Biomass Conversion and Biorefinery
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Module 05
Lecture-15
Products and Commercial Success Stories

Good morning students, this is lecture 3 of module 5. And in this lecture as you know that we are discussing about the thermochemical processes. Today we will discuss about the thermal conversion products and some commercial successful stories. So, let us begin.

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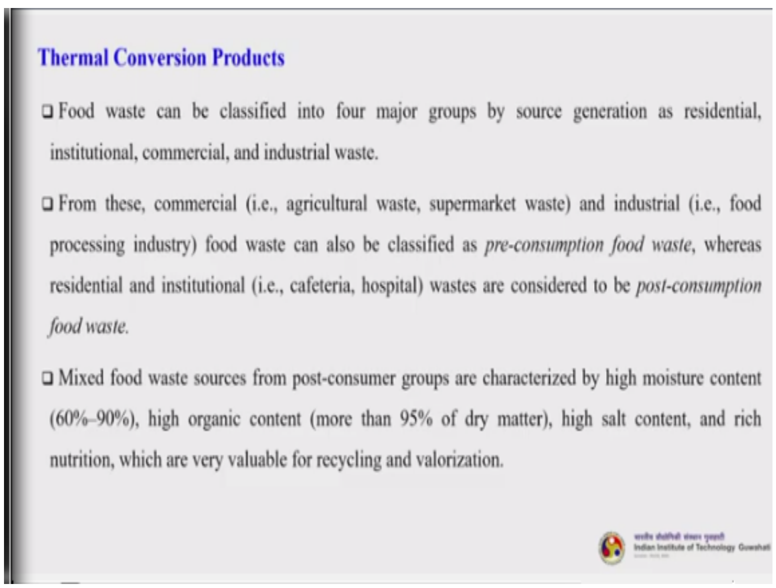

Food waste can be classified into four major groups by source generation as residential, institutional, commercial and industrial. So, we have discussed about different types of biomasses which includes this type of wastes also. And we will try to understand that how this food waste has been commercially used to generate different types of value added products including the biofuels.

Now from these type of food waste, commercial (which takes into account agricultural waste, supermarket waste), and industrial (for example, food processing industry). So, these food wastes can be classified as pre-consumption food waste, and whereas residential and institutional like cafeteria, hospital etc, these wastes are considered to be the post-consumption food waste.

So, mixed food waste sources from post consumer groups are characterized by high moisture content almost 60 to 90% very, very high moisture content, including also high organic content almost 95% dry matter. Along with that there is high salt content and rich nutrition which are very valuable for recycling and valorization.

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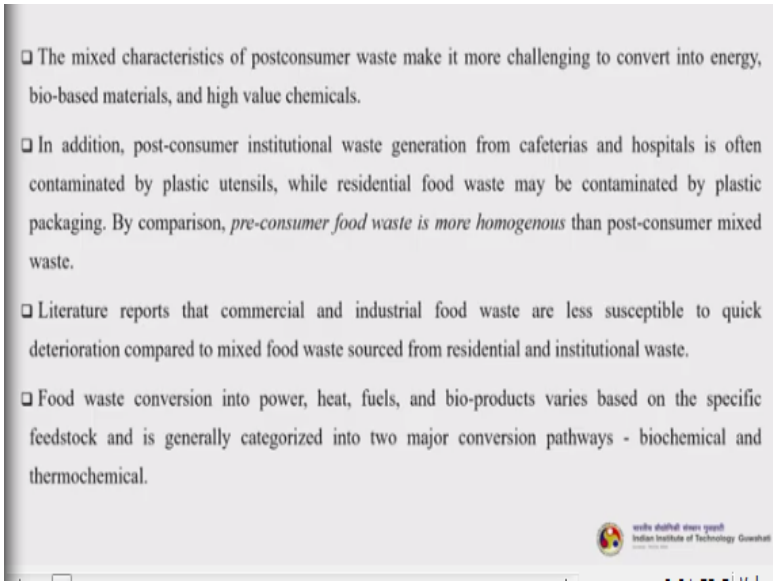

The mixed characteristics of postconsumer waste make it more challenging to convert into energy, bio based materials and high value chemicals. In addition, post consumer institutional waste generation from cafeterias and hospitals is often contaminated by plastic utensils, because you know that we have a habit of carrying all these materials in plastic. So, when we consume the food, we just dump it along with the rest of food waste, so that creates a big problem.

So, by comparison pre consumer food waste is more homogeneous than post consumer mixed waste. So, post consumer waste is always a mixed waste, so it comes with mixing up polyethylenes that means plastics as well as paper and some other materials also. So, literature reports that commercial and industrial food waste are less susceptible to quick deterioration compared to mixed food waste from residential and institutional waste.

Now food waste conversion into power, heat, fuels and bio-products varies based on the specific feedstock and is generally categorized into 2 major conversion pathways either biochemical or thermochemical.

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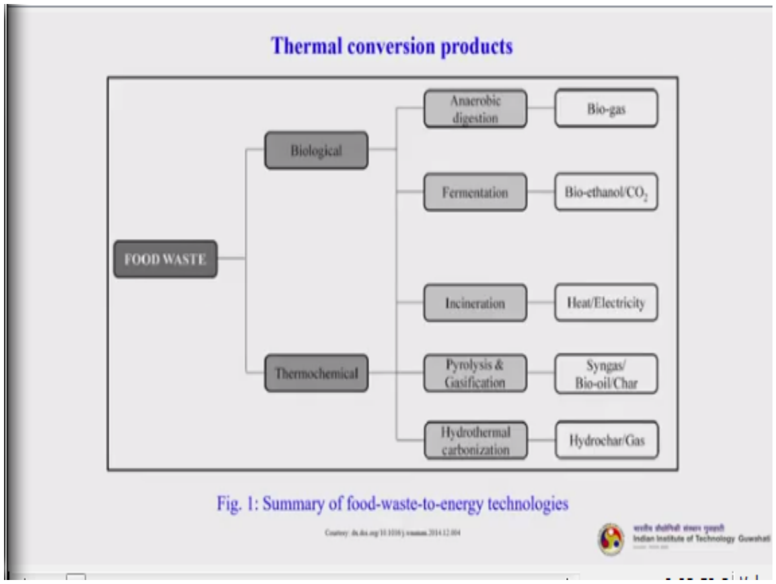

So, let us understand the thermochemical conversion products of the food waste. Now this schematic will make you understand that how the different food waste can be converted by both the routes, one is biochemical as well as thermochemical. So, let us see the first one, biological one. So, you can go for anaerobic digestion, which will yield me biogas enriched with methane, you can ferment it.

So, after taking the carbohydrate parts and again do hydrolysis to get glucose. We will get an ethanol platform, so bio-ethanol apart from small carbon dioxide. So, then coming to thermochemical, so we can have incineration, incineration will give me heat and electricity. If you go for pyrolysis and gasification it gives me bio oil, char which is coming from the pyrolysis and syngas which is a product from gasification, this we have discussed in our last class.

So, another important thing is hydrothermal carbonization. So, that will give me hydrochar or char and some gases. Now this makes an understanding that food waste having enormous potential to be converted into so many different types of value added products apart from the energy either using the biological route or your thermochemical route.

