.8	--	5.4
Kanlow (stem)	37.01	26.31	18.11	--
Kanlow (leaves)	31.66	25.04	17.29	--

So, this is the lignocellulosic composition of switch grass from the Iowa State. So, different species you can see listed here. So, literature showed that the dried biomass of switch grass contained 3400 to 4200 milligrams per kg of phosphorous and 8100 to 10900 milligrams per kg of potassium. In general, the results show that the relative concentration of the elements in the switch grass samples was Silicon=potassium > phosphate=calcium > chlorine > Sulphur > Aluminium. So, the results from Kanlow do indicate that there are differences in these components dependent on plant constituents (basically whether it is leaves, whether it is a stem, or other parts).

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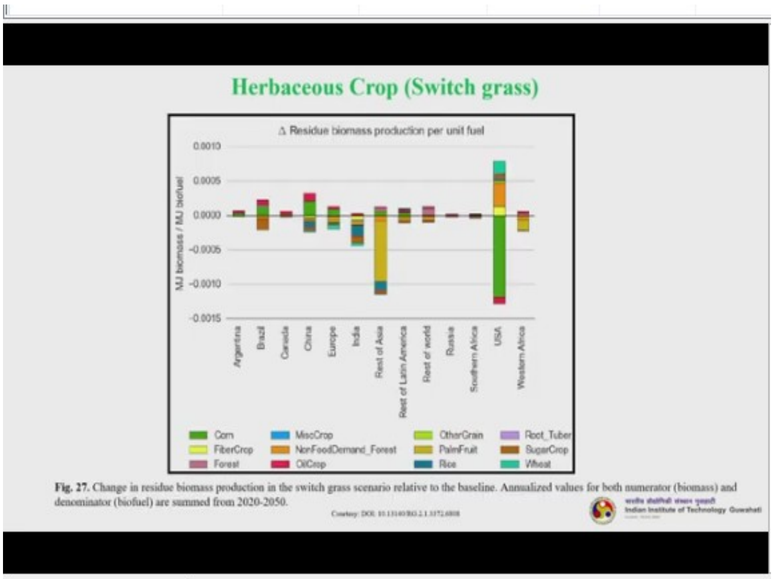

So, this particular scheme will tell you the residual biomass production for unit fuel in different countries. So, you can see the United States top among all that followed by the rest of Asia.

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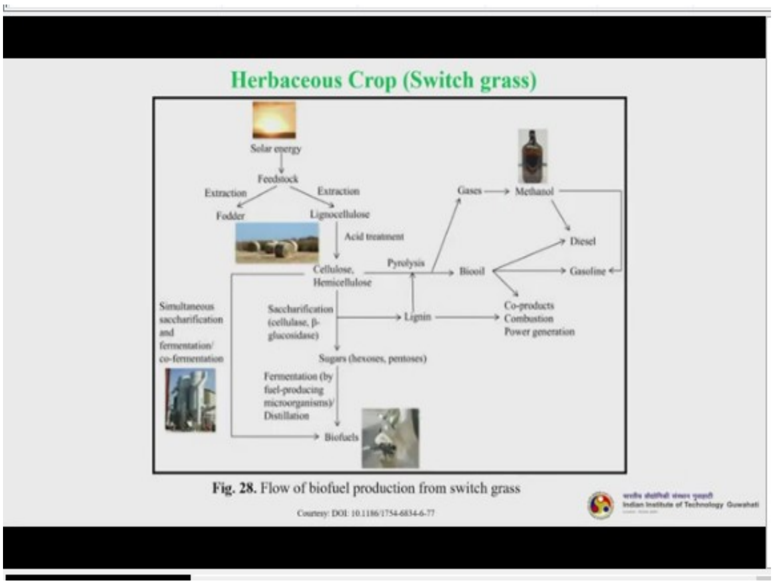

And this is the flow of biofuel production from switch grass. This is interesting, I will just explain. So, you can see that solar energy being utilized to grow the switchgrass. So, then you get the feedstock, then it goes for the fodder part or lignocellulosic part you just differentiate them, then go for acid treatment, you get cellulose and hemicellulose. That is cellulose and hemicellulose can be sccharified to sugars, hexoses and pentoses, now then can be fermented to get biofuels. Now you can have simultaneous scarification and fermentation which is called co-fermentation. So, that also can be possible. This is a biochemical part, now here the cellulose, hemicellulosic part including the lignin part can be pyrolyzed which is a thermochemical conversion part.

