Biomass Conversion and Biorefinery
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Module-02
Lecture-03
Biomass Basics

Good morning students. This is module 2 and lecture 1.

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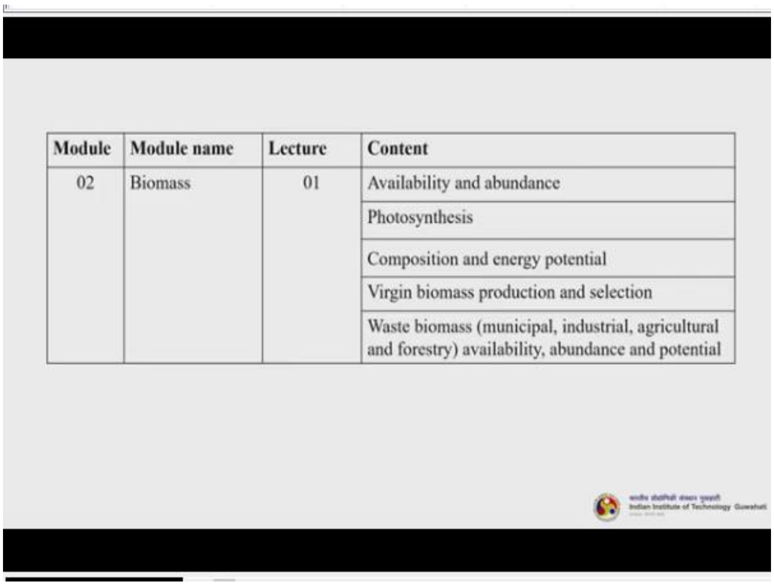

Module	Module name	Lecture	Content
02	Biomass	01	Availability and abundance
			Photosynthesis
			Composition and energy potential
			Virgin biomass production and selection
			Waste biomass (municipal, industrial, agricultural and forestry) availability, abundance and potential

So, in this entire module, basically we will be discussing about biomass and biomass structure, its availability, then composition, their energy potential, what type of biomass are available, what type of land requirements are there; all these things slowly we will be discussing.

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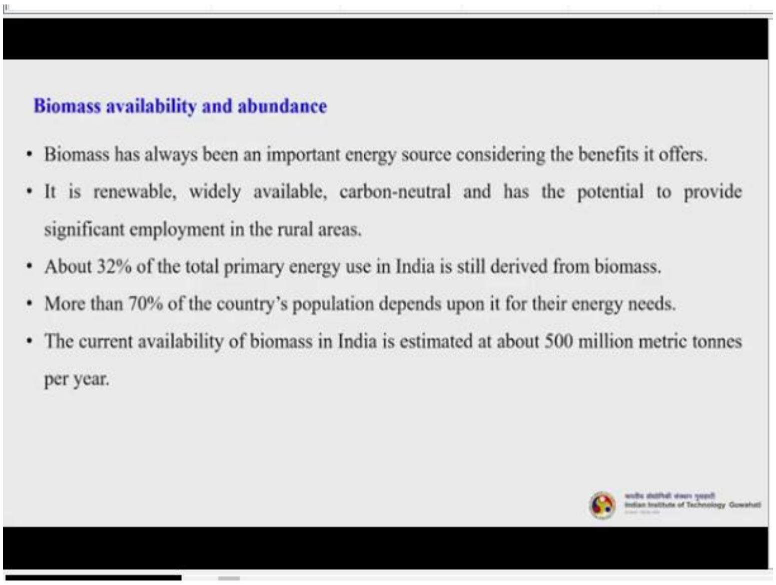

So, let us start our lecture today. So, as you know, biomass has always been an important energy source, considering the benefits it offers. It is renewable, widely available and carbon neutral and has the potential to provide significant employment in the rural areas. This is what I discussed (in the) last class also; that how biomass based industry is going to effect the economics of the rural people.

About 32% of the total primary energy use in India is still derived from biomass. More than 70% of the country's population depends upon it for their energy needs. The current availability of biomass in India is estimated at about 500 million metric tons per year.

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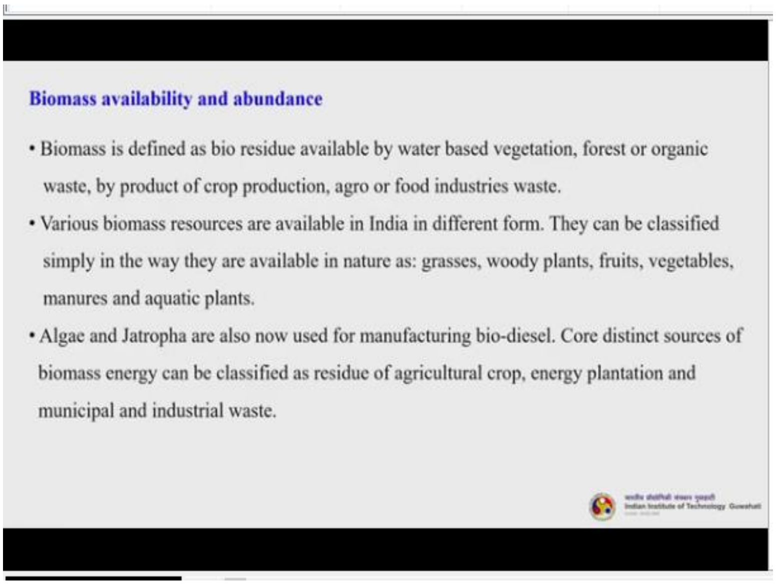

So, biomass is defined as the bio residue available by water based vegetation, forest or organic waste, by product of crop production, agro or food industries waste. Various biomass resources are available in India in different form. They can be classified simply in the way they are available in nature as: grasses, woody plants, fruits, vegetables, manures and aquatic plants.

Algae and Jatropha are also now used for manufacturing biodiesel (we will be discussing about them in detail later on). Core distinct sources of biomass energy can be classified as residue of agricultural crop, energy plantation and municipal and industrial waste.

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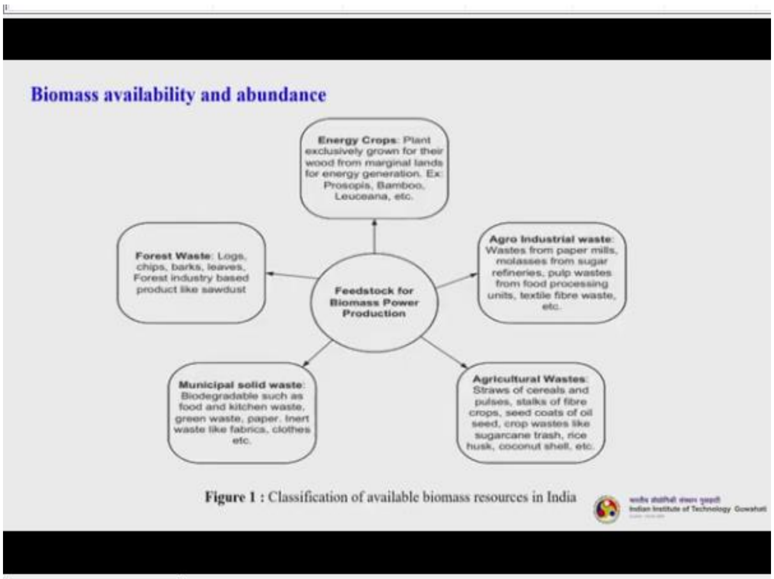

So, let us have a look at this particular slide. So, (first) you can see energy crops; plants exclusively grown to derive energy. Basically it can be fuel, liquid fuel, solid fuel as well as gaseous fuel. So, here there are some examples, bamboo, prosopis, leuceana, then we have miscanthus, elephant grass, switch grass etc.

Then we have agro industrial wastes. So wastes from paper mills, molasses from sugar refineries, pulp wastes from wood processing industries, textile fibre waste etc. Then we have agricultural waste. So, waste that is coming from farming; such as straws of cereals and pulses, stalks of fiber crops, seed coats of oil seed (basically de-oiled cake), then crop waste like sugar cane trash, rice husk, coconut shell etc.

Then we have MSW, which we call municipal solid waste. So, mostly they are biodegradable, such as food and kitchen waste, green waste, paper, inert waste, like fabrics, clothes come under that (needs to be separated basically). Forest waste; so, basically logs, chips, barks, leaves, forest industry waste products like sawdust.

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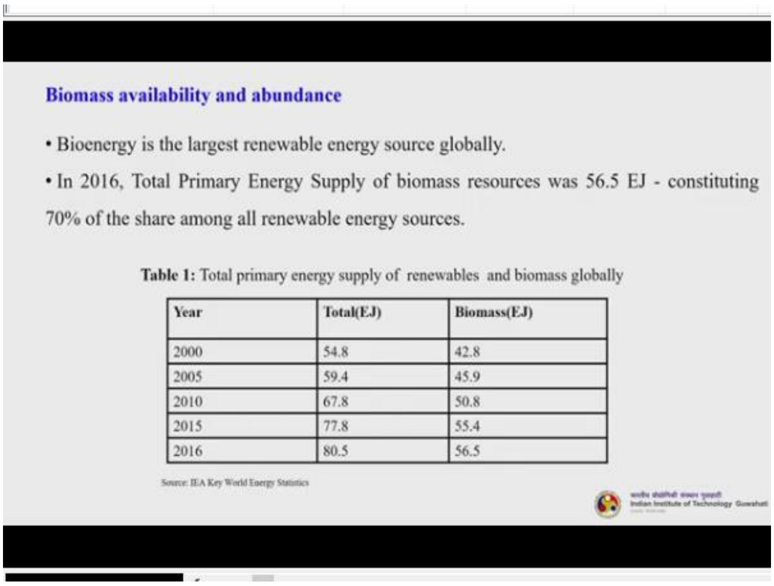

Now, bioenergy is the largest renewable energy source globally. In 2016, total primary energy supply of biomass resources was 56.5 Exajoules, constituting almost 70% of the share among all renewable energy sources. So, this table will give you an idea about, what is the total energy that is available and the biomass based energy. So, you can see that in 2016 (latest figures), if you see 80.5 is the available energy of the renewables and out of that 56.5 comes from the biomass.

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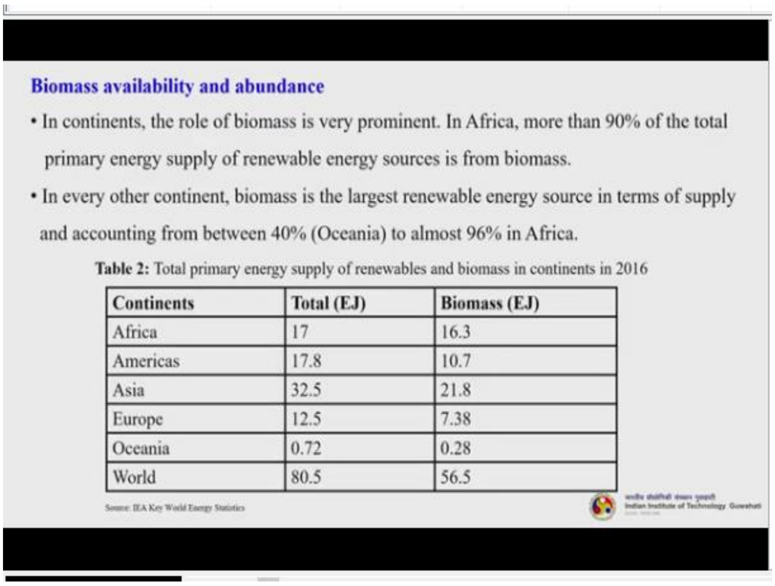

In continents, the role of biomass is very prominent. In Africa more than 90% of the total primary energy supply of renewable energy sources comes from biomass. In every other continent, biomass is the largest renewable energy source in terms of supply and accounting from between 40% (Oceania) to almost 96% in Africa. So, this particular table shows you what is the biomass fraction, basically from various continents, Africa, Americas and Asia. The biomass is huge almost everywhere. It is more in Asia, okay followed by Africa.

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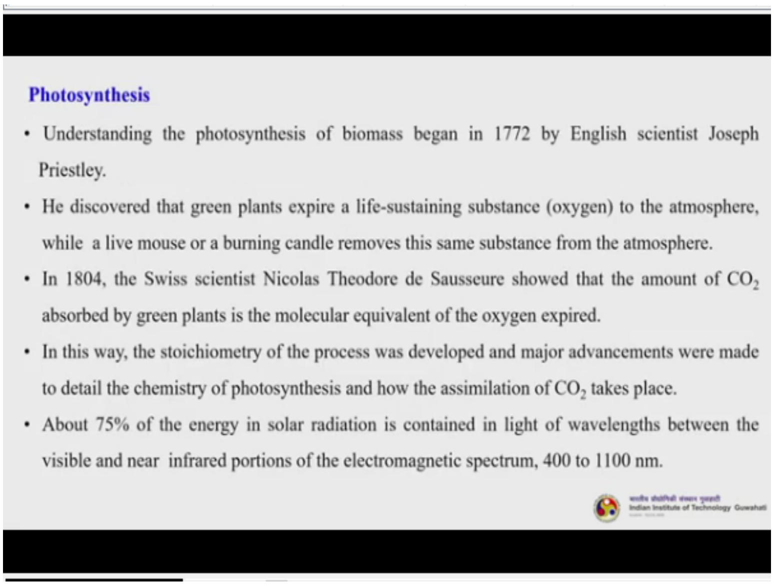

So, understanding photosynthesis is the most important thing related to biomass. So, understanding the photosynthesis of biomass began long back, in 1772 by the English scientist, Joseph Priestley. So, he discovered that, green plants expire a life-sustaining substance (that is basically oxygen) to the atmosphere, while a live mouse or a burning candle removes the same substance from the atmosphere (removed meaning it is consumed basically).

So, in 1804, the Swiss scientist Nicolas Theodore de Sausseure showed that the amount of carbon dioxide absorbed by green plants is the molecular equivalent of the oxygen expired. That means, he found out that, how much carbon dioxide is being consumed, is almost equivalent (on a molecular level) to the oxygen that the plants expire. So, in this way, the stoichiometry of the process was developed and major advancements were made to detail the chemistry of photosynthesis, and how the assimilation of carbon dioxide takes place. About 75% of the energy in solar radiation is contained in light of wavelengths between the visible and near infrared portions of the electromagnetic spectrum. So, that is almost in the range of 400 to 1100 nanometers.