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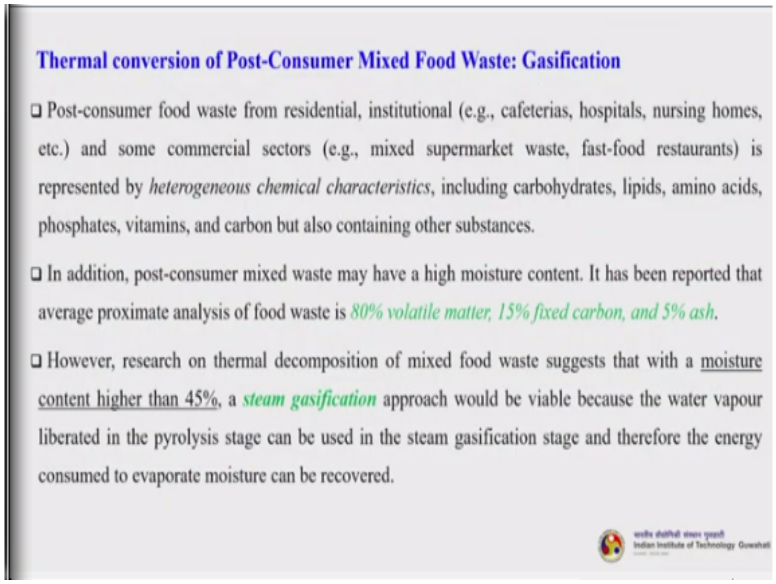

Let us understand the thermal conversion of post consumer mixed food waste by gasification. So, postconsumer food waste from residential, institutional and some commercial sectors is represented by heterogeneous chemical characteristics. So, because they include carbohydrates, lipid, amino acids, phosphates, vitamins and carbon, but also containing other substances. In addition, postconsumer mixed waste may have a high moisture content.

Now it has been reported that average proximate analysis of food waste is 80% volatile matter, 50% fixed carbon, 5% ash. So, this is just a generalized statistic for most of the so called postconsumer mixed waste. However, research on thermal decomposition of mixed food waste suggests that with a moisture content higher than 45%, a steam gasification approach would be viable because the water vapor liberated in the pyrolysis test can be used in the gasification stage and therefore, the energy consumed to evaporate moisture can be recovered.

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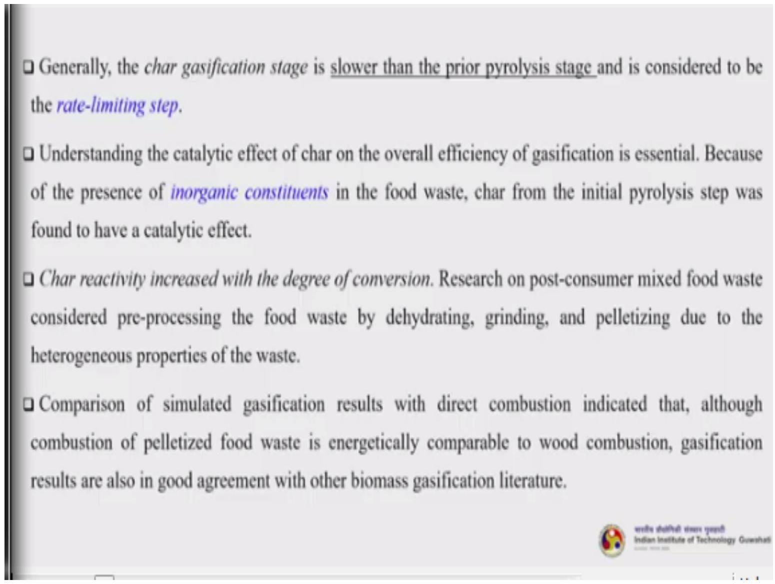

Generally, the char gasification stage is slower than the prior pyrolysis stage and that is why it is the rate limiting step. And understanding the catalytic effect of char on the overall efficiency of gasification is essential. Because of the presence of inorganic constituents in the food waste, char from the initial pyrolysis step was found to have a catalytic effect. If you recall our last lecture, then I precisely told you that when you talk about pyrolysis and gasification, please understand that pyrolysis is also a part of gasification.

This is what we are talking about here also. So, when gasification proceeds or starts, so the initial step is your dehydration or let us we can say that removal of the moisture around up to 150, 200 degrees centigrade beyond that your pyrolysis reaction starts in, so in the pyrolysis we will get a char. So, the resultant is char and very small amount of gas and other materials will come into picture.

Now this char with the help of either steam or air will be converted or let us say will be gasified with less than a theoretical amount of oxygen that is required to do combustion is required for the gasification process. So, that much amount of oxygen will gasify either it can be oxygen or it can be a steam. So, another important thing which here also we are mentioning that the char may contain several different types of inorganic materials.

So, these inorganic materials have a vital role to play during the gasification process. So, they may act as a catalyst during the gasification process thereby enhancing the rate of reaction and also increasing the yield. So, char reactivity increased with the degree of conversion. Research on post-consumer mixed food waste considered pre-processing the food waste by dehydrating, grinding and palletizing due to the heterogeneous properties of the waste.

Comparison of simulated gasification results with direct combustion indicated that, although combustion of pelletized food waste is energetically comparable to wood combustion, gasification results are also in agreement with other biomass gasification literature.

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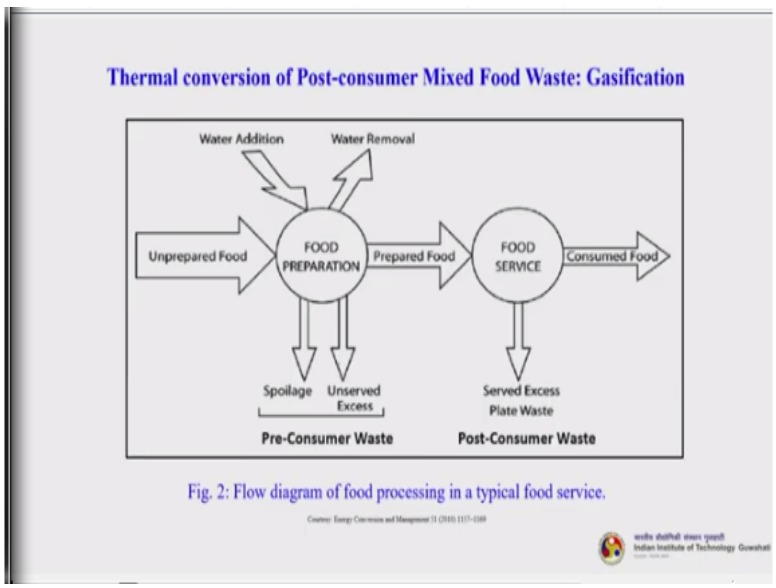

So, this is the schematic of the thermal conversion of post consumer mixed food waste through gasification**.** So, unprepared food, so this is the food preparation, so you can see the spoilage, unserved excess, so this is pre consumer waste. So, then of course water is hugely consumed during the processing of the food.

So, then prepared food, that goes to the food service, so you get consumed food and whatever served excess plate waste all these different types of wastes are being mixed. Plastics, then some cutlery things, your paper napkins all these things come into this, so that is post consumer waste.