Pyrolysis to what; usually highest yield is the bio-oil or you can call it pyrolytic oil and you get some gases also. Those gases can be converted to methanol and again it can be blended, then from bio oil we can make diesel and we can get some other co-product. It is very interesting to note that this bio-oil, basically from pyrolysis what we get, from any lignocellulosic biomass when you settle it, is easily settle able to 2 different phases.

One phase which is rich in the organic components, and that is the oil part, and the other part is the aqueous part. Now, that aqueous part also contains very useful chemicals and which, if they are present in a particular amount or in a good amount, then that can be purified to get some platform chemicals; some value added products, nothing is waste basically.

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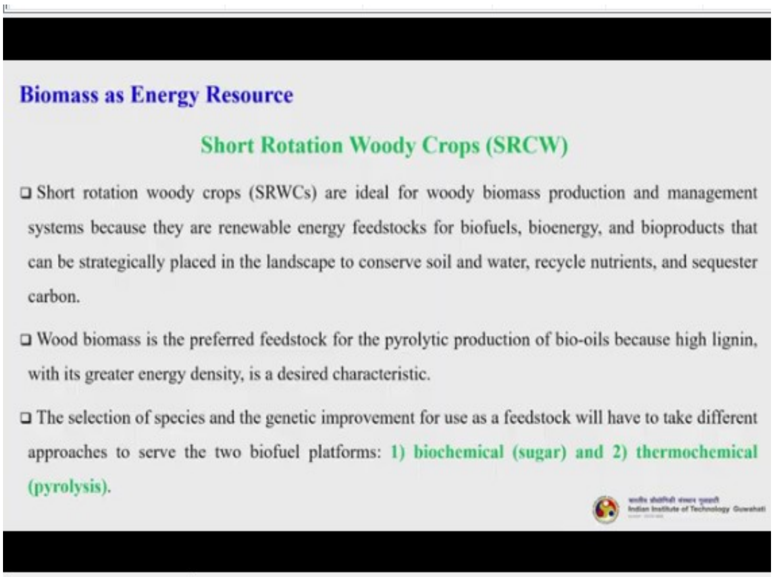

So, then let us talk about the short rotation woody crops. The short rotation woody crops are ideal for woody biomass production and management system because they are renewable energy feedstocks for biofuels, bioenergy and bioproducts, that can be strategically placed in the landscape to conserve soil and water, recycle nutrients and sequester carbon. Wood biomass is a preferred feedstock for the pyrolytic production of bio oils because high lignin, with its greater energy density is a desired characteristic.

The selection of species and the genetic improvement for use as a feedstock will have to take different approaches to serve the two biofuel platforms. So, either you can go for the biochemical conversion using the sugars or you go for the thermochemical conversion using the pyrolysis.

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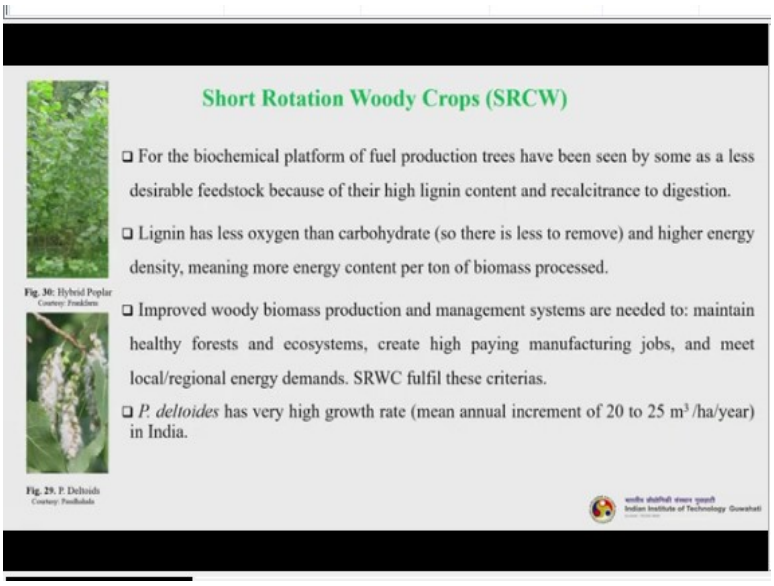