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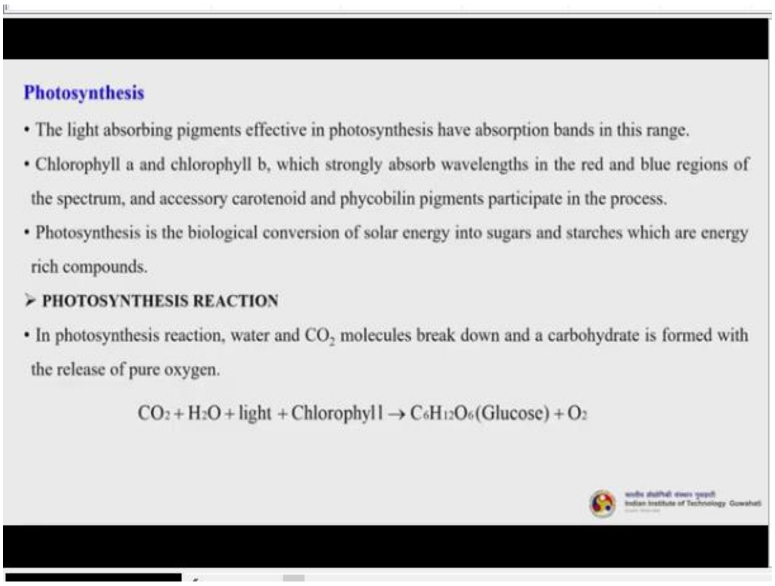

The light absorbing pigments effective in photosynthesis have absorption bands in this range, particularly in that 400 to 1100 range. So, chlorophyll a and chlorophyll b, which strongly absorb wavelengths in the red and blue regions of the spectrum, and accessory carotenoid and phycobilin pigments participate in the process. So, photosynthesis is a biological conversion of solar energy into sugars and starches, which are energy rich compounds.

So, in photosynthesis reaction, water and carbon dioxide molecules break down and a carbohydrate is formed with the release of pure oxygen.

$$CO_2 + H_2O + \text{light} + \text{Chlorophyll} \rightarrow C_6H_{12}O_6 \text{ (Glucose)} + O_2$$

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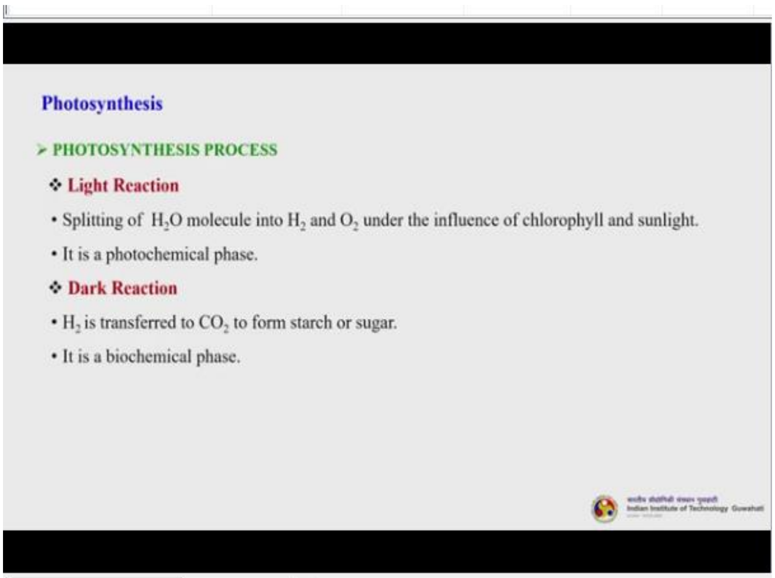

Now, there are two reactions, light reaction and dark reaction in photosynthesis. So, in the light reaction, the splitting of water molecule into hydrogen and oxygen is happening under the influence of chlorophyll and sunlight. So it is a photochemical phase reaction. Under the dark reaction hydrogen is transferred to carbon dioxide to form starch or sugar, and it is a biochemical phase reaction.

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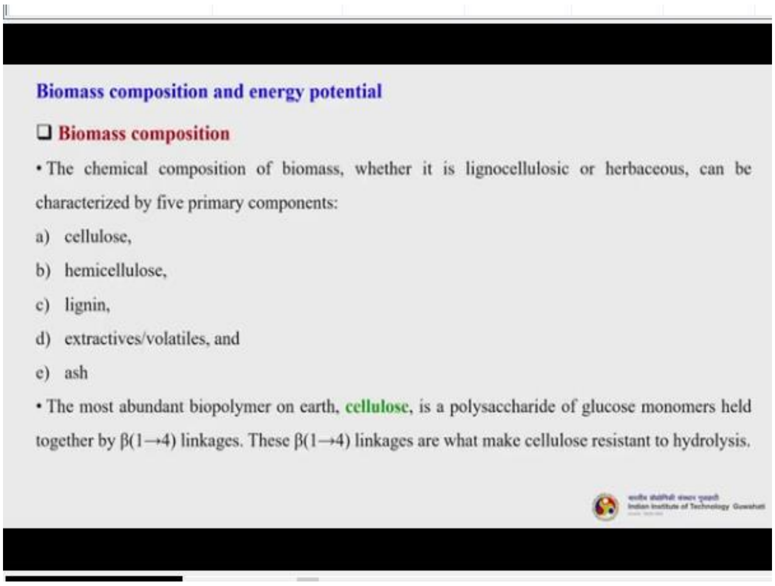

So, let us now understand the biomass composition. I can tell you that biomass composition is a significant property that has so much to do with biomass processing and further their value added product generation. So, what type of composition it has? If we talk about the lignocellulosic biomass, these basically consists of 3 primary components, first one is cellulose, then hemicellulose, and then lignin.

Apart from that there are other components also. So, how much cellulose and how much lignin and how much the hemicellulose is present. So, this has to be calculated a priori. So, this comes under the physicochemical characterization of the biomass. So, you need to characterize it and you need to find out what is the crystallinity of the cellulose.

So, there is a process called delignification in which you basically remove the lignin from the lignocellulosic biomass, to make them more amorphous and you will get the cellulose in a pure form. So, that can be further processed and made into sugars. So, the chemical composition of biomass, whether it is lignocellulosic or herbaceous, can be characterized by 5 primary components: cellulose, hemicellulose, lignin, extractives/volatiles and ash. So, these are the components which are present in almost all biomass. But, what varies, is their amount from biomass to biomass. In some biomass, like hard woody biomass lignin presence will be more, the amount of lignin will be very high. And in some soft biomass like creeps and leaves the lignin presence will be very less okay.

So, the most abundant biopolymer on the earth is cellulose. It is a polysaccharide of glucose monomers held together by β $(1 \rightarrow 4)$ linkages (it is a bond, a glycosidic bond basically). So, these β $(1 \rightarrow 4)$ linkages are what makes cellulose resistant to hydrolysis. That means it's all about the crystallinity of the cellulose. So, if it is more crystalline, then you need to process it further, you need more energy to break it. So, if we remove lignin, then the crystallinity will also come down (reduce).

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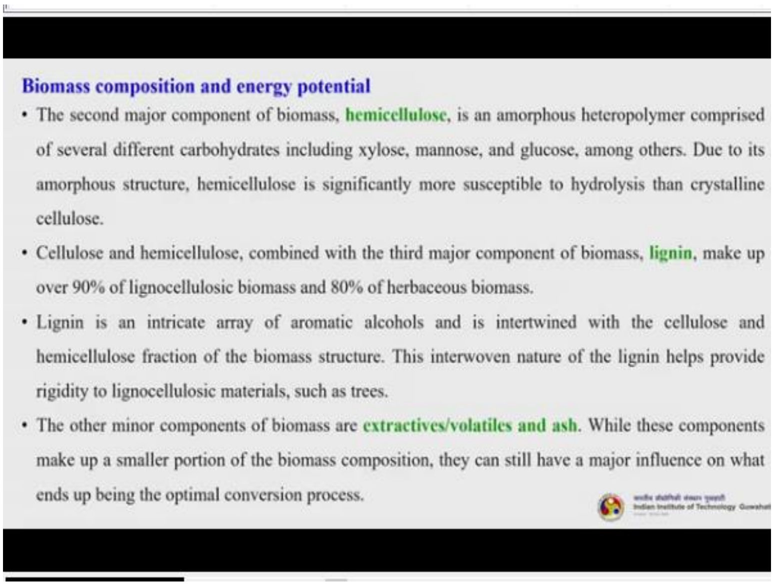

The second major component of the biomass is hemicellulose. It is an amorphous heteropolymer comprised of several different carbohydrates including xylose, mannose and glucose, among others. Due to its amorphous structure hemicellulose is significantly more susceptible to hydrolysis than crystalline cellulose. So, cellulose and hemicellulose combined with the third major component of the biomass, that is lignin, make up about 90% of lignocellulosic biomass and 80% of herbaceous biomass.

So, lignin is an intricate array of aromatic alcohols and it is intertwined with the cellulose and hemicellulose fraction of the biomass structure. So, this interwoven nature of the lignin helps provide rigidity to lignocellulosic materials such as trees. So, lignin is bound along with cellulose and hemicellulose in a very intertwined manner. So, that is why there is a need to de-lignify (basically remove lignin) so, that cellulose and hemicellulose may be released from the interlinking bond that was present previously. So, that cellulose will be more accessible for hydrolysis purposes. The other minor components of the biomass are extractives/volatiles and ash. While these components make up a smaller portion of the biomass composition, they can still have a major influence on what ends up being the optimal conversion process.

So, please again note that the amount of volatiles/extractives present and the amount of ash present plays a significant role. If there is huge ash present in the biomass, then they are not good for certain particular processing, whether it is the thermochemical or biochemical. So, every component has a role to play and will somehow effect the conversion technology or conversion process.

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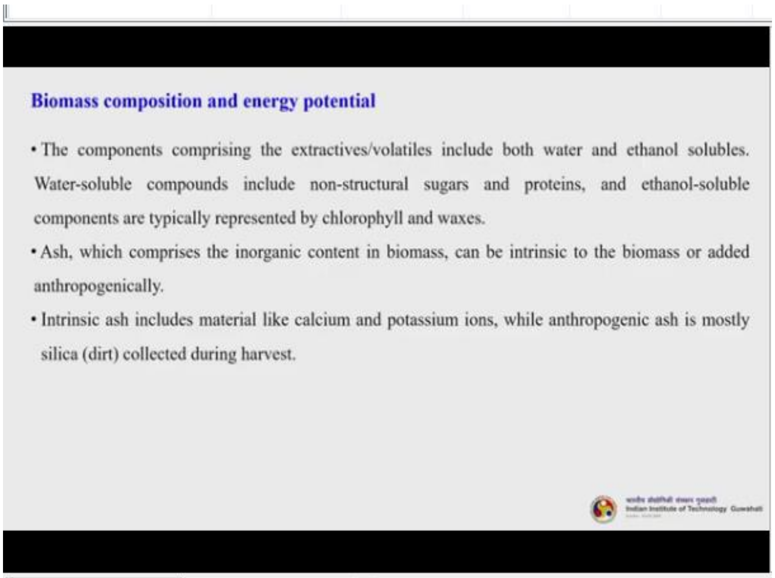

The components comprising the extractives/volatiles include both water and ethanol solubles. So, water soluble compounds include non-structural, sugars and proteins and ethanol soluble compounds are typically represented by chlorophyll and waxes. Ash, which comprises the inorganic content in biomass can be intrinsic to the biomass or added anthropogenically.

Anthropogenically means man-made (basically during the processing), so it is getting added from the outside, it is not present inside the biomass. So, intrinsic ash includes material like calcium and potassium ions, while anthropogenic ash is mostly silica. Silica is basically coming from the dirt. When you are processing it in the field, it is getting dumped on the field. So, you are taking it out. So, silica is coming into picture, that is how it is getting added anthropogenically during harvesting.

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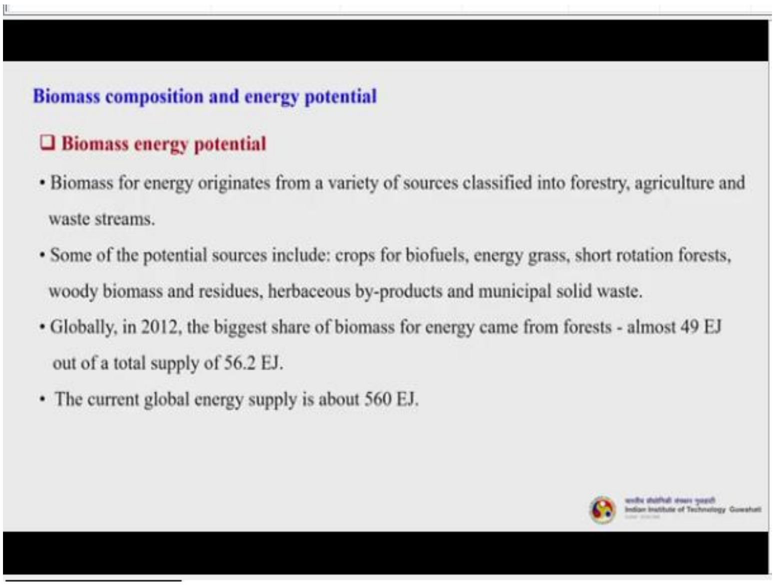

So, let us talk about biomass energy potential. So, biomass for energy originates from a variety of sources classified into forestry, agricultural and waste streams. Some of the potential sources include: crops for biofuels (dedicated crops), energy grass, short rotation forests, woody biomass and residues, herbaceous by-products and municipal solid waste.

Globally, in 2012, the biggest share of biomass for energy came from the forests- almost 49 Exajoule out of a total supply of 56.2 Exajoule. So, the current global energy supply is about 560 Exajoule.