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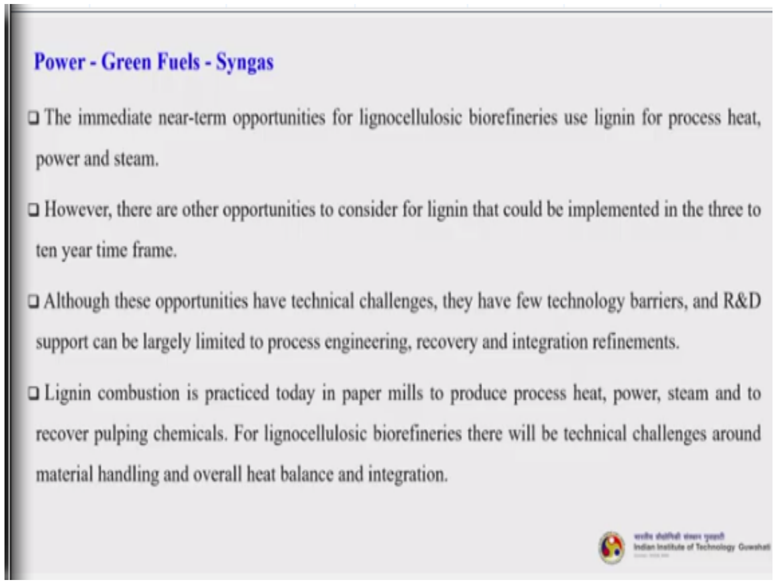

Now let us talk about the another very important product of the gasification that is, the syngas**.** So, the immediate near-term opportunities for lignocellulosic biorefineries use lignin for the process heat, power and steam. However, there are other opportunities to consider for lignin that would be implemented in the 3 to 10 years' timeframe. Although these opportunities have technical challenges, they have few technology barrier, and R & D support can be largely limited to process engineering, recovery and integration refinements.

Lignin combustion is practiced today in paper mills to produce process heat, power, steam and to recover pulping chemicals. For lignocellulosic biorefineries, there will be technical challenges around material handling, and overall heat balance and integration.

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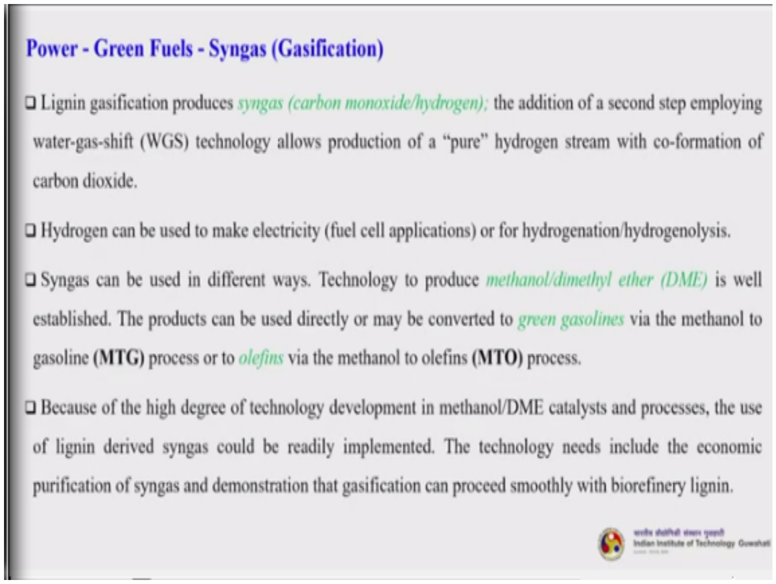

Lignin gasification produces syngas which is enriched with carbon monoxide and hydrogen. The addition of a second step employing water gas shift technology allows production of a pure hydrogen steam with co formation of carbon dioxide. Now hydrogen can be used to make electricity, for example in fuel cell applications or for hydrogenation and hydrogenolysis applications.

Now syngas can be used in different ways; technologies to produce DME that is the methanol/ dimethyl ether is well established. The products can be used directly or maybe converted to green gasoline via the methanol to gasoline that is called MTG process or to olefins via the methanol to olefin process which is known as MTO. So, these processes are very well established and commercially adapted also.

Now because of the high degree of technology development in the methanol DME catalysts and processes, the use of lignin derived syngas could be readily implemented. Now the technology needs include the economic purification of syngas and demonstration that gasification can proceed smoothly with biorefinery lignin.

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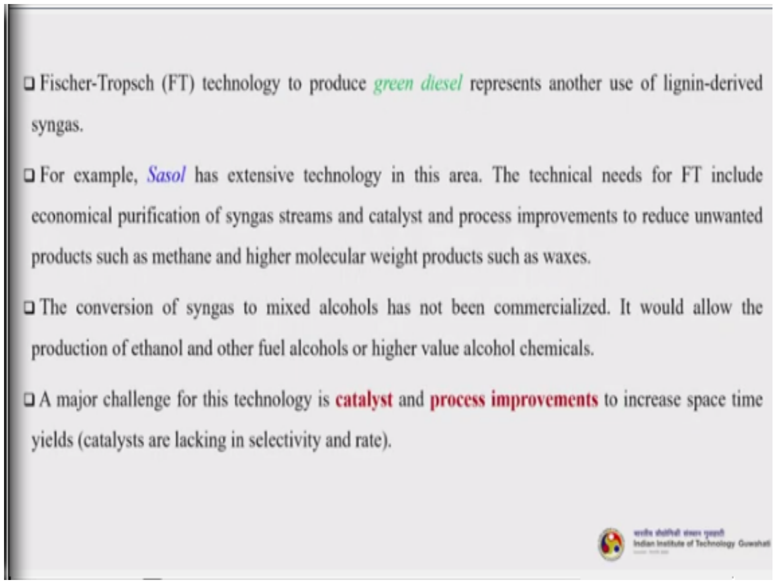

The FT technology, the Fischer Tropsch technology to produce green diesel represents another use of lignin derived syngas. For example, Sasol has a extensive technology in this area. The technical needs for the FT include economical purification of syngas streams and catalysts and process improvements to reduce unwanted products such as methane and higher molecular weight compounds such as waxes.

So, there are a lot of technology development has happened since last 2 decades for the FT technology. So, that all these, such drawbacks which has been mentioned would be overcome. The conversion of syngas to mixed alcohols has not been commercialized, it would allow the production of ethanol and other fuel alcohols or high value alcohol chemicals. A major challenge for this technology is catalyst and process improvements to increase space time yields.

So, the catalysts are lacking in selectivity and rate and that is the reason so many academicians and scientists are working day and night on developing different types of catalysts, which will have a better selectivity as well as rate for different processes, it is not about FT also, there are many other processes. In chemical reaction engineering, in energy production in other environmental application, in so many different areas.