So for the biochemical platform for fuel production trees have been seen by some as a less desirable feedstock because of the high lignin content and recalcitrance to digestion. So, lignin has less oxygen than carbohydrates (so there is less to remove) and high energy density meaning more energy content per ton of biomass that is processed. The first one you can see here on the left hand side the top one is the hybrid poplar plant. And the below one is the *P deltoides*. Improved woody biomass production and management systems and needed to maintain healthy forests and ecosystem, create high paying manufacturing jobs and meet local and regional energy demands. And these short rotation woody crops fulfill all these criteria. So, *P. deltoides* has a very high growth rate (mean annual increment of 20 to 25 metre cube per hectare per year) in India.

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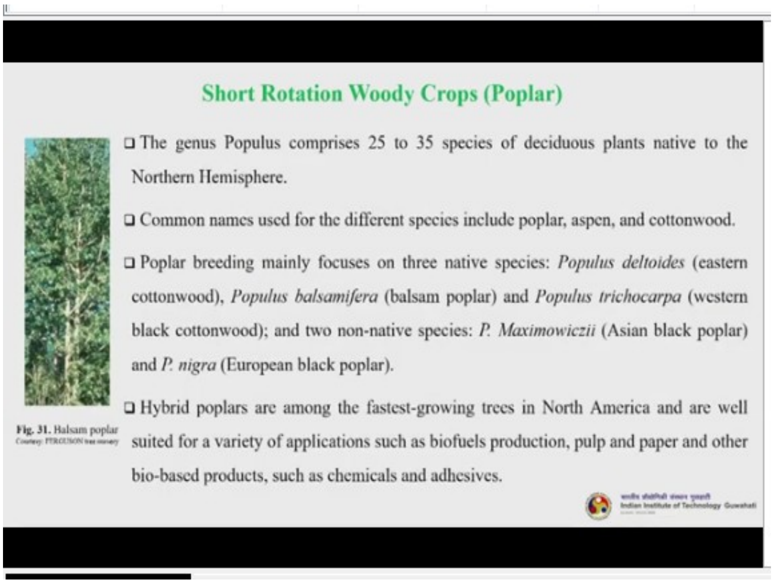

The genus Populus comprises (let us understand about poplar plant) 25 to 35 species of deciduous plants native to the Northern Hemisphere. Common names used for the different species include poplar, aspen and cottonwood. Poplar breeding mainly focuses on three native species: *Populus deltoides*, *Populus balsamifera* and *Populus trichocarpa*; and two non-native species: *Populus maximowiczii* and *Populus nigra*. So, hybrid poplars are among fast growing trees in North America and are well suited for a variety of applications such as biofuel production, pulp and paper applications and other bio based products such as chemicals and adhesives.

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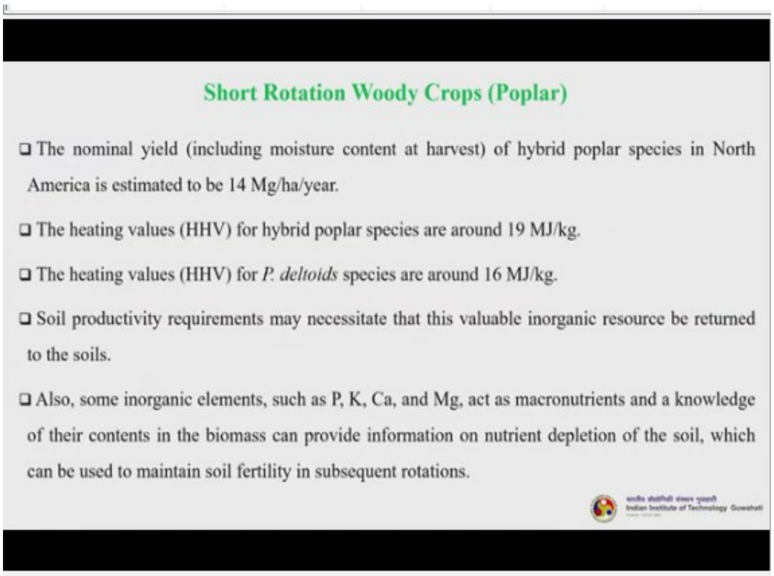