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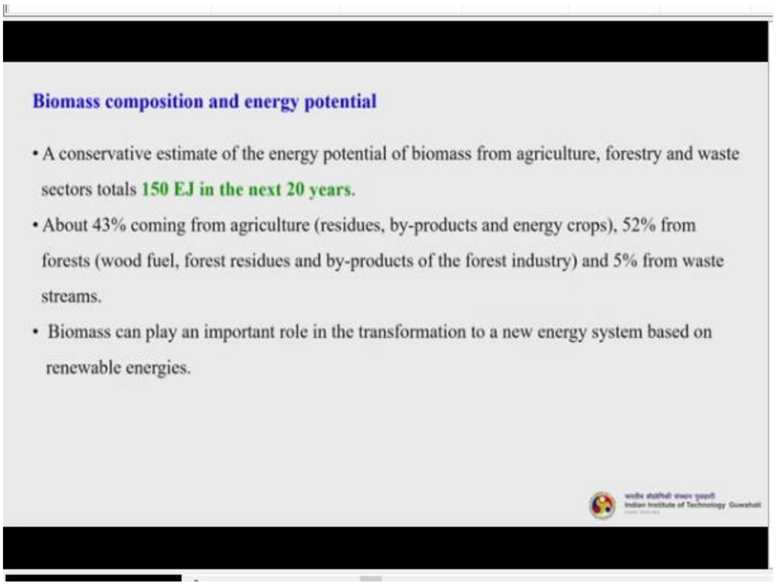

So, a conservative estimate of the energy potential of biomass from agriculture, forestry and waste sectors is totalling to almost 150 Exajoule in the next 20 years. It is a huge energy potential. About 43% coming from agricultural (so, that is residues by-products and energy crops), 52% from the forest (which is wood fuel, forest residues and by-products of the forest industry like sawdust) and 5% from waste streams. Now, biomass can play an important role in the transformation to a new energy system based on renewable energies.

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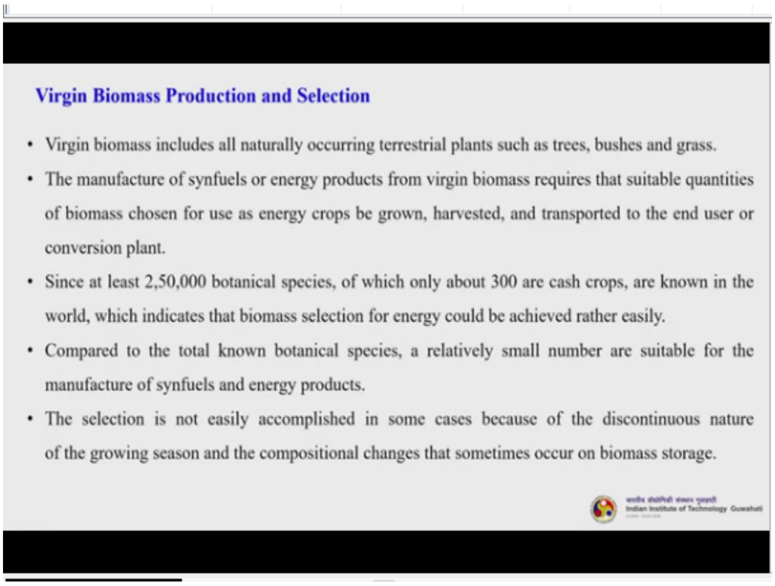

Let us now understand virgin biomass production and selection, how the biomass is getting produced, the land requirements, etc, and how do we select them. So, virgin biomass includes all naturally occurring terrestrial plants, such as trees, bushes and grass. The manufacture of synfuels or synthetic fuels or energy products from virgin biomass requires that suitable quantities of biomass chosen for use as energy crops be grown, harvested and transported to the end user or to the conversion plant.

Since at least 2,50,000 botanical species of which only about 300 are cash crops are known in the world, which indicates that biomass selection for energy could be achieved rather easily. Because it is a narrowed loop, it is not a very big loop. And compared to the total known botanical species, a relatively small number are suitable for the manufacture of synfuels and other energy products.

The selection is not easily accomplished in some cases, because of the discontinuous nature of the growing season and the compositional changes that sometimes occur on biomass storage.

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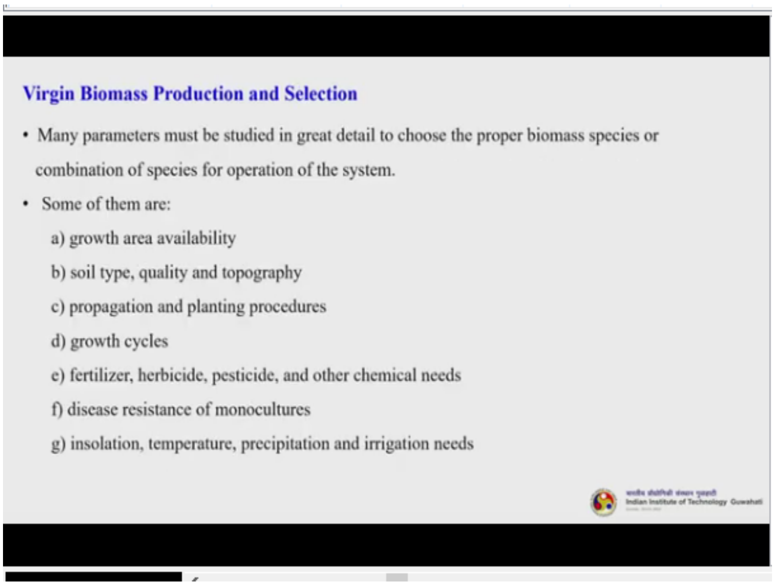

Many parameters must be studied in great detail to choose the proper biomass species or combination of species for operation of the system. Some of them are growth area availability, soil type, quality and topography, propagation and planting procedures, growth cycles, fertilizer, herbicide, pesticide and other chemical needs, disease resistance of the monocultures, insolation, temperature, precipitation and irrigation needs.

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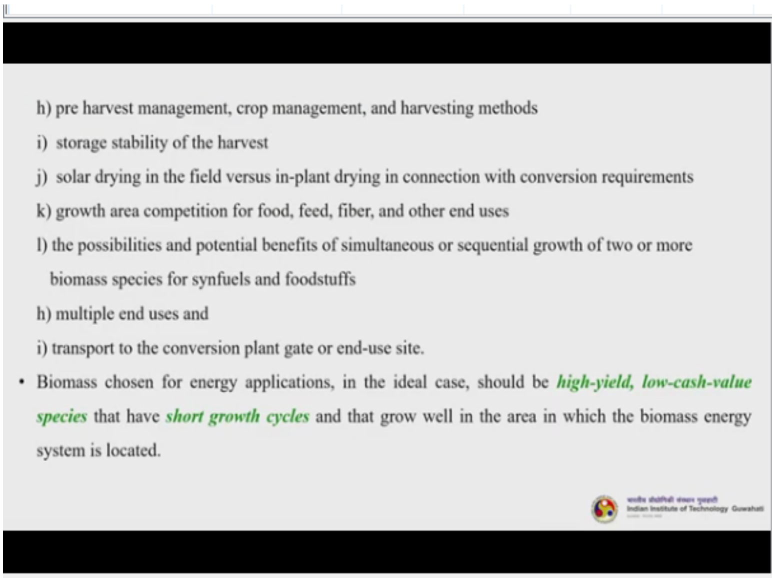

And there is pre harvest management, crop management and harvesting methods, storage stability of the harvest, solar drying in the field versus in-plant drying in connection with conversion requirements, growth area competition for food, feed, fiber and other end uses, the possibilities and potential benefits of simultaneous or sequential growth of two or more biomass species for synthetic fuels and foodstuffs, multiple end uses and transport to the conversion plant gate or end-use site.

Biomass chosen for energy applications, in the ideal case should be a high-yield, low-cash-value species, that have short growth cycles and that grow well in the area in which biomass energy system is located. Now, again, I am telling you, last class also we have discussed, apart from these listed things (there are so many), one of the major costs usually comes from the transportation of the biomass.

Now, we discussed in the last class about the biomass chipping and all, basically, the shape of biomass and the moisture content of the biomass. So, if the moisture content is very high almost 30% (let us say in most of the biomasses), then I am transporting almost 300 kgs of water along with the transport of 1 tonne of biomass.

So, it is a huge thing and it is of no use, because even if you go for a thermo chemical process or a biochemical or any other process, you need to have a dry biomass. If it is not 100% moisture free, some moisture is okay, but you need to dry it. So, you cannot have 30% moisture. So, you have to reduce it almost to a 5% or even less than that. Certain conversion technologies require not more than 1%, 2% or 3% moisture.

So, then shape also plays a very important role. So, I was telling you in the last class if you recall, that it is better for the policymakers, the implementers, industry people who are going to set up such plants, that they must choose the location of their plant in such a way that transportation cost should be reduced, it should be as less as possible.

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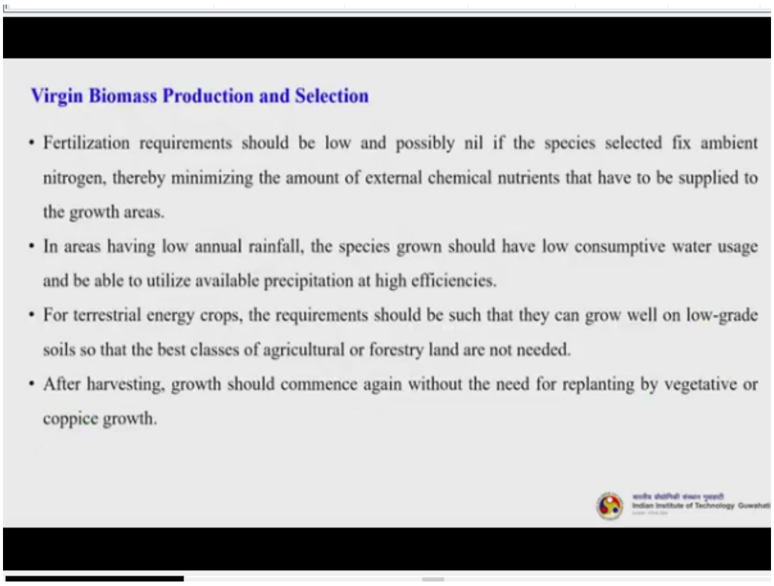

So, fertilization requirements should be low and possibly nil if the species selected fix ambient nitrogen, thereby minimizing the amount of external chemical nutrients that have to be supplied to the growth areas. In areas having low annual rainfall, the species grown should have low consumptive water uses and be able to utilize available precipitation at high efficiencies.
For terrestrial energy crops the requirements should be such that they can grow well in low grade soils so, that the best classes of agricultural or forestry lands are not needed. After harvesting, growth should commence again without need for replanting by vegetative or coppice growth. So, what do we understand basically is that, lands should be chosen in such a way to grow the dedicated energy crops, which are not been used for our traditional crops. So, agricultural fields basically. So, most of the agricultural fields which are being utilized in India to grow crops, cereals, pulses etc., even for vegetables production are extremely fertile. So, in no way we are going to use those land for biomass production or let us say, for growing energy crops or some other biomasses.

So, you must look for such lands which are either barren or are not fertile enough to grow the energy crops. So, those types of lands are sufficiently available. So, this is one point. Second thing is that, we should go for short rotation species. So, that means in another way I can tell a fast growing species. There are certain species of softer bamboo which grow very fast.

So, those are being utilized or can be utilized for making bioethanol or other biomass based products from bamboo. So, like that there are many other species which are having fastest growth rate. And you should also take care that such species should be planted, which required minimum attention.

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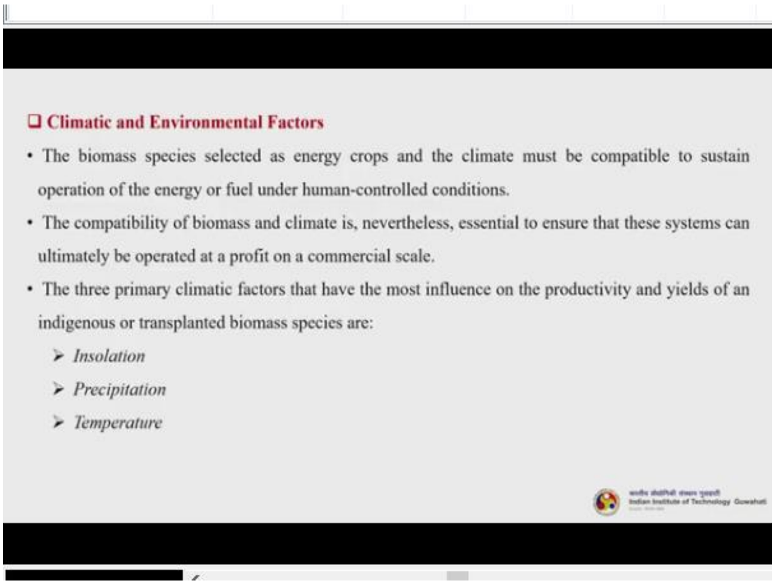

So, then let us talk about climatic and environmental factors. So, the biomass species selected as energy crops and the climate must be compatible to sustain operation of the energy or fuel under human controlled conditions. So, the compatibility of biomass and climate is nevertheless essential to ensure that these systems can ultimately be operated at a profit on a commercial scale.

The 3 primary climatic factors that have most influence on the productivity and yields of an indigenous or transplanted biomass species are insolation (that is the solar radiation), precipitation (rainfall & moisture), and temperature. So, we will discuss one by one.

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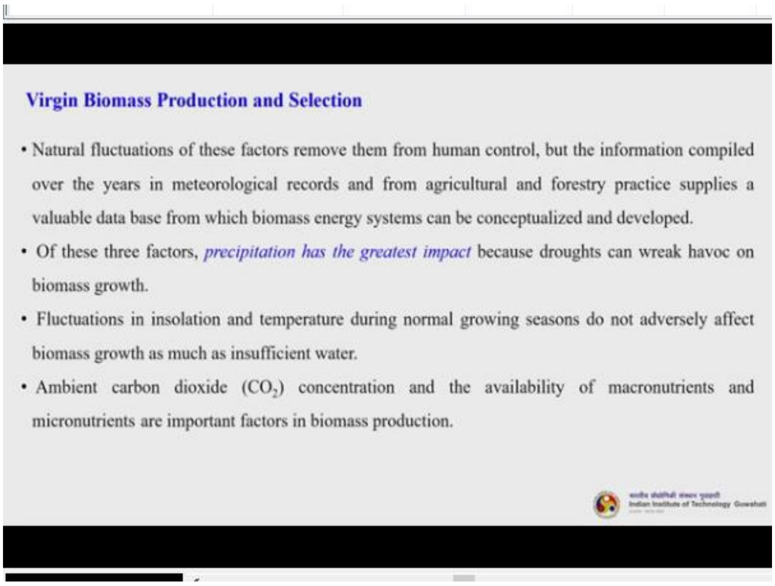

So, natural fluctuations of these factors remove them from human control. But the information compiled over the years in meteorological records and from agricultural and forestry practice, supplies a valuable database from which biomass energy system can be conceptualized and developed. That means all these records are going to help us in choosing and selecting a particular biomass as well as the area or land for growing this biomass.