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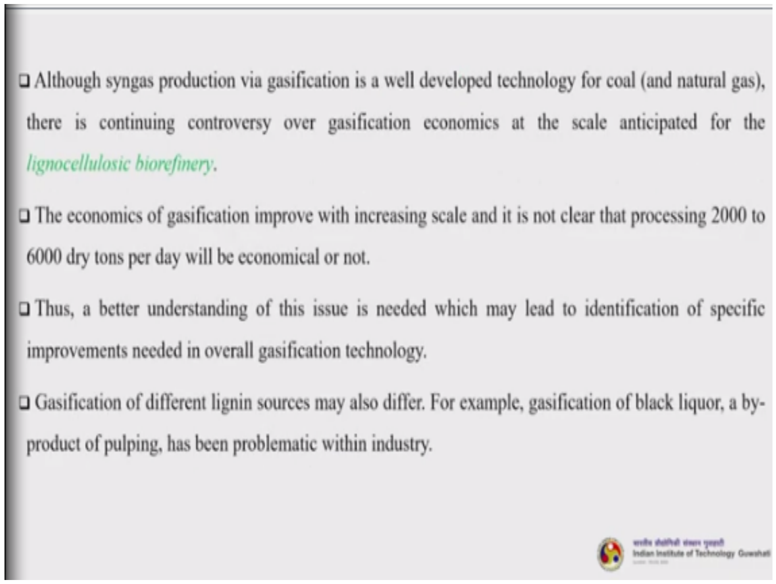

Although syngas production via gasification is a well developed technology for coal and natural gas, there is continuing controversy over gasification economics at the scale anticipated for the lignocellulosic biorefinery. Because see if you remember we have discussed all these things, one of the most important aspect of the entire biorefinery or if you precisely talk about lignocellulosic biorefinery is that unless until we aim and get or we produce, let us say we produce different high value products which comes out or derived from the byproducts as well as from the waste, then the lignocellulosic biorefinery cannot be sustainable. And one more important part lignocellulosic biorefinery aspect is that, the different types of feedstocks that required to be treated in a single biorefinery without changing the equipments, process streams or maybe with a little modification or less interference in the process dynamics.

So, these are the challenges already exist, and people are working day and night to overcome this. So, a better understanding of this issue is needed which may lead to identification of specific improvements needed in overall gasification technology. Gasification of different lignin sources may also differ; this is what I was just mentioning. For example, gasification a black liquor a byproduct of pulping has been problematic within industry, that has due to the concentration as well as also the viscosity also played a big role during conversion.

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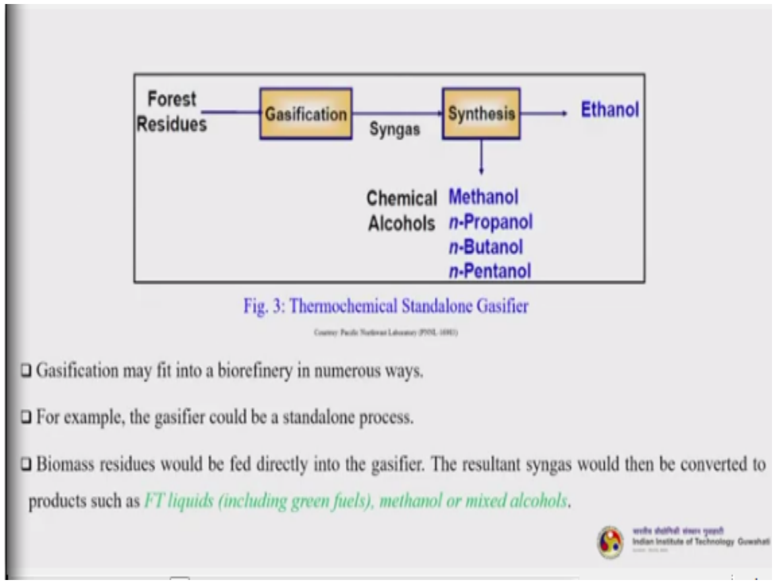

So, this is a thermochemcial standalone gasifier, where it fits into a biorefinery in numerous ways. For example, this is a standalone process where the biomass residues would be fed directly into the gasifier, the resultant syngas would then be converted to products such as FT liquids. That means we can call it green fuels, methanol or mixed alcohols.

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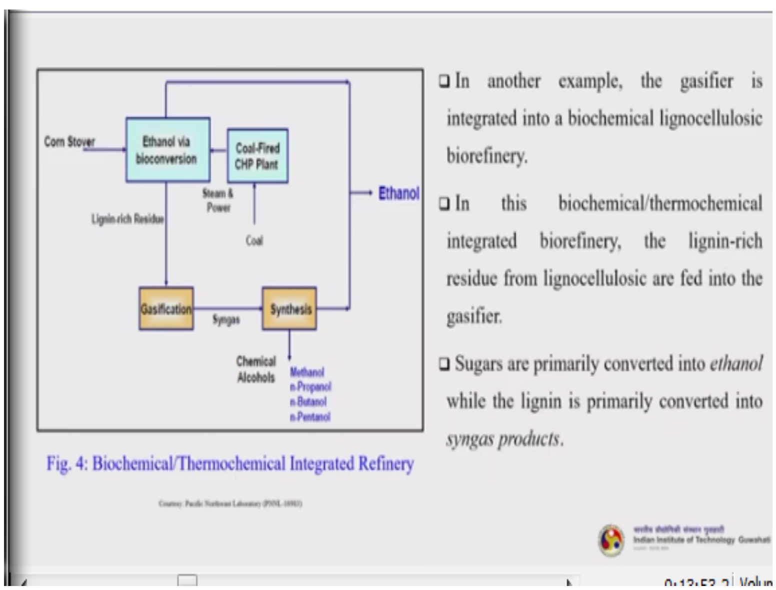

So in another example, the gasifier is integrated into a biochemical lignocellulosic biorefinery. Now in this particular example, the biochemical or thermochemical integrated biorefinery, the lignin rich residues from lignocellulosic feedstock are fed into the gasifier. Now sugars are primarily converted to ethanol while the lignin is primarily converted into the syngas products. So, this is also very simplified and highly adapted technology across various biorefineries.

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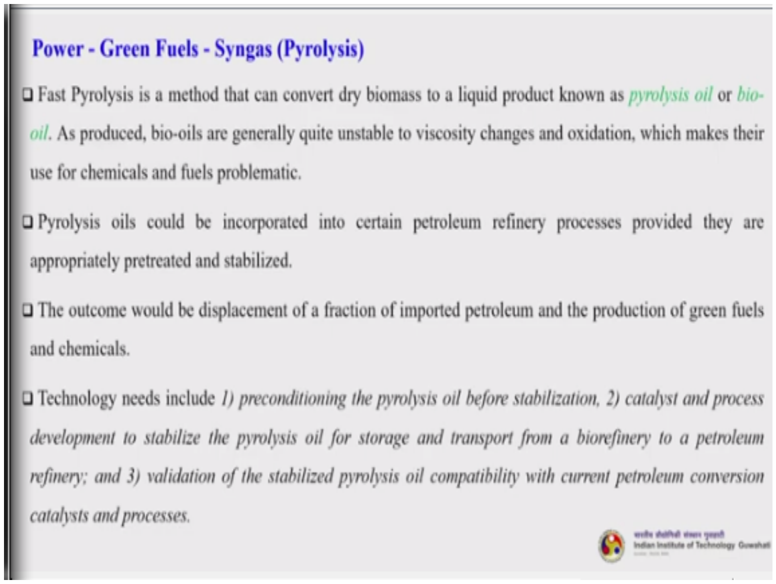

So, now let us understand the pyrolysis products. So, among all the different types of pyrolysis which we have discussed in last class, fast pyrolysis is readily adaptable by most of the industries, because of it is high yield of bio oil or pyrolysis oil. So, fast pyrolysis is a method that converts dry biomass to a liquid product known as pyrolysis oil or bio oil.