The nominal yield of hybrid poplar species in North America is estimated to be 14 Mg per hectare per year. The heating values for hybrid popular species are 19 megajoules per kg. The heating values for *P. deltoids* species are around 16 megajoules per kg. Soil productivity requirements may necessitate that this valuable inorganic resource be returned to the soils. Also, some inorganic elements, such as phosphorus, calcium, magnesium are present. So, they have their different roles during thermochemical or biochemical conversion.

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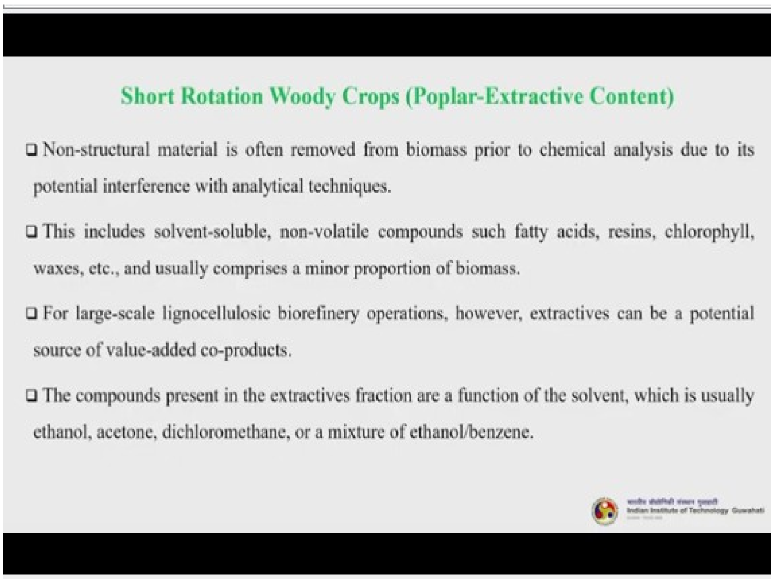

So, non structural material is often removed from biomass prior to chemical analysis. We have solvent soluble and non-volatile compounds such as fatty acid, resins, chlorophylls and usually that comprises a minor proportion of the biomass. For large-scale biorefinery operation extractives can be a potential source of value added co-products. The compounds present in the extractive fraction are a function of the solvent, which is usually ethanol, acetone, dichloromethane or a mixture of ethanol/benzene.

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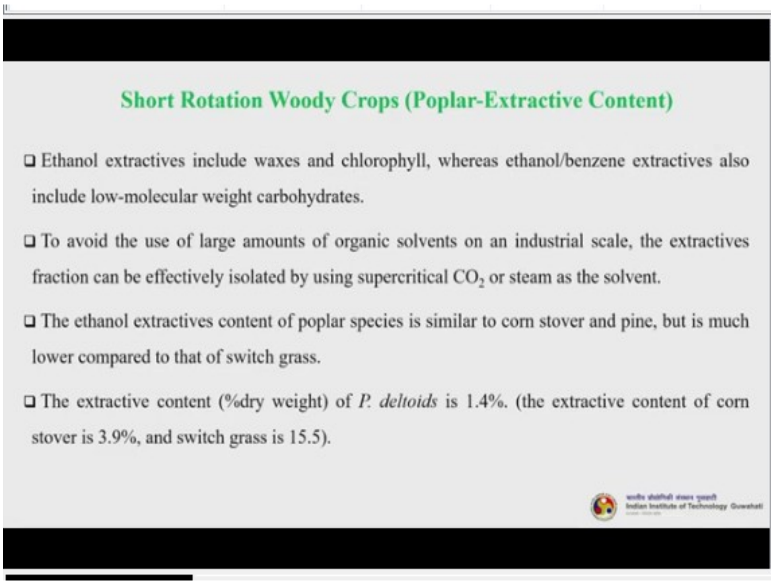