Of these three factors, precipitation has the greatest impact, because droughts can wreak havoc on biomass growth. And that is not only true for biomass, that is true for any plantation or any crop. So fluctuations in insolation and temperature during normal growing seasons do not adversely affect the biomass growth as much as insufficient water. So, ambient carbon dioxide concentration and the availability of macronutrients and micronutrients are important factors in the biomass production.

Having said that, we may look for such lands which are not highly fertile. But we need to again remember that we need to supply certain nutrients (micro or macro) for the biomass growth. However, that can be supplied in limited quantity throughout the year, in a sequential manner so that the growth of the biomass does not get hindered.

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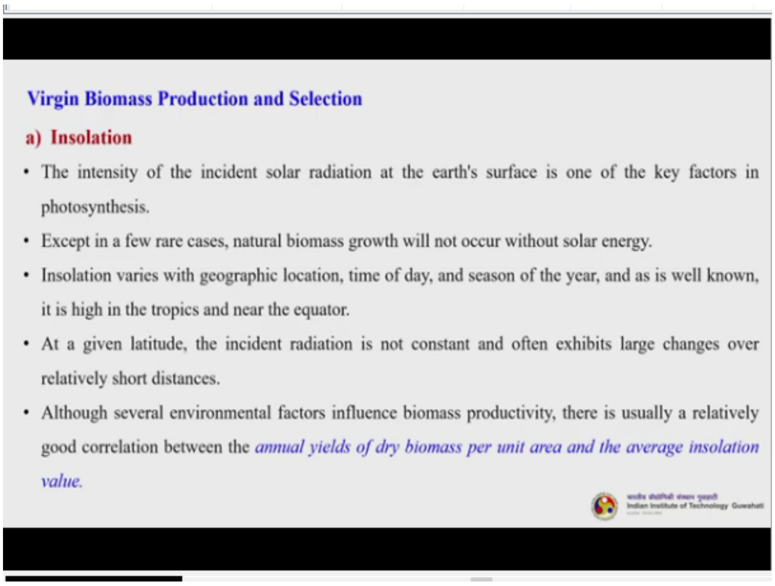

So, let us understand insolation. So, the intensity of the incident solar radiation at the Earth's surface is one of the key factors in photosynthesis. Except in a few rare cases, natural biomass growth will not occur without solar energy. Insolation varies with geographical location, time of day and season of the year, and as is well known, it is high in the tropics and near the equator. At a given latitude, the incident radiation is not constant and often exhibits large changes over relatively short distances.

Although several environmental factors influence biomass productivity, there is usually a relatively good correlation between the annual yields of the dry biomass per unit area and the average insolation value (there is a correlation that exists).

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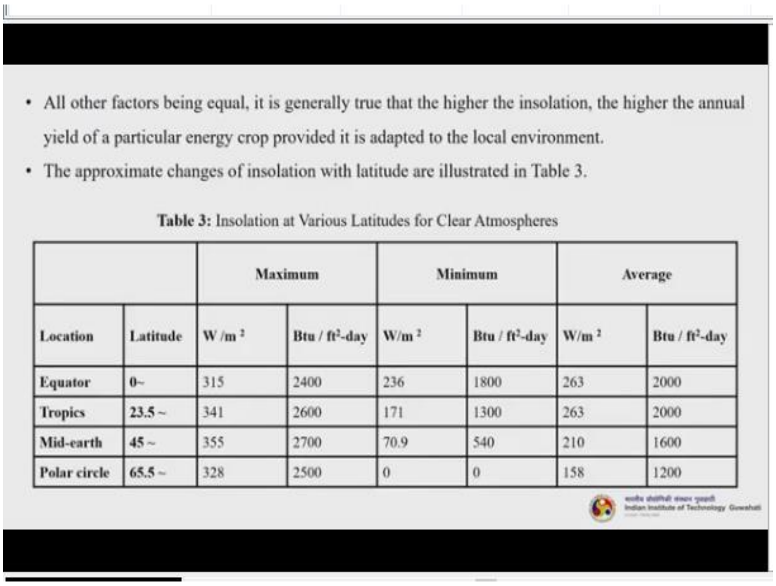

		Maximum		Minimum		Average	
Location	Latitude	W/m^2	Btu/ft^2-day	W/m^2	Btu/ft^2-day	W/m^2	Btu/ft^2-day
Equator	0~	315	2400	236	1800	263	2000
Tropics	23.5 ~	341	2600	171	1300	263	2000
Mid-earth	45 ~	355	2700	70.9	540	210	1600
Polar circle	65.5 ~	328	2500	0	0	158	1200

All other factors being equal, it is generally true that the higher the insolation, the higher the annual yield of a particular energy crop provided it is adapted to the local environment. The approximate changes of insolation with latitude are illustrated in this table. You can have a look in this table and you can understand that location wise what is the maximum, minimum and average insolation at these places.

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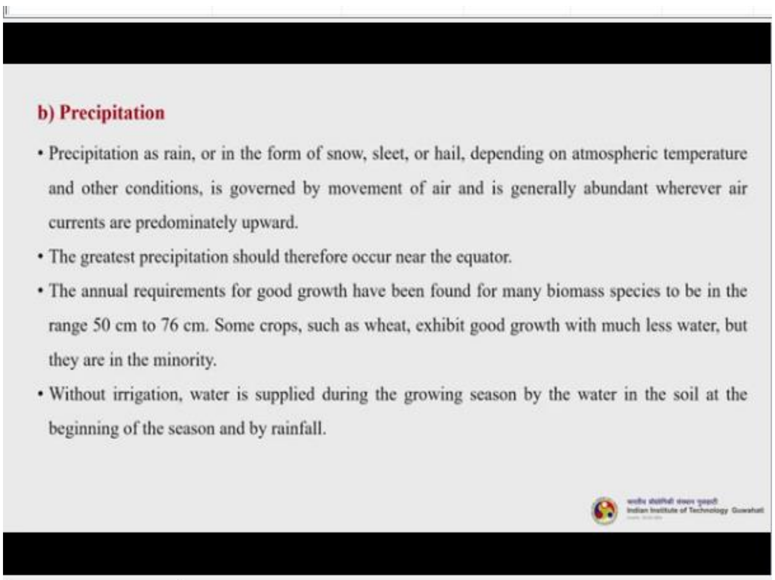

So, the next is precipitation. Precipitation as rain or in the form of snow, sleet or hail, depending on atmospheric temperature and other conditions is governed by the movement of air and is generally abundant wherever air currents are predominantly upward. So, the greatest precipitation should therefore, almost occur near the equator. The annual requirements for good growth have been found for many biomass species to be in the range 50 centimeter to 76 centimeter.

Some crops such as wheat, exhibit good growth with much less water, but they are in the minority (minority means when we compare with other cereals or pulses on a global scale, they are less; that is why it is being mentioned as minority). Without irrigation, water is supplied during the growing season by the water in the soil at the beginning of the season and by rainfall.

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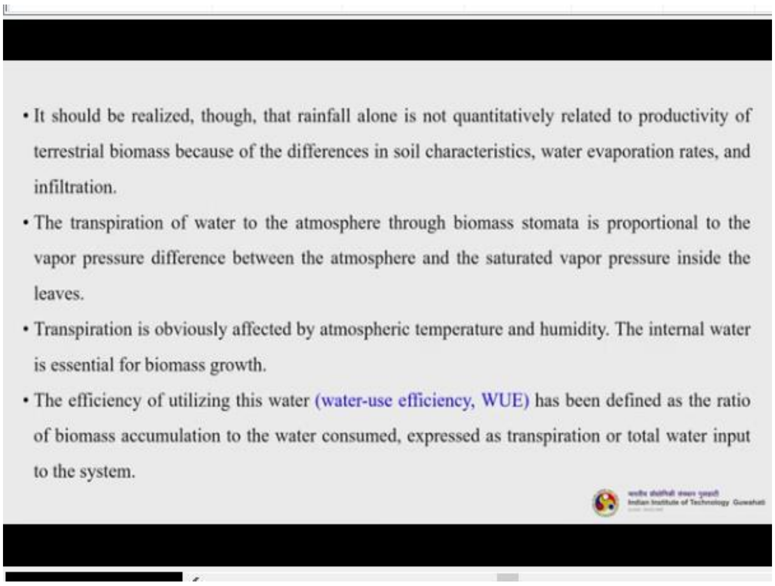

So, it should be realized, though, that rainfall alone is not quantitatively related to the productivity of terrestrial biomass, because of the differences in soil characteristics, water evaporation rates and infiltration. The transpiration of water to the atmosphere through biomass stomata is proportional to the vapour pressure difference between the atmosphere and the saturated vapour present inside the leaves.

Now, having said that, we must understand that, the vapour pressure inside the leaves and the pressure outside or the ambient pressure do play a role on controlling that stomata opening. Transpiration is obviously affected by atmospheric temperature and humidity. The internal water is essential for biomass growth. The efficiency of utilizing this water (we call it water use efficiency or WUE) has been defined as the ratio of biomass accumulation to the water consumed, expressed as transpiration or total water input to the system.

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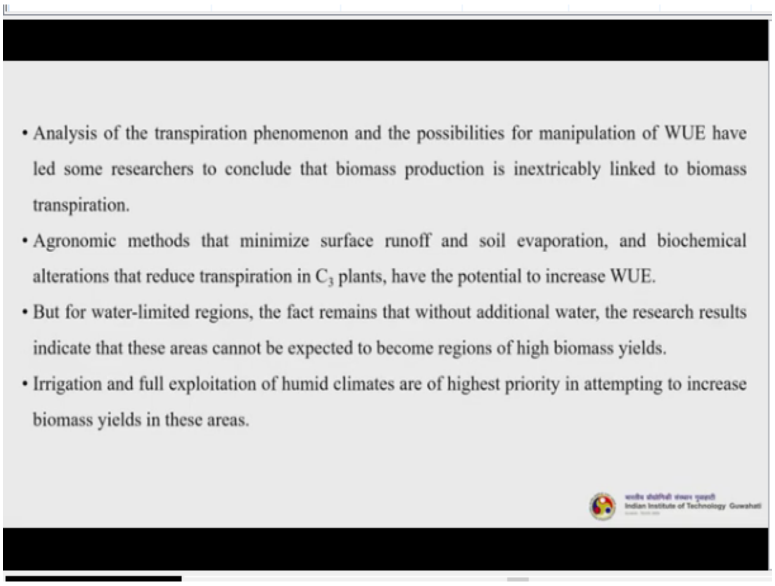

Analysis of the transpiration phenomena and the possibilities for manipulation of WUE have led some researchers to conclude that biomass production is inextricably linked to the biomass transpiration. Agronomic methods that minimize surface runoff and soil evaporation and biochemical alterations that reduce transpiration in C_3 plants have the potential to increase the WUE.

But for water limited regions fact remains that without additional water the research results indicate that these areas cannot be expected to become regions of high biomass yields. Irrigation and full exploitation of humid climates are of the highest priority in attempting to increase biomass yield in these areas. So, basically in India, you know, most of our agricultural lands till date depends on the natural rain fall. We will always be looking towards a better monsoon this year or that year (and so on). So, as we do not have lift irrigation system in most of the agricultural lands. Though in many areas it is there, but almost I can say about 50% or 40% has been covered (if I am correct, according to the statistics), but still almost 50% people completely depend upon the rainfall. Rainfall during the monsoon season and during other season also. So, irrigation has to be done properly whether it is for the biomass production in a large scale for the dedicated energy crops or for our usual agricultural purposes also.

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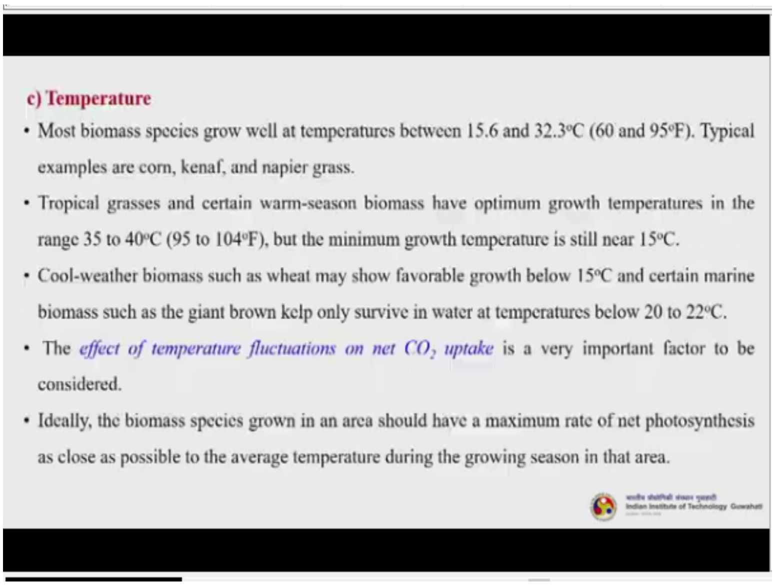

Now, let us understand the effect of temperature. Most biomass species grow well at temperatures between 15.6 and 32.3 degrees centigrade. Typical examples are corn, kenaf and napier grass. So, kenaf is basically in the African continent, it is being planted for years together for food and fiber purposes. Napier grass is another plant in grass family which is being used for fuel production.

So, tropical grasses and certain warm season biomass have optimum growth temperatures in the range of 35 to 40 degrees centigrade, but minimum growth temperature is still near 15 degrees. So, cool weather biomass such as wheat may show favourable growth below 15 degrees centigrade and certain marine biomass such as the giant brown kelp only survive in water at temperature below 20 to 22 (degree centigrade).