As produced bio oils are generally quite unstable to viscosity changes and oxidation, which makes their use for chemicals and fuels problematic. So, pyrolysis oils could be incorporated into various petroleum refinery processes provided they are appropriately pretreated and stabilized. So, the outcome, would be displacement of a fraction of imported petroleum and the production of green fuels and chemicals.

Now technology needs include preconditioning, the pyrolysis oil before stabilization, then catalyst and process development to stabilize the pyrolysis oil for storage and transport from a bio refinery to a petroleum refinery. Then validation of the stabilized pyrolysis oil compatibility with current petroleum conversion catalysts and processes.

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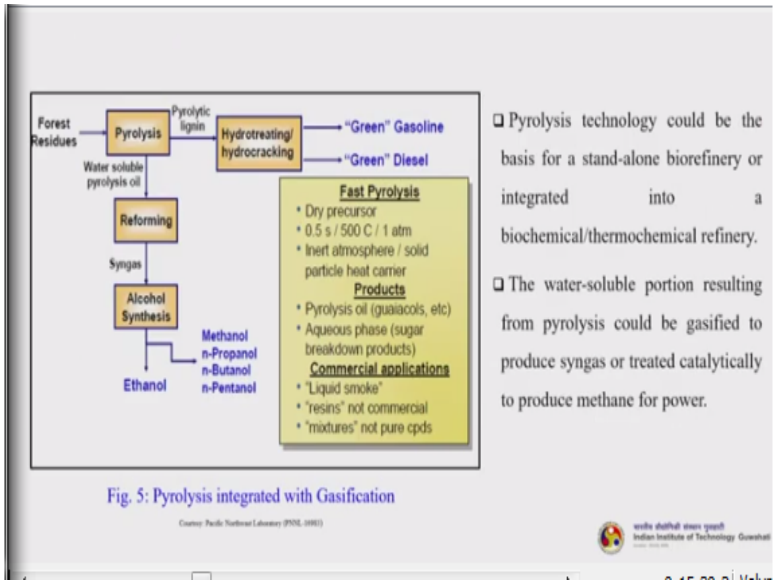

Now let us look at this particular pyrolysis integrated with gasification technology process. So, the pyrolysis technology could be the basis for a standalone biorefinery, that is integrated into a biochemical or thermochemical refinery. So, you can see here, so the forest residue is pyrolyzed, this is a pyrolysis technology here. So, whatever the pyrolytic lignin is left out that goes to the hydrotreating or hydrocracking, where we get green gasoline, green diesel, this type of fractions.

Then water soluble pyrolysis oil, because I told you and again I am repeating, that whenever we talk about bio oil, pyrolytic oil, pyrolysis oil, please understand that it has a huge amount of aqueous fraction and that needs to be decanted, because the oil is the only organic phase that is useful for us. So, that goes to reforming, then syngas, then alcohol synthesis, then we get a ethanol or we may get methanol, n- propanol, n-butanol and n-pentanol.

So, the fast pyrolysis needs a dry precursor, absolutely dry precursor, dry feedstock, 0.5 second, 500 degrees centigrade, 1 atm - very fast process and it needs inert atmosphere and solid particle heat carrier, so this is what is required. So, products are pyrolysis oil, aqueous phase. So aqueous phase as I told you, again I am telling you that it may contain different types of valuable chemicals, now depending upon what is the feedstock.

And if their concentration in this aqueous phase is good enough, and it is a high value product then it should be purified. But please again note that purification that is the downstream processing part is a very costly affair. So in commercial applications are liquid, smoke, resins, mixtures, there are so many applications.

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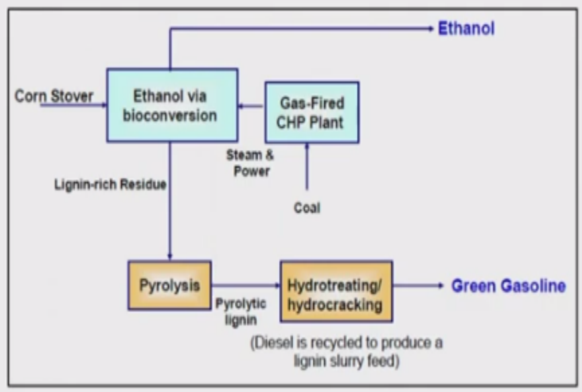

Fig. 6: Biochemical/Thermochemical Pyrolysis Biorefinery

So, this is the biochemical thermochemical pyrolysis biorefinery. So, here the feedstock is corn stover. So, the corn stover is being processed into the ethanol platform where ethanol is being produced as one of the product whatever left out is the lignin residues goes to pyrolysis. Then it again another stage where we are hydrotreating or hydrocracking it to get green gasoline. And the coal also can be used to do the steam generation and steam as well as power and it is a integrated part of the entire biorefinery system, where both gasification and pyrolysis are taking place .

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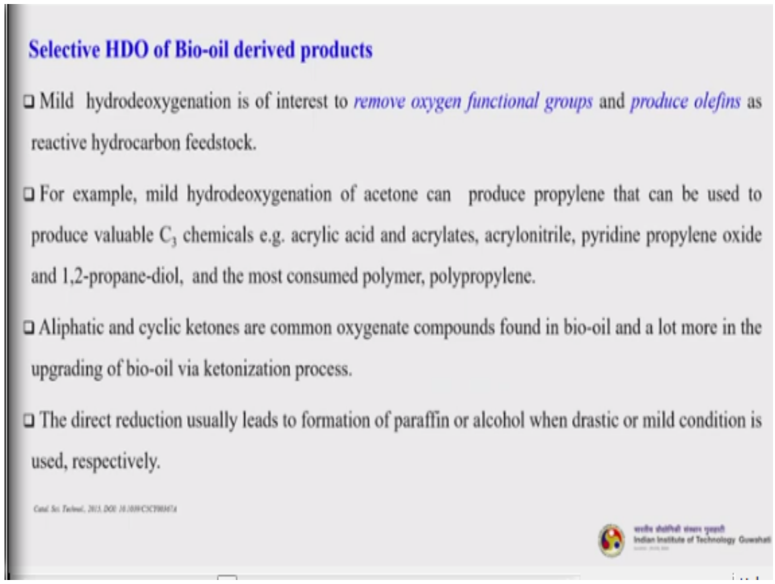

So, the next example is the bio oil derived products' selective hydro deoxygenation. Now mild hydro deoxygenation is of interest to remove oxygen functional groups and produce olefins as reactive hydrocarbon feedstock. Now please note that, bio oil usually contains a huge amount of oxygen which are not desirable, if we are going to use in any engines, where the fuel is getting burnt, so it has to be removed. So, to do that hydro deoxygenation is one of the technology.