So, ethanol extractives include waxes and chlorophyll, whereas ethanol/benzene extractives also include low-molecular-weight carbohydrates. To avoid the use of large amounts of organic solvents on an industrial scale the extractive fraction can be effectively isolated by using supercritical carbon dioxide or steam as the solvent. So, the ethanol extractives content of poplar species is similar to corn stover and pine, but is much lower compared to that of the switchgrass.

The extractive content of *P. deltoides* is 1.4% (the extractive content from corn is 3.9% and switchgrass is 15.5%). So, this is very less in case of *P. deltoides*.

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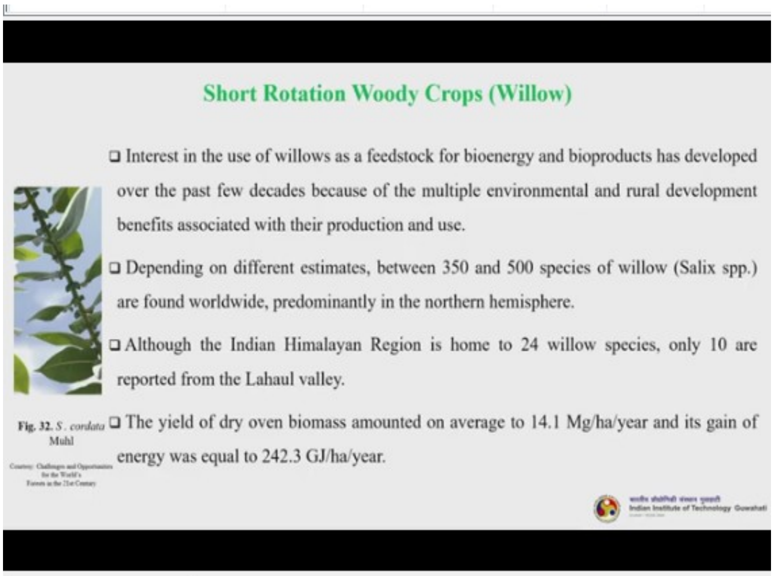

Interest in the use of willows as a feedstock for bioenergy and bioproduct has developed over the past few decades because of the multiple environmental and rural development benefits associated with their production and use. Depending on different estimates between 350 to 500 species of willow, basically the Salix species, are found worldwide and predominate in the Northern hemisphere.

Although the India Himalayan region is home to 24 willow species only 10 are reported from the Lahaul valley itself. The yield of dry oven biomass amounted on average 14.1 Mg per hectare per year and its gain of energy is equal to 242.3 GJ per hectare per year.

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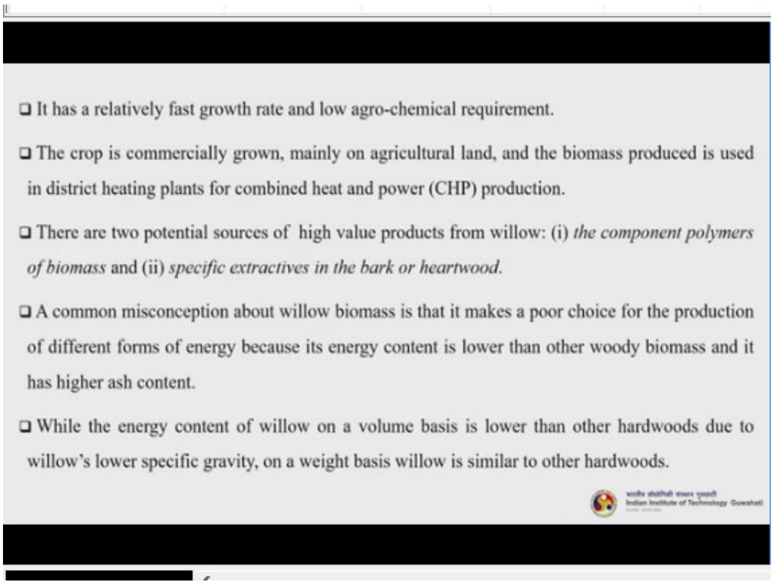