Giant brown kelp is an algae. So, it is a big algae (which) basically looks like plant inside the sea. So, it cannot survive at a temperature more than 22 degrees centigrade. The effect of temperature fluctuations on net carbon dioxide uptake is a very important factor to be considered. Ideally, the biomass species grown in an area should have a maximum rate of net photosynthesis as close as possible to the average temperature during the growing season in that particular area.

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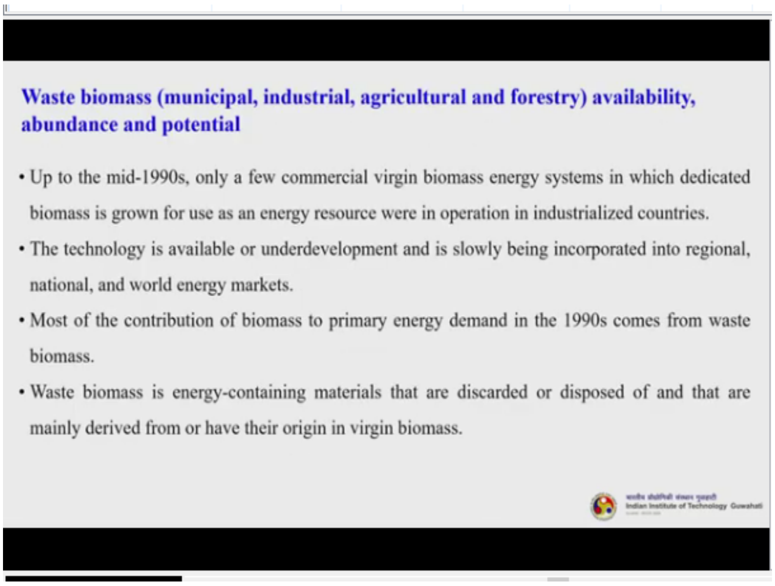

So, now let us understand about different wastes one by one. So, waste biomass, municipal, industrial, agricultural and forestry, their availability, abundance and potential. So, up to the mid 1990s only a few commercial virgin biomass energy systems in which dedicated biomass is grown for use as an energy resource were in operation in industrialized countries (basically Europe and America).

So, the technology is available or under development and is slowly being incorporated into regional, national and world energy markets. Most of the contribution of biomass to primary energy demand in the late 1990s comes from waste biomass. Now, waste biomass is energy containing materials that are discarded or disposed of and that are mainly derived from or have their origin in the virgin biomass.

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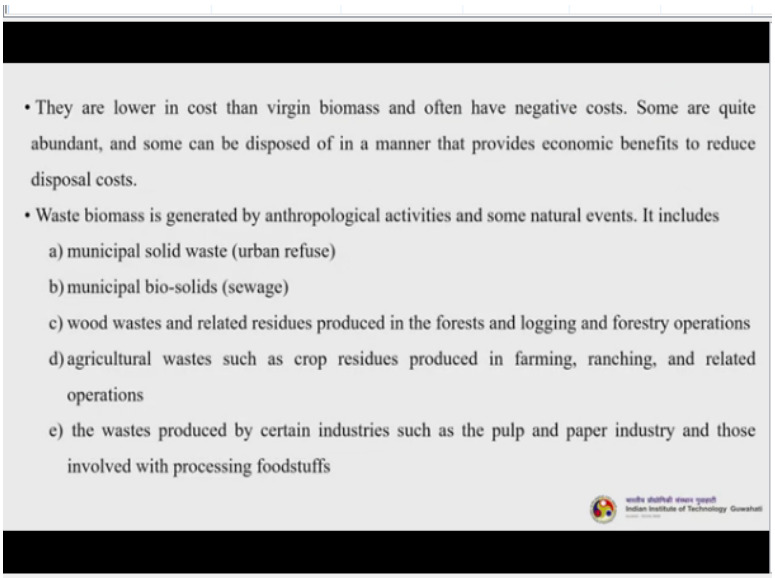

So, they are lower in cost than the virgin biomass and often have negative costs, because they are being just thrown away. So, some are quite abundant and some can be disposed of in a manner that provides economic benefits to reduce disposal costs. So, having said that, another most important thing we must understand and we are slowly getting aware of the fact is segregation of the wastes. Whether segregation of the wastes is at home or in offices, whether it is in plants where we are processing biomass, or whether it is in hotels and restaurants and canteens. So, it is having a very big effect on the further downstream processing. So waste biomass is generated by anthropological activities and some natural events also. So, it includes municipal solid waste, basically urban refuse, municipal bio-solids (sewage), wood wastes and related wastes produced in the forest and logging and forestry operations, agricultural waste such as crop residues produced in farming, ranching and related operations, the wastes produced by certain industries such as the pulp and paper industry and those involved with processing of foodstuffs.

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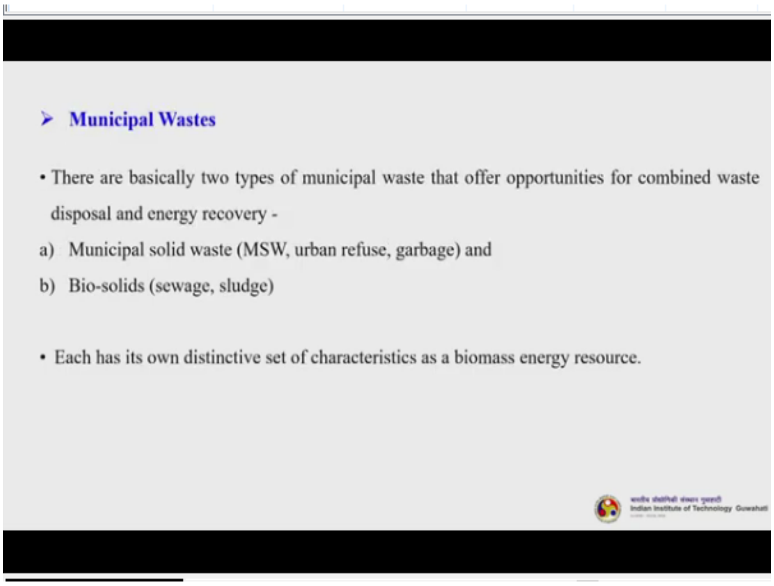

Now let us understand municipal wastes. So, there are basically two types of municipal wastes that offer opportunities for a combined waste disposal and energy recovery. First is the municipal solid waste that is MSW, the garbage, urban refuse and then the bio-solids, that is coming from the sludge and sewage. So, each has its own distinctive set of characteristics as a biomass energy resource. There are huge works already reported in literature. So, you can refer to those.

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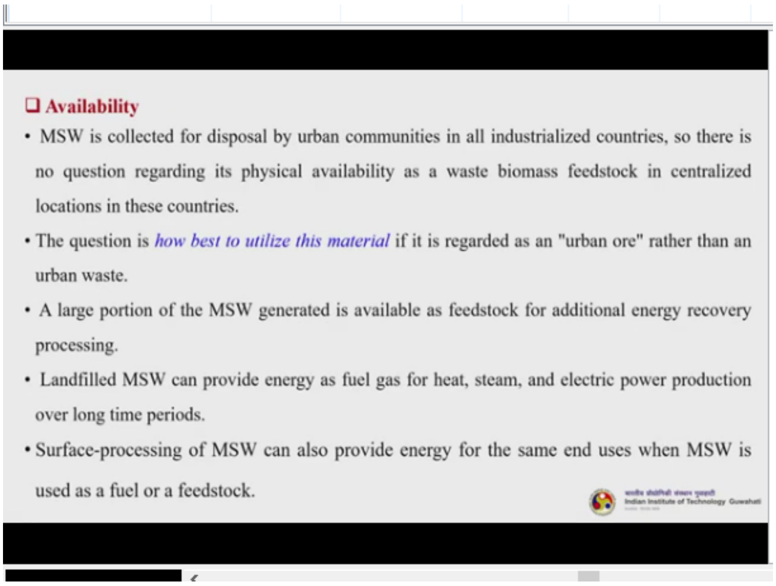

MSW is collected for disposal by urban communities in all industrialized countries. So, there is no question regarding its physical availability as a waste biomass feedstock in centralized location in these countries. The question is *how best to utilize this material* if it is regarded as an “urban ore” rather than urban waste. A large portion of the MSW generated is available as feedstock for additional energy recovery processing.

Landfilled MSW can provide energy as fuel gas for heat, steam and electric power production over a long period of time. Surface processing of MSW can also provide energy for the same end uses when MSW is being used as a fuel or feedstock. So, basically what we need to understand is, how best we are going to use. Please understand that technologies are available to process MSW, there is nothing new to be done. Available technologies are already available.

But segregation of waste is the most important thing. Then another important thing is basically how you are going to utilize it and where. Again you are collecting the municipal solid waste from the entire municipal area, city, townships or even the rural areas; then you have to transport it. Again transportation cost is a big thing. Where your plant is located, the location of the land plant is again important thing.

So, we need to have an integrated approach thereby understanding the value of the MSW what type of value it is. Now, please do not think that every MSWs economic value, let us say, with respect to energy production is same. It is not so. So, the MSW from Bombay will have certain value, the MSW from Guwahati maybe something else. So, component wise it may vary.

So, we have to see which MSW is best suited for what technology; that is also to be seen. So, we need an integrated approach where MSW can be properly utilized, converted for energy purposes as well as for other value addition also.

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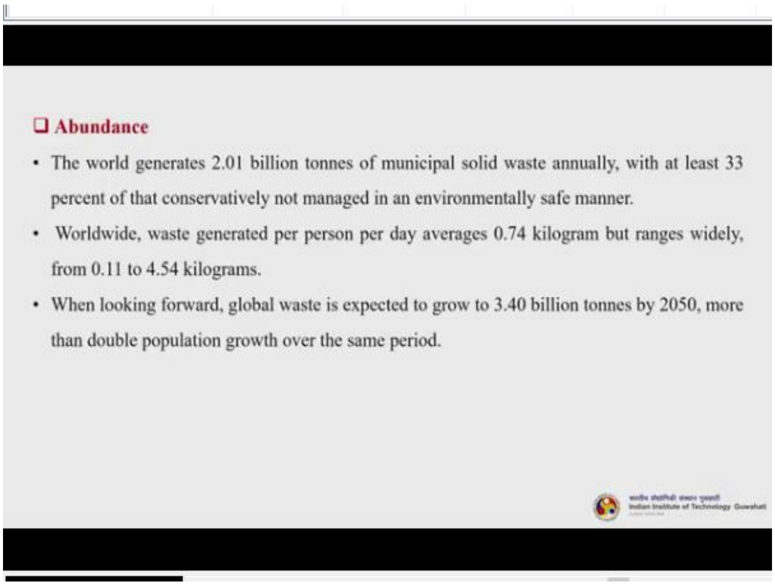

So, the world generates almost 2.01 billion tonnes of municipal solid waste annually with at least 33% of that conservatively not managed in an environmentally safe manner. I am sure this percentage 33% may be very high in Asian and African countries. So, worldwide waste generated per person per day averages almost 0.74 kilogram, but ranges widely from 0.11 to 4.54 kilograms.

The waste generated per person from the developed countries is much, much higher than that generated from the underdeveloped or developing countries. So, when looking forward, global waste is expected to grow to 3.4 billion tonnes by 2050, more than double population growth over the same period.

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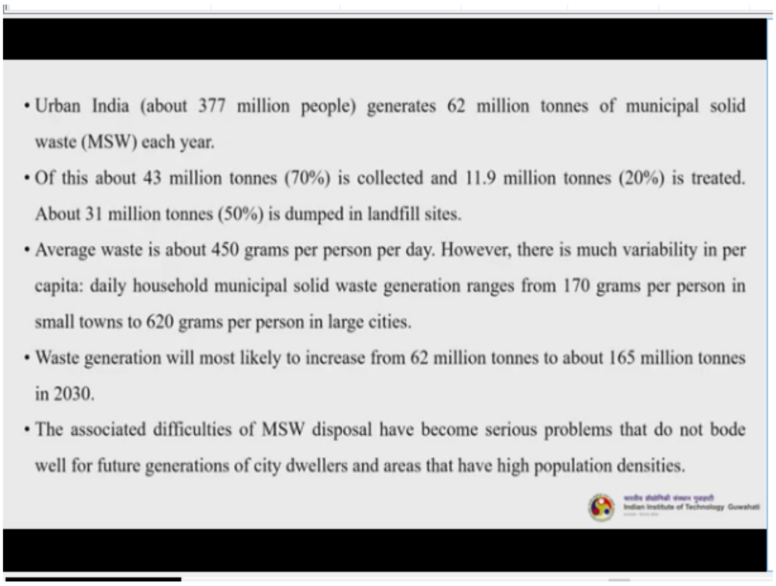

Let us talk about India. Urban India about 377 million people generates 62 million tonnes of municipal solid waste each year. Of this about 43 million tonnes (amounting to almost 70%) is collected and 11.9 million tonnes is treated. About 31 million tonnes is dumped in landfill sites. Now when we dump MSW in landfill sites, many a times it produces many different types of gases, including methane and some toxic gases, thereby polluting the nearby environment.

So, if it is not properly landfilled, then it is going to affect two things**.** First is the environment in the form of leakages of gases. Second is, leaching of the components to the groundwater sources (toxic components). Average waste is about 450 grams per person per day (this is an Indian figure). However, there is much variability in per capita: daily household municipal solid waste generation ranges from 170 grams per person in small towns to 620 grams per person in large cities.

So, the trend is same; the urbanized people living in the large cities, produce more waste than the people those are staying in the rural areas. So, waste generation will most likely increase from 62 million tonnes to about 165 million tonnes in 2030. The associated difficulties of MSW disposal have become a serious problem that do not bode well for the future generations of city dwellers and the areas that have high population densities.