So, for example, mild hydro deoxygenation of acetone can produce propylene that can be used to produce valuable C3 chemicals. As for example acrylic acid and acrylates, acrylonitrile, pyridine propylene oxide and 1, 2-propane diol, and the most consumed polymer is polypropylene. Aliphatic and cyclic ketones are common oxygenate compounds found in bio oil and a lot more in upgrading of the bio oil by ketonization process. The direct reduction usually leads to formation of paraffin and alcohol when drastic and/or mild condition is used respectively.

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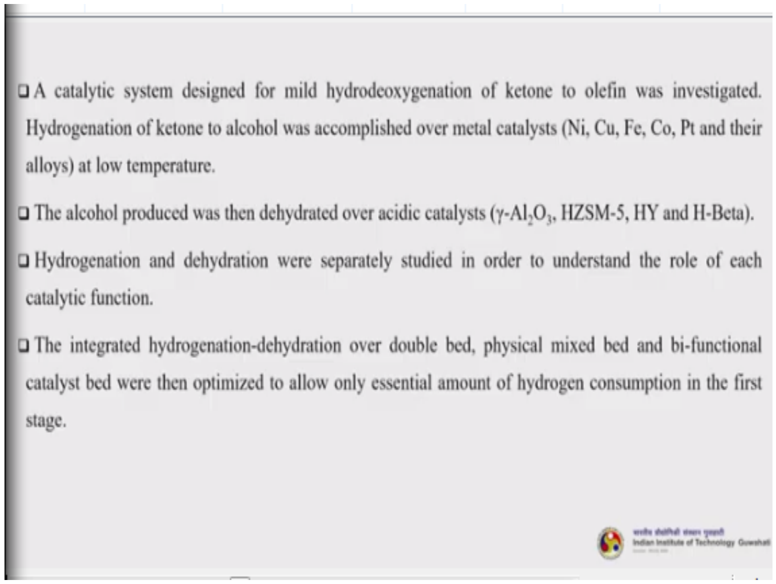

A catalytic system designed for mild hydro deoxygenation of ketone to olefin was investigated. Hydrogenation of ketone to alcohol was accomplished over metal catalyst, various types of metals has been studied - nickel, copper, iron, cobalt, platinum and their alloys - at low temperature. The alcohol produced was then dehydrated over acidic catalyst. Hydrogenation and dehydration were separately studied in order to understand the role of each catalytic function.

Now that integrated hydrogenation-dehydration over double bed, physical mixed bed and bi-functional catalyst bed were then optimized to allow only essential amount of hydrogen consumption in the first stage.

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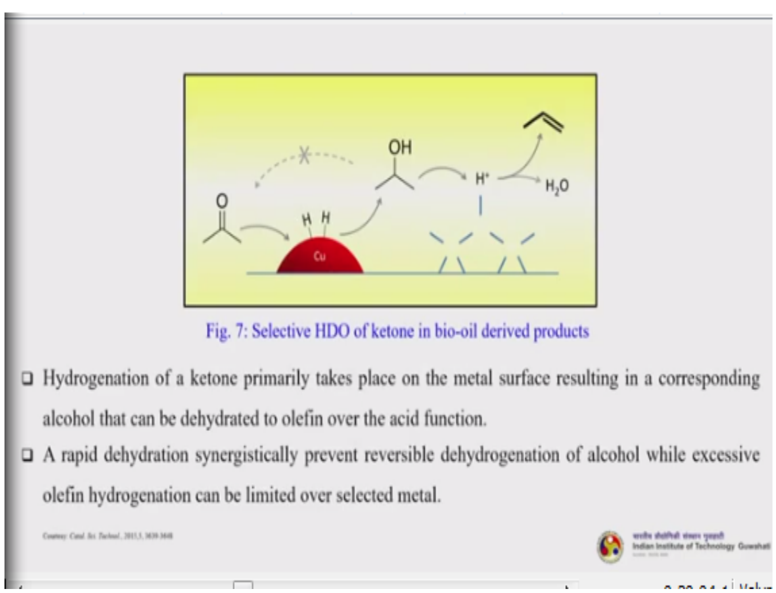

This is one schematic of how selective HDO ketone is being carried out. So, this is the reference of this particular paper has been given here, you can go through it later, Catalysts science and technology; it is a very nice interesting work. So, what is happening here you can see this is ketonization. So, your bio oil is getting impregnated over the catalyst surface here it is copper.

So, resulting in a corresponding alcohol, now that alcohol will be dehydrated using another catalyst which are basically acidic catalyst. So, a rapid dehydration synergistically prevents reversible dehydrogenation of alcohol while excessive olefin hydrogenation can be limited over selected metal. So, you can read a little more and about this particular work.

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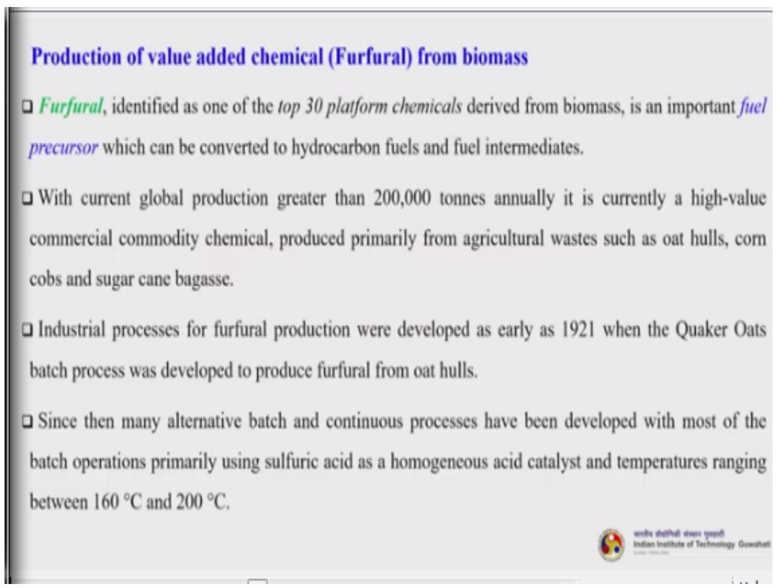

So, let us now discuss about furfural, which is one of the most important platform chemicals from such biorefineries. Now furfural identified as one of the top 30 platform chemicals derived from biomass is an important fuel precursor, which can be converted to hydrocarbon fuels and fuel intermediates. With current global production greater than 200,000 tonnes annually it is currently a high value commercial commodity chemical produced primarily from agricultural waste, such as oat hulls, corn cobs and sugarcane bagasse.

Industrial processes for furfural production were developed as early as 1921 when the Quaker Oats batch process was developed to produce furfural from oat hulls. Since then many alternative batch and continuous processes have been developed, with most of the batch operations primarily using sulfuric acid as a homogeneous acid catalyst, and temperatures ranging between 160 to 200 degrees centigrade.