It is relatively fast growth rate and low agro-chemical requirement. It is a commercially grown crop. You can go for the CHP, that is combined heat and power production. There are 2 potential sources of high value products from the willows. The first is the component polymers of biomass and second is the extractives in the bark and heartwood. So, a common misconception about willow biomass is that it makes a poor choice for the production of different forms of energy because its energy content is lower than other woody biomass and has higher ash content. While the energy content of willow on a volume basis is lower than the hardwoods, due to willow's lower specific gravity however, on the weight basis willow is almost similar to other hardwoods.

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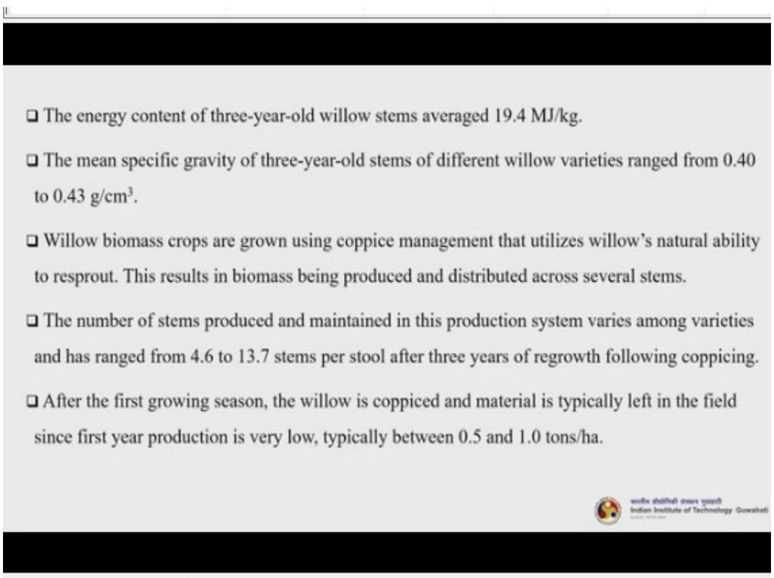

So, the energy content of a three-year-old willow stems averaged almost 19.4 mega joule per kg. The mean specific gravity of three-year-old stems for a different willow varieties ranges from 0.4 to 0.43 gram per cm^3. So, this willow biomass crops are grown using coppice management that utilizes the willows natural ability to resprout. So, this results in biomass being produced and distributed across several stems.

The number of stems produced and maintained in this production system varies among varieties and has ranged from 4.6 to 13.7 stems per stool after three years of regrowth following coppicing. After the first growing season the willow is coppiced and material is typically left in the field since first year production is very low, typically between 0.4 and 1.0 tons per hector.

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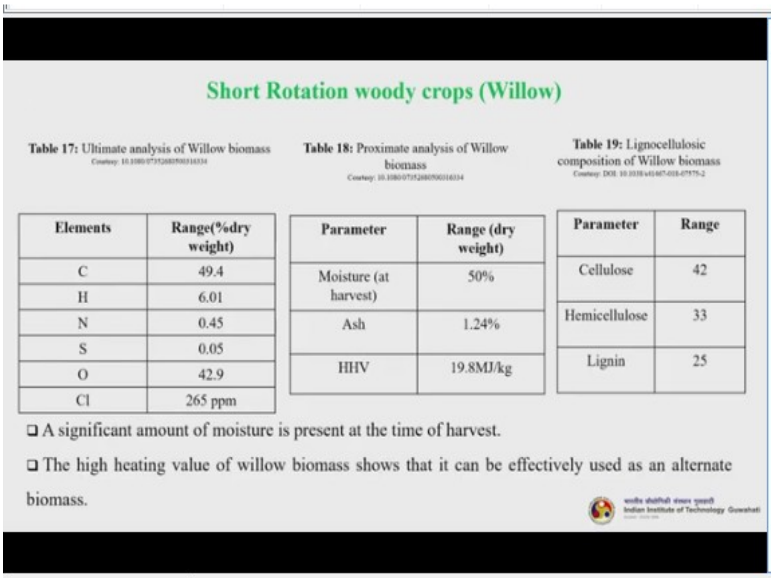