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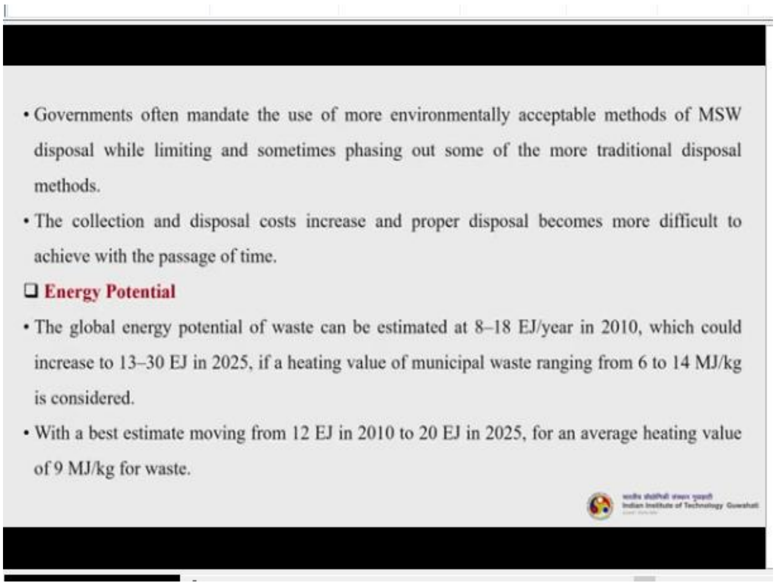

So, governments often mandate the use of more environmentally acceptable methods of MSW disposal by limiting and sometimes phasing out some of the more traditional disposal methods. The collection and disposal costs increase and proper disposal becomes more difficult to achieve with the passage of time. And talking about the energy potential; the global energy potential of waste can be estimated at 8 to 18 Exajoule per year in 2010, which could increase to 13 to 30 in 2025, if a heating value of municipal waste ranging from 6 to 14 mega joules per kg.

So, with the best estimate moving from 12 Exajoule in 2010 to 20 Exajoule in 2025, for an average heating value of 9 mega joules per kg for waste. Some sort of estimation basically; exact figures may vary depending upon the type of waste we are dealing with.

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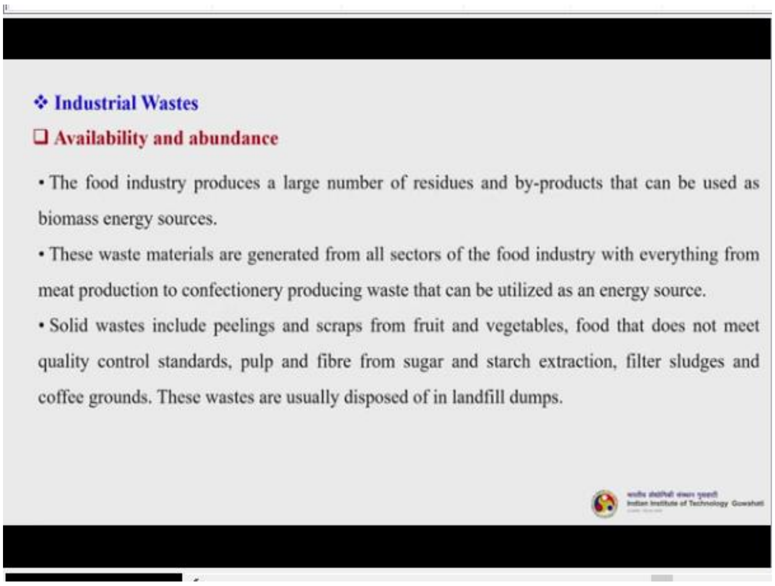

So, now, let us talk about industrial wastes. So, the food industry produces large number of residues and by-products that can be used as biomass energy sources. These waste materials are generated from all sectors of the food industry, with everything from meat production to confectionery producing waste that can be utilized as an energy source. Solid wastes include peelings and scraps from fruit and vegetables, food that do not meet quality control standards, pulp and fiber from sugar and starch extraction, filter sludges and coffee grounds. These wastes are usually disposed of in the landfill dumps.

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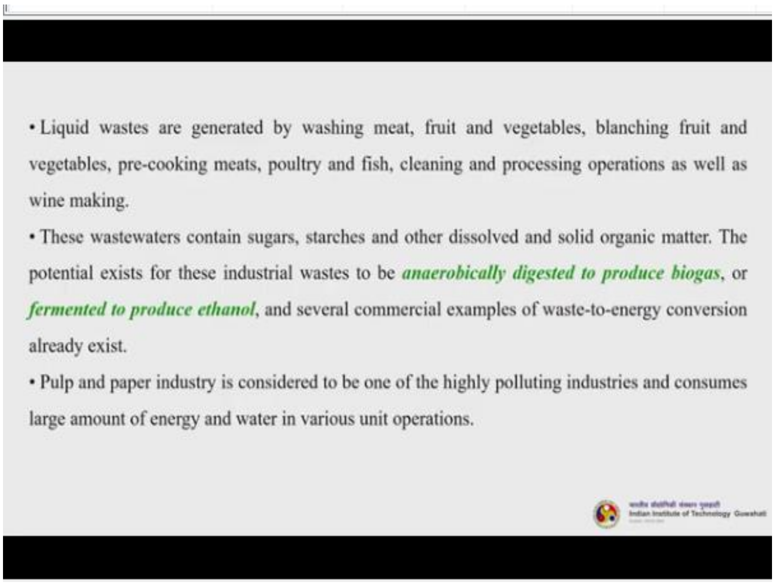

Now, there are liquid wastes too. So, liquid wastes are generated by washing meat, fruit and vegetables, blanching fruit and vegetables, pre cooking meats, poultry and fish, cleaning and processing operation as well as wine making. These wastewaters contain sugars, starches and other dissolved and solid organic matter. The potential exists for these industrial wastes to be anaerobically digested to produce biogas or fermented to produce ethanol (bio-ethanol), and several commercial examples of waste to energy conversion already exist. Pulp and paper industry is considered to be one of the highly polluting industries and consumes large amount of energy and water in various unit operations.

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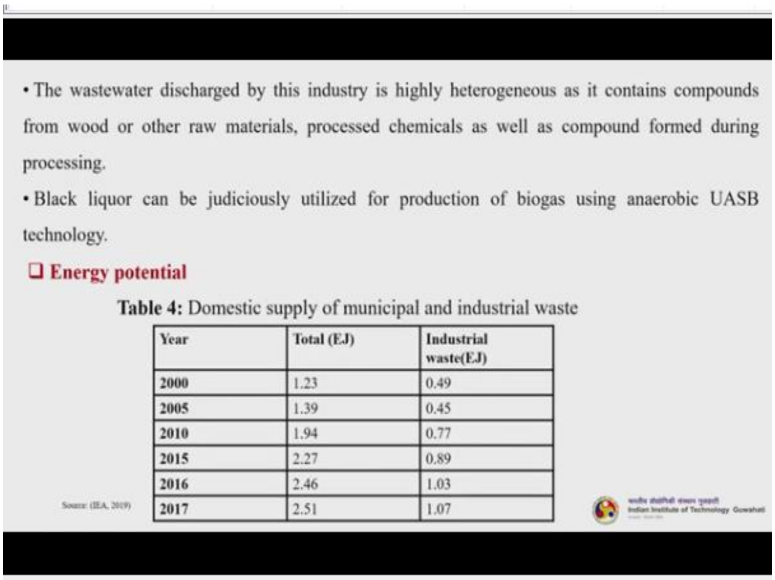

Year	Total (EJ)	Industrial waste(EJ)
2000	1.23	0.49
2005	1.39	0.45
2010	1.94	0.77
2015	2.27	0.89
2016	2.46	1.03
2017	2.51	1.07

The wastewater discharged by this industry is highly heterogeneous as it contains compounds from wood and other raw materials, processed chemicals as well as compound formed during processing. Black liquor can be judiciously utilized for production of biogas using anaerobic UASB technology. We will discuss about that technology later on in one of our class. So, if you look at this particular table, you can see that this gives the domestic supply of municipal and industrial waste. So, it is the total value and how much the industrial waste is contributing (that is almost close to 50%).

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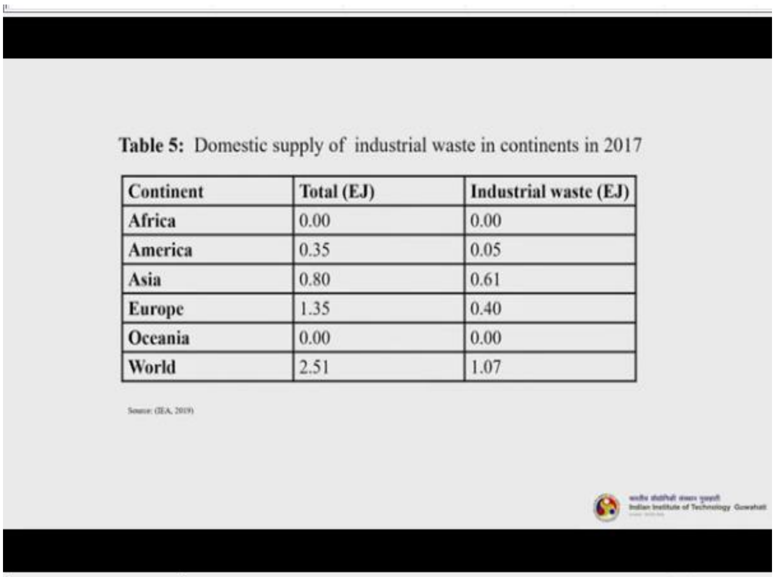

Continent	Total (EJ)	Industrial waste (EJ)
Africa	0.00	0.00
America	0.35	0.05
Asia	0.80	0.61
Europe	1.35	0.40
Oceania	0.00	0.00
World	2.51	1.07

So, this is again continent wise and understanding of the industrial waste and their energy values. So, again, almost close to 40% here, if you look at the global data.

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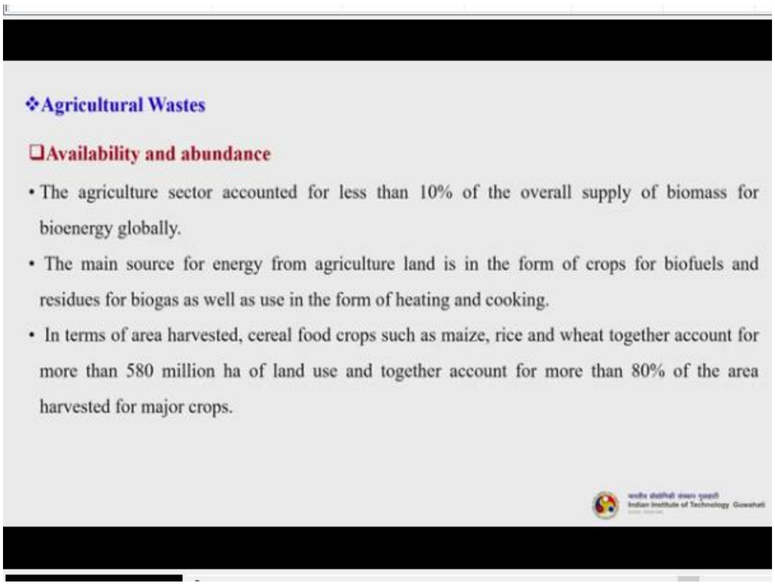

Now, we are discussing about the agricultural wastes. So, out of all the wastes, my understanding is that, agricultural waste has the greatest potential that can be utilized for energy production or the bioenergy production, whether it is pyrolysis, whether it is gasification, whether it is producing ethanol or use the ABE fermentation to get butanol, biogas. Any such thing can be done using the agricultural residues, because they are very clean and are produced in very large quantities. So, there is certainly a sustainable issue for throughout the year getting this one (availability), but we do not have to segregate things. Rather, technologies are now developed, where we can mix more than one type of agricultural waste including forest waste to produce and convert them to value added products and of course fuels.

So, the main source for energy from agricultural land is in the form of crops for biofuels and residues for biogas, as well as use in the form of heating and cooking. In terms of area harvested, cereal food crops, such as maize, rice and wheat, together account for more than 580 million hectares of the land use and together account for more than 80% of the area harvested for major crops.

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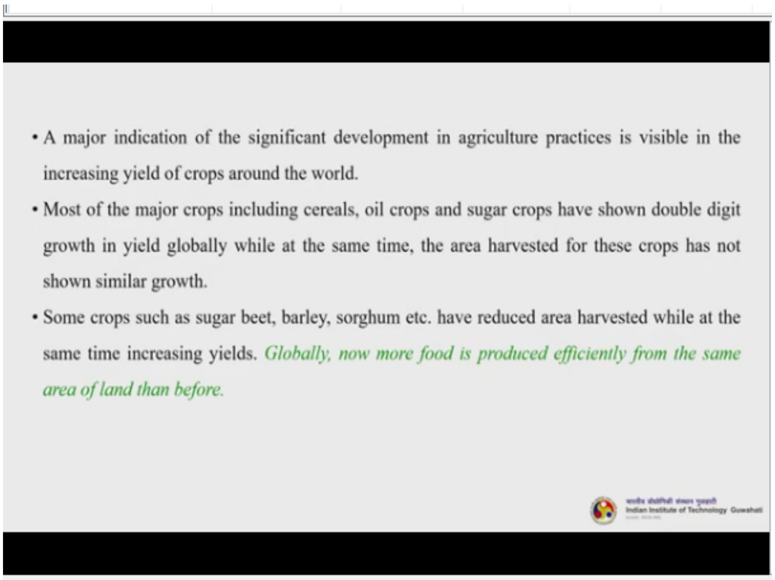

So, a major indication of the significant development in agricultural practices is visible in the increasing yield of crops around the world. Most of the major crops including cereals, oil crops and sugar crops have shown double digit growth in yield globally, while at the same time the area harvested for these crops has not shown similar growth. Now, some crops such as sugar beet, barley, sorghum, etc., have reduced area harvested while at the same time increasing yields.

So, globally, now, more food is being produced efficiently from the same area of land than before. Thanks to the development in agricultural sector. So, high yield crops are now being planted, which gives better yield and they are also pest resistant, thereby increasing their overall yield.