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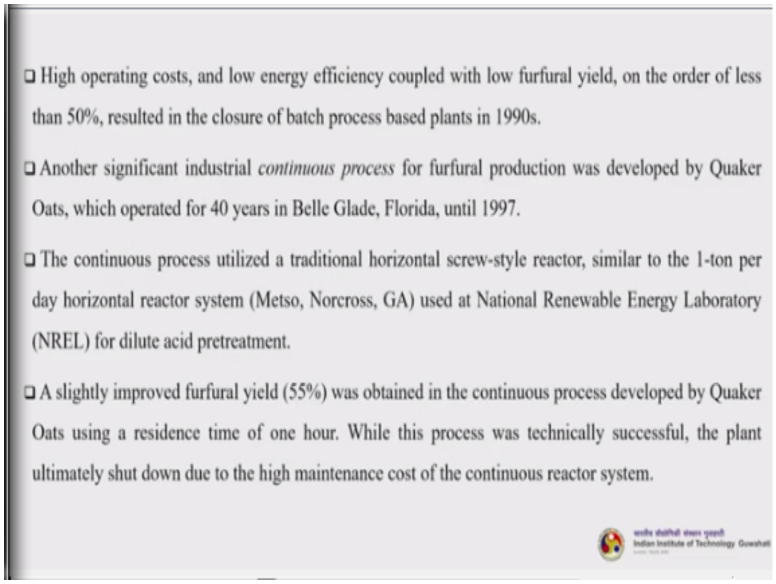

High operating costs and low energy efficiency coupled with low furfural yield, on the order of less than 50% resulted in the closure of batch plants in 1990s. So, another significant industrial continuous process for furfural production was developed by Quaker Oats which was operated for 40 years in Belle Glade in Florida until 1997. Now the continuous process utilized a traditional horizontal screw style reactor similar to the 1 ton per day horizontal reactor system which was installed in Metso, used at the NREL laboratory for diluted acid pretreatment. A slightly improved furfural yield of about 55% was obtained in the continuous process developed by the Quaker Oats using a residence time of one hour. While this process was technically successful, the plant ultimately shut down due to the high maintenance cost of the continuous reactor system. So, with this you can understand it is not about only the technology, the processing cost is very important.

The yield is important, the entire cost whatever you are actually going to have it during the processing of this any product is very much important. So, in industrial parlance the most important thing to decide is about the cost. The cost means several different types of costs, which we have already discussed.

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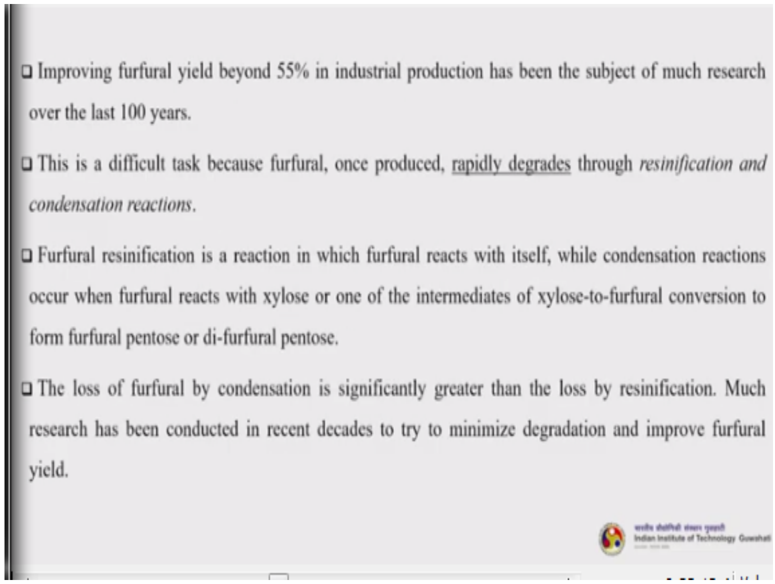

So, improving furfural yield beyond 55% in industrial production has been the subject of much research since last 100 years. This is a difficult task because furfural once produced, rapidly degrades through resinification and condensation reactions. So, furfural resinification is a reaction in which furfural reacts with itself, while condensation reactions occur when furfural reacts with xylose or one of the intermediates of xylose to furfural conversion to form furfural pentose or di-furfural pentose.

Now resinification is, you can say some sort of autonomous process. The loss of furfural by condensation is significantly greater than those by resinification. Much research has been conducted in recent decades to try to minimize degradation and improve furfural yield.

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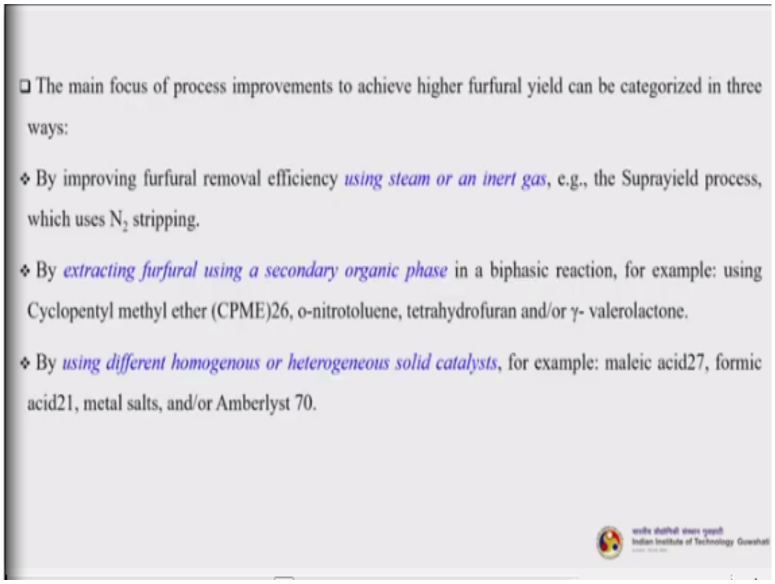

The main focus of the process improvements to achieve higher furfural yield can be categorized into three ways. First is by improving furfural removal efficiency using steam or an inert gas, for example the Suprayield process which uses nitrogen stripping. Second is that by extracting furfural using a secondary organic phase in a biphasic reaction, for example using cyclopentyl methyl ether CPME 26, o-nitortoluene, tetrahydrofuran, and/or γ-valerolactone.

So, another technique is by using different homogeneous or heterogeneous solid catalyst, for example maleic acid27, formic acid21, metal salts and or Amberlyst70.

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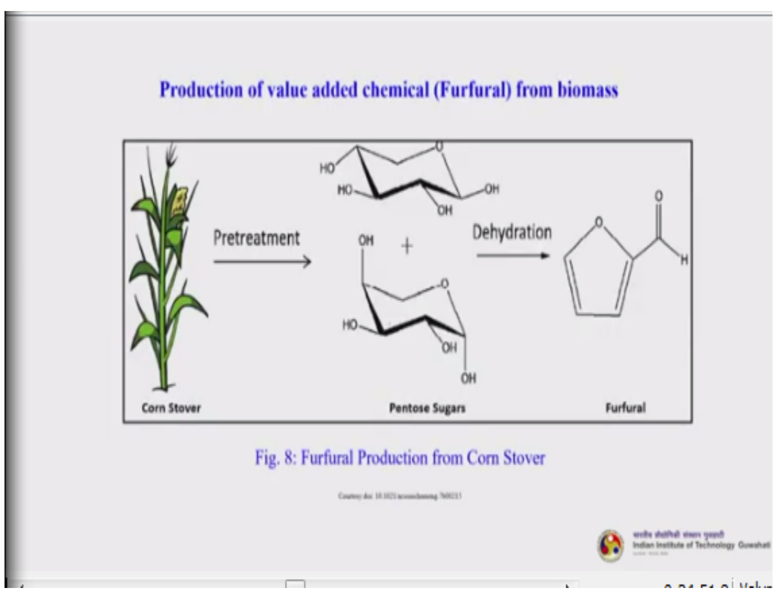

Now production value of added chemical furfural from biomass you can understand, this is just a schematic. A corn stover has been shown, it has to be pretreated, pretreated is very important we have discussed how it has been carried out in one of our module exclusively that dedicated to this. Then it will give us pentose sugars, now this pentose sugar under dehydration will give me furfural.