So, this you can have a look. The ultimate analysis of the willow biomass; proximate analysis and the lignocellulosic composition; you can see that the cellulose content is 42% hemicellulose is 33% and lignin is 25%. That means it can be utilized under various platforms to produce bioenergy, whether it is thermochemical or biochemical. So, a significant amount of moisture is present during the time of harvest (50%), which is not good when you go for a thermochemical conversion process. So, the high heating value of willow biomass shows that it can be effectively used as an alternate biomass.

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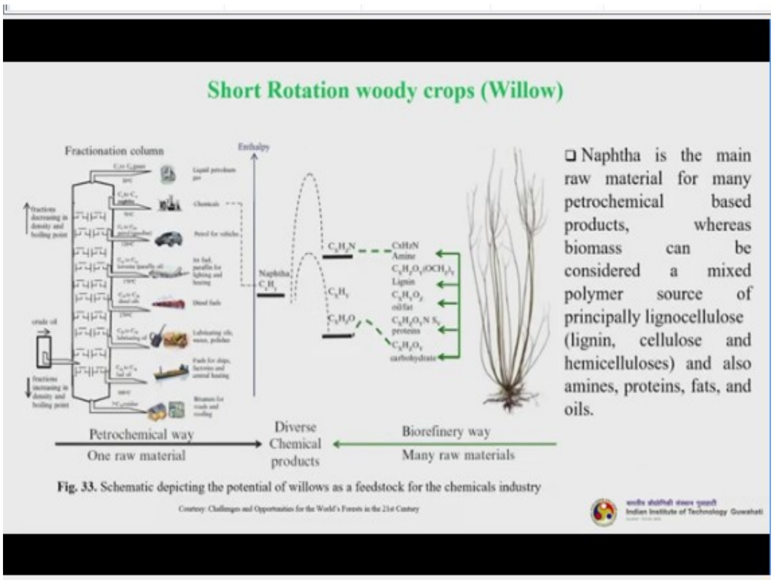

So, you can see this; if you compare it with the usual petro, Naphtha (crude oil basically), the same sort of things (products) you can get it from the biorefinery way using the willow. So, in petrochemical way one raw material and you get diverse chemical products, whereas, in a biorefinery way you have many raw materials and you get many different products. This is the beauty of the biorefinery concept.

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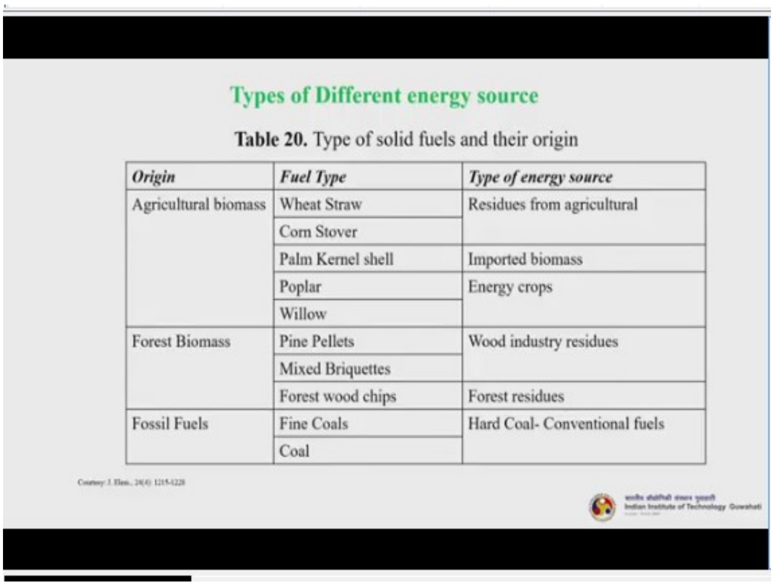

Table 20. Type of solid fuels and their origin

Origin	*Fuel Type*	*Type of energy source*
Agricultural biomass	Wheat Straw	Residues from agricultural
	Corn Stover	
	Palm Kernel shell	Imported biomass
	Poplar	Energy crops
	Willow	
Forest Biomass	Pine Pellets	Wood industry residues
	Mixed Briquettes	
	Forest wood chips	Forest residues
Fossil Fuels	Fine Coals	Hard Coal- Conventional fuels
	Coal	

So, this will tell you about the type of solid fuels and their origin. So, from the agricultural biomass, forest biomass and fossil fuels.