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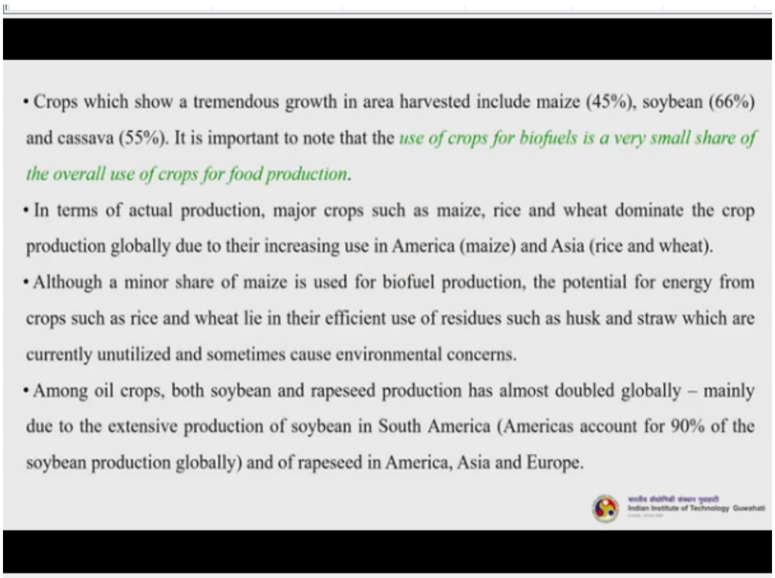

Crops which show a tremendous growth in area harvested include maize 45%, soybean 66% and cassava 55%. Now, it is important to note that the use of crops for biofuels is a very small share of the overall use of crops for food production. In terms of actual production major crops such as maize, rice and wheat dominate the crop production globally due to their increasing use in America (maize) and Asia (rice and wheat).

Although a minor share of maize is used for biofuel production, the potential for energy from crops such as rice and wheat lie in their efficient use of residues such as the husk and straw, which are currently unutilized and sometimes cause environmental concerns. In India you know that every year there is a big problem near Delhi; from the Punjab and Haryana side the agricultural crop residues are being burnt up. So, in huge quantities the entire polluted air affects the National Capital Region, and breathing also becomes a problem. So, it is a very serious problem. Now, many farmers have understood the bioenergy potential of the residues or wastes that is generated from their crops to produce some value added products and they have started making small plants near their agricultural lands and farms, to produce energy. So, there are certain reports that farmers are producing energy from gasification unit and even pyrolysis unit (small scale). So, things are happening in a very positive way, in India, as well as in other developing and developed countries.

So, although a minor share of maize used for biofuels production, the potential for energy from crops such as rice and wheat lie in their efficient use of residues such as husk and straw, which are currently unutilized and sometimes cause environmental concerns. So, now, let us talk about the oil crops. Both soybean and rapeseed production has almost doubled globally because of their huge demand - mainly due to the extensive production of soybean in South America (Americas itself account for 90% of the soybean production globally) and of rapeseed in America, Asia and Europe.

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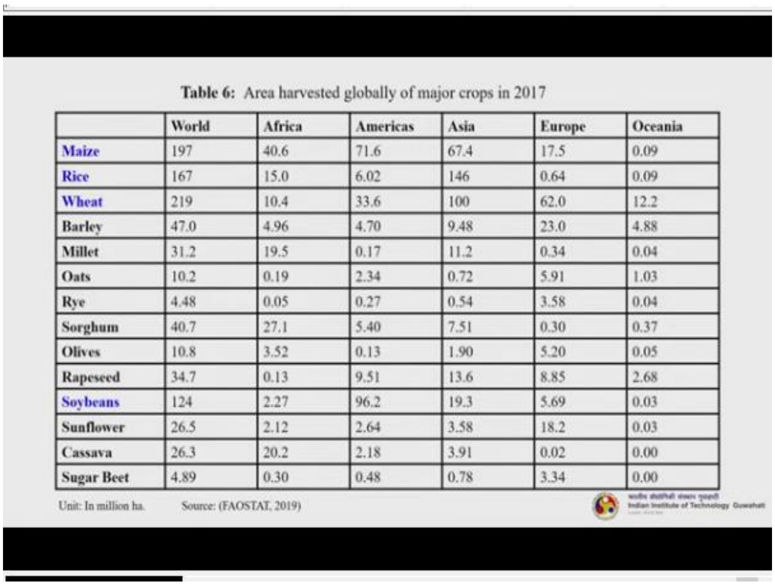
Table 6: Area harvested globally of major crops in 2017

	World	Africa	Americas	Asia	Europe	Oceania
Maize	197	40.6	71.6	67.4	17.5	0.09
Rice	167	15.0	6.02	146	0.64	0.09
Wheat	219	10.4	33.6	100	62.0	12.2
Barley	47.0	4.96	4.70	9.48	23.0	4.88
Millet	31.2	19.5	0.17	11.2	0.34	0.04
Oats	10.2	0.19	2.34	0.72	5.91	1.03
Rye	4.48	0.05	0.27	0.54	3.58	0.04
Sorghum	40.7	27.1	5.40	7.51	0.30	0.37
Olives	10.8	3.52	0.13	1.90	5.20	0.05
Rapeseed	34.7	0.13	9.51	13.6	8.85	2.68
Soybeans	124	2.27	96.2	19.3	5.69	0.03
Sunflower	26.5	2.12	2.64	3.58	18.2	0.03
Cassava	26.3	20.2	2.18	3.91	0.02	0.00
Sugar Beet	4.89	0.30	0.48	0.78	3.34	0.00

Unit: In million ha. Source: (FAOSTAT, 2019)

This will make you understand region wise the areas that is being utilized for harvesting certain crops, (this is in 2017). In the worldwide figure if you see, out of all these crops, maize, rice, wheat and soybeans constitute more than 80% (75 to 80%).

So, similarly, this will tell us, continent wise crop yield globally. Again, you can see here, that the sugar beet and the sugarcane are the highest in yields because they are produced in an extremely large scale in the Americas. So, this is production quantity of crops globally in 2017. Again you can see that sugarcane, maize, rice and wheat, they constitute almost more than 75%.

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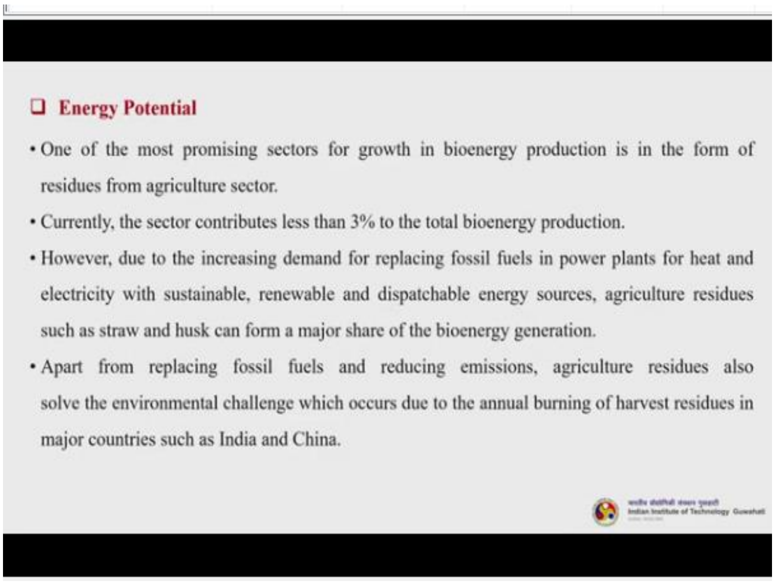

So, let us talk about energy potential. Now one of the most promising sectors for growth in bioenergy production is in the form of residues from agriculture sector. Currently, that sector contributes less than 3% to the total bioenergy production. However, due to the increasing demand for replacing fossil fuels in power plants for heat and electricity with sustainable, renewable and dispatchable energy sources, agricultural residues such as straw and husk can form a major share of the bioenergy generation. Now, apart from replacing fossil fuels and reducing emissions, agricultural residues also solve the environmental challenge, which can occur due to the annual burning of harvested residues in major countries such as China and India. This is what I just mentioned about; burning of the crop residues.

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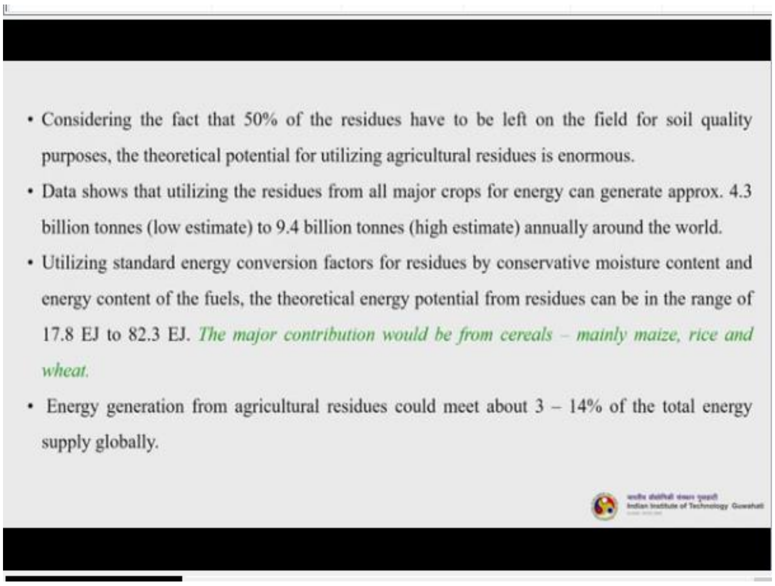

Considering the fact that 50% of the residues have to be left on the field for soil quality purposes (basically to enhance the soil quality), the theoretical potential for utilizing agricultural residue is still enormous. Data shows that utilizing the residues from all major crops for energy can generate approximately 4.3 billion tonnes to 9.4 billion tonnes annually around the world.

Utilizing standard energy conversion factors for residues by conservative moisture content and energy content of the fuels, the theoretical energy potential from residues can be in the range of 17.8 Exajoule to 82.3 Exajoule. The major contribution is coming from the cereals, mainly maize, rice and wheat. So energy generation from agricultural residues could meet about 3 to 14% of the total energy supply globally. So, this is an estimated figure for around 2030.

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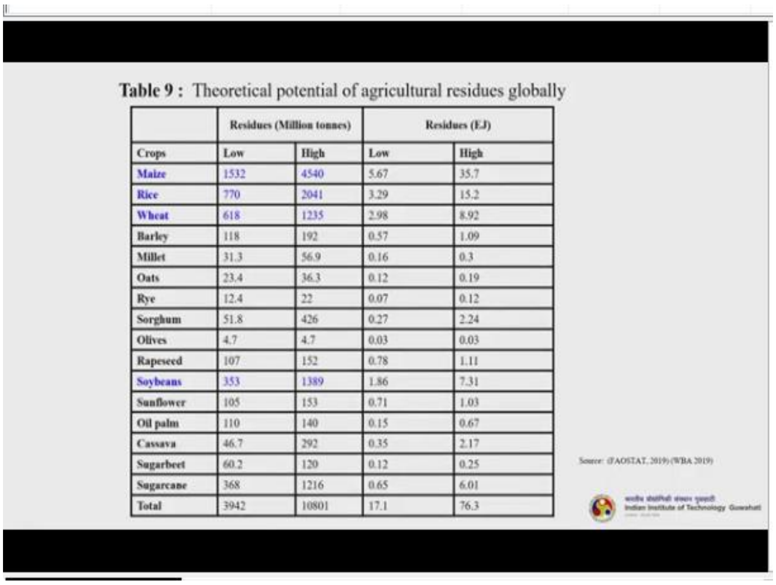

Table 9 : Theoretical potential of agricultural residues globally

	Residues (Million tonnes)		Residues (EJ)	
Crops	Low	High	Low	High
Maize	1532	4540	5.67	35.7
Rice	770	2041	3.29	15.2
Wheat	618	1235	2.98	8.92
Barley	118	192	0.57	1.09
Millet	31.3	56.9	0.16	0.3
Oats	23.4	36.3	0.12	0.19
Rye	12.4	22	0.07	0.12
Sorghum	51.8	426	0.27	2.24
Olives	4.7	4.7	0.03	0.03
Rapeseed	107	152	0.78	1.11
Soybeans	353	1389	1.86	7.31
Sunflower	105	153	0.71	1.03
Oil palm	110	140	0.15	0.67
Cassava	46.7	292	0.35	2.17
Sugarbeet	60.2	120	0.12	0.25
Sugarcane	368	1216	0.65	6.01
Total	3942	10801	17.1	76.3

Source: (FAOSTAT, 2019) (WBA 2019)

So, this is the theoretical potential of the agricultural residues globally. You can see that the first column is giving you the different types of crops, then the residues in million tonnes and then the residues' energy potential. You can see that maize, rice, wheat and soybean is constituting more than 80% of the total production. And if you look at the corresponding energy values, they are actually excellent. So, they are better and higher than other crops like barley, oats, sorghum, olive etc.

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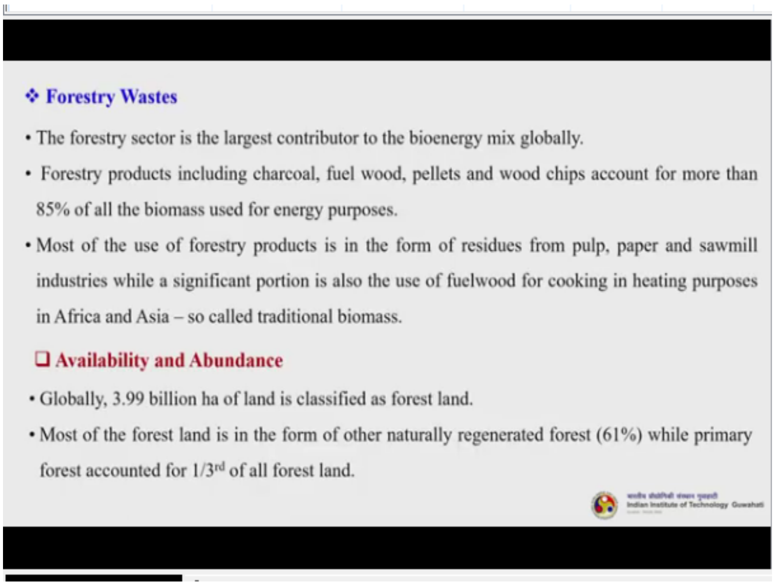

Now, let us understand the importance of the forestry wastes. The forestry sector is the largest contributor to the bioenergy mix globally. Forestry products, including charcoal, fuel, pellets and wood chips account for more than 85% of the biomass used for energy purposes. Most of the use of the forestry product is in the form of residues from pulp, paper and sawmill industries while a significant percentage also the use of fuelwood for cooking and heating purposes in Africa and Asia - so called traditional fuelwood or biomass. Globally, 3.99 billion hectares of the land is classified as forest land. Most of the forest land is in the form of other naturally regenerated forest (almost 61%), while primary forest accounted for one third of the all forest land.