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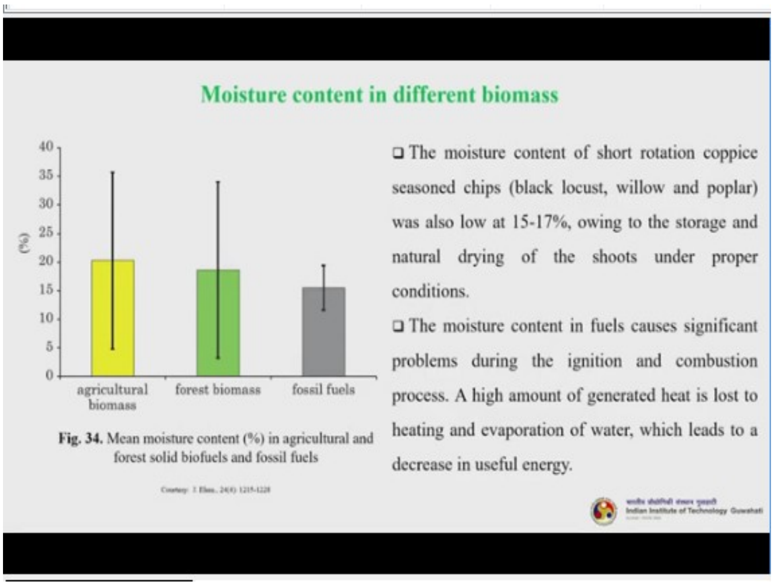

And moisture content of different biomass varies from agricultural biomass (where it is highest), followed by the forest and the fossil fuel. So, the moisture content in fuel causes significant problems during ignition and combustion process. A high amount of generated heat is lost to heating and evaporation of water which leads to a decrease in the useful energy. So, before you process for the thermochemical conversion especially, you need to reduce the moisture content of the biomasses.

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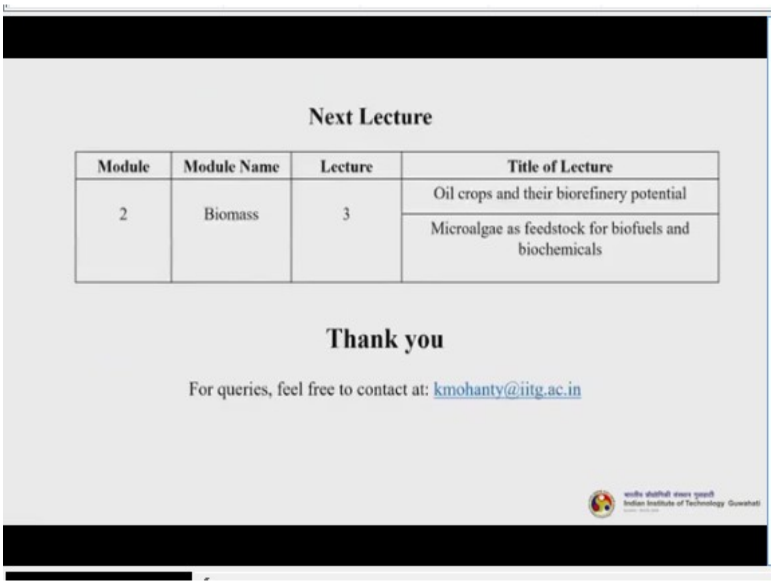

So, with this I wind up and in the next lecture we will be discussing about the dedicated oil crops and their biorefinery potential. Then we will also discuss about the microalgae as feedstock for biochemicals and biofuel production. So, thank you very much and if you have any query please feel free to write to me at kmohanty@iitg.ac.in, thank you.