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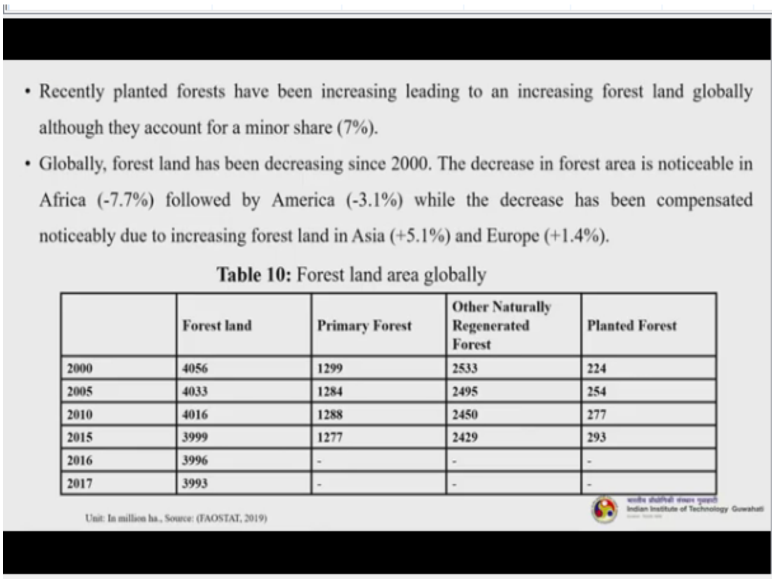

Recently, planted forests have been increasing, leading to an increasing forest land globally, although they account for a minor share (7%). Globally, forest land has been decreasing since 2000. The decrease in forest area is noticeable in Africa (almost -7.7%), followed by America (-3.1%) while the decrease has been compensated noticeably due to the increasing forestland in Asia (+ 5.1%) and Europe (+ 1.4%). I can tell you that India played a significant role in afforestation adding up to this number. So, you can see in this particular table, the forest land area that is globally available.

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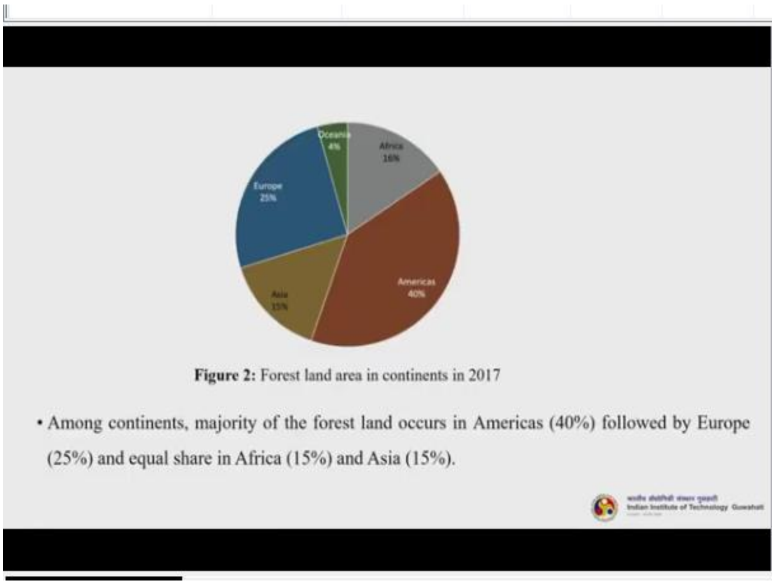

So, among continents, majority of the forest land occurs in the Americas (40%), followed by Europe (25%) and equal share in Africa and Asia (15% each).

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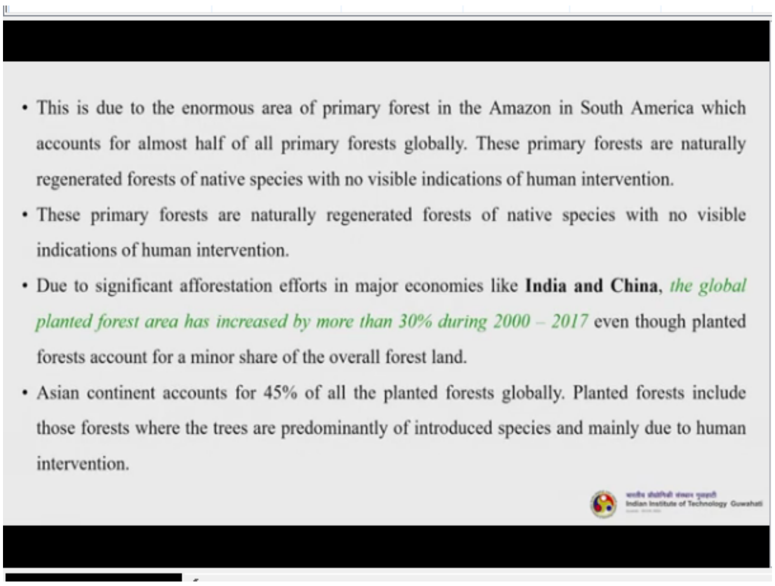

So, this is due to the enormous area of primary forest in the Amazon in South America, which accounts for almost half of all primary forests globally. These primary forests are naturally regenerated forests of native species with no visible indications of human intervention.

So, due to significant afforestation efforts in the major economies like India and China, the global planted forest area has increased by more than 30% during 2000 to 2017 even though planted forests account for a minor share of the overall forest land. China and India are engaged in huge afforestation. So, as a result, there is a huge upsurge in the total amount of forest area that is available, but these are basically manmade forest.

So, Asian continent accounts for 45% of all the planted forests globally. Planted forests include those forests where the trees are predominantly of introduced species and mainly due to human intervention.

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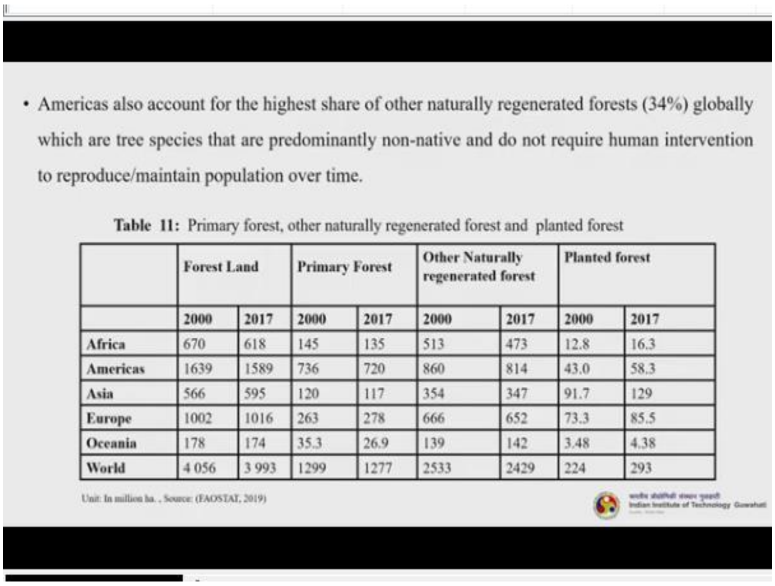

- Americas also account for the highest share of other naturally regenerated forests (34%) globally which are tree species that are predominantly non-native and do not require human intervention to reproduce/maintain population over time.

Table 11: Primary forest, other naturally regenerated forest and planted forest

	Forest Land		Primary Forest		Other Naturally regenerated forest		Planted forest	
	2000	2017	2000	2017	2000	2017	2000	2017
Africa	670	618	145	135	513	473	12.8	16.3
Americas	1639	1589	736	720	860	814	43.0	58.3
Asia	566	595	120	117	354	347	91.7	129
Europe	1002	1016	263	278	666	652	73.3	85.5
Oceania	178	174	35.3	26.9	139	142	3.48	4.38
World	4 056	3 993	1299	1277	2533	2429	224	293

Unit: In million ha., Source: (FAOSTAT, 2019)

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Americas also account for the highest share of other naturally regenerated forest (34%) globally, which are tree species that are predominately non native and do not require human intervention to reproduce/maintain population over time. So, this particular table will tell you about the primary forest, other naturally regenerated forest and the planted forest that is available.

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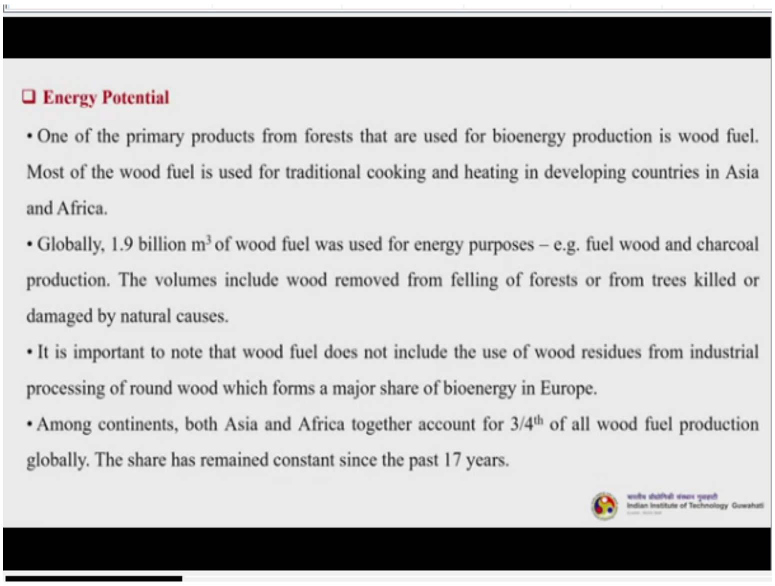

Now, let us understand their energy potential. So, one of the primary products from forests that are used for bioenergy production is wood fuel. Most of the wood fuel is used for traditional cooking and heating in developing countries in Asia and Africa. Globally 1.9 billion meter cube of wood fuel was used for energy purposes - for example, fuel wood and charcoal production.

Now, the volume includes wood removed from felling of forest or from trees killed or damaged by natural causes. We are not supposed to cut the trees, for making any fuel. So, it is important to note that wood fuel does not include the use of wood residues from industrial processing of round wood, which forms a major share of the bioenergy in Europe. Among continents, both Asia and Africa together account for three fourths of all wood fuel production globally. India and China both adding a larger share. And the share has remained constant in the last past 17 years, which is a good thing.

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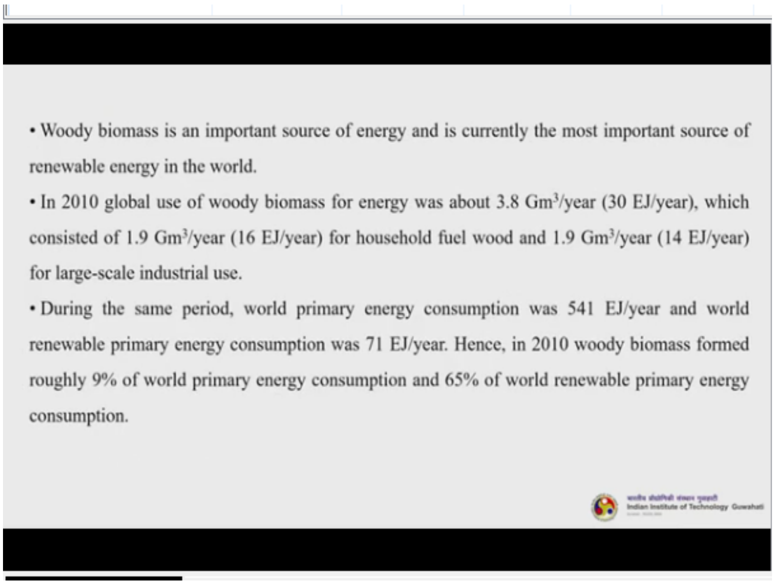

So, woody biomass is an important source of energy and is currently the most important source of renewable energy in the world. In 2010, global use of woody biomass for energy was about 3.80 Gm^3/year, which consisted of 1.90 Gm^3/year for households fuel wood and the similar number for large scale industrial use. During the same period, world primary energy consumption was 541 Exajoule per year and world renewable primary energy consumption was 71 Exajoule per year. Hence in 2010, woody biomass formed roughly 9% of the world primary energy consumption and 65% of the world's renewable primary energy consumption.

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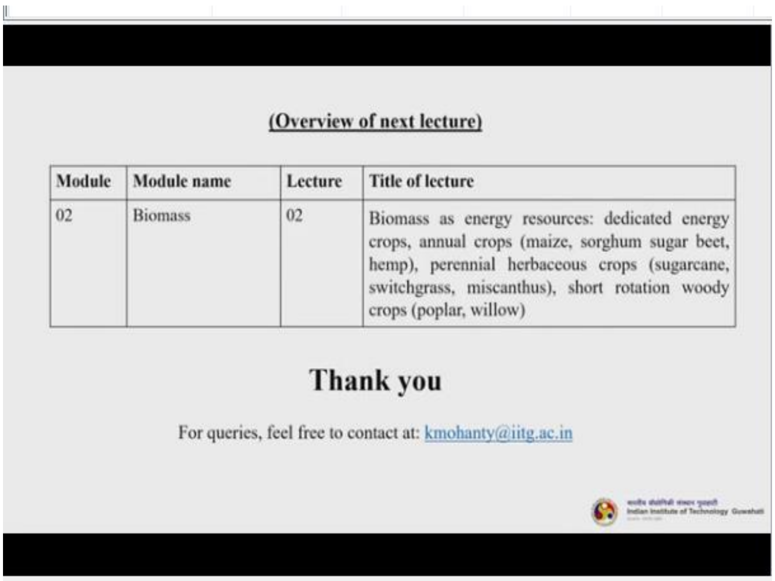

So, I wind up with this today and in our next class, we are going to discuss about the biomass as energy resources. We will be discussing about the dedicated energy crops that I talked about in today's lecture and even last lecture. So, some of those crops we'll understand in a better way. How they are being grown, what are their properties and how best they can be utilized, like maize, sorghum, sugar beet, etc. And some perennial crops such as sugar cane, switch grass, miscanthus, etc.

So, thank you very much. And in case you have any query, please drop a mail to me at kmohanty@iitg.ac.in or feel free to log into the Swayam portal and post your query there. I will be happy to address those. Thank you.