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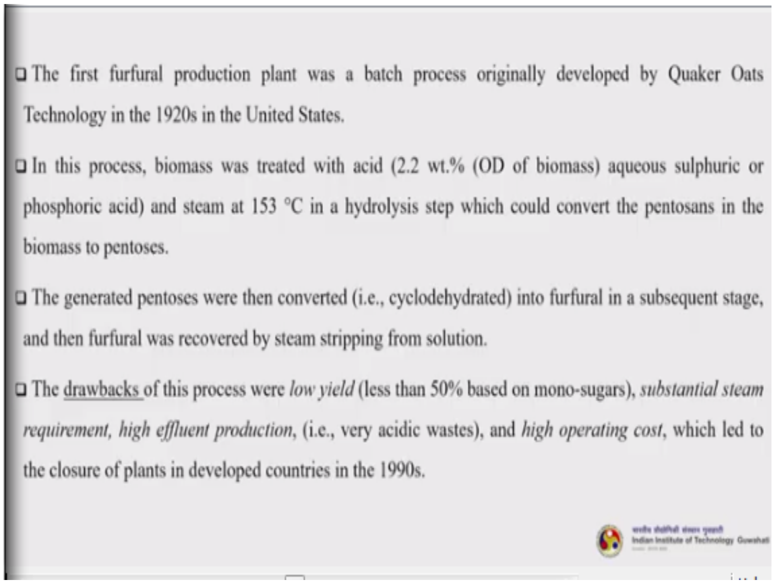

The first furfural production plant was a batch process originally developed by Quaker Oats in 1920s in the United States. In this process, biomass was treated with acid, aqueous sulfuric acid or phosphoric acid and steam at 153 degrees centigrade in a hydrolysis step, which could convert the pentosans in the biomass to pentoses. The generated pentoses were then converted into furfural in a subsequent stage, and then furfural was recovered by steam stripping from solution.

However, the drawback of this process was very low yield - less than 50% based on mono sugars, substantial steam requirements, steam is a very costly product in any process industries, then high effluent production. High effluent in this case is very acidic wastewater and high operating costs which lead to the closure of the plants in developed countries till 1990s.

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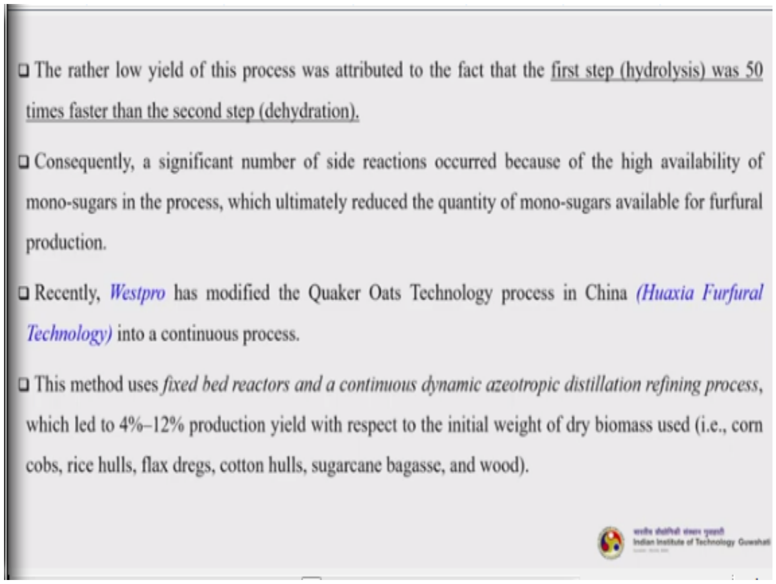

The rather low yield of this process was attributed to the fact that the first step that was the hydrolysis reaction was 50 times faster than the second step that is the dehydration. So, there is a mismatch about the rate of reaction of both the steps. So consequently a significant number of side reactions occurred because of the high availability of mono sugars in the process, which ultimately reduce the quantity of mono sugars available for furfural production.

Recently, Westpro has modified the Quaker Oats technology process in China into a continuous process, and it has been quite successful process. Now this method uses fixed bed reactors and a continuous dynamic azeotropic distillation refining process, which led to a 4 to 12% production yield with respect to the initial weight of dry biomass used, corn cobs, rice hulls, flax dregs, cotton hulls, sugarcane bagasse, wood, so many different types of feedstock has been tried.

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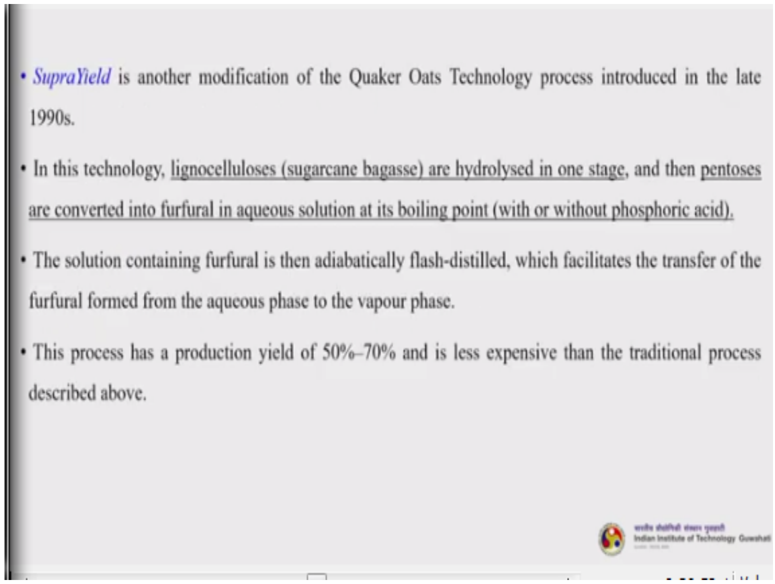

SupraYield is another modification of the Quaker Oats technology process introduced in the late 1990s. In this technology lignocelluloses are hydrolyzed in one stage and then pentoses are converted into furfural in the aqueous solution at it is boiling point with or without phosphoric acid as a catalyst. The solution containing furfural is then adiabatically flash distilled, which facilitates the transfer of the furfural formed from the aqueous phase to the vapor purpose. This process has a production yield of 50 to 70% and is less expensive than the traditional process described above.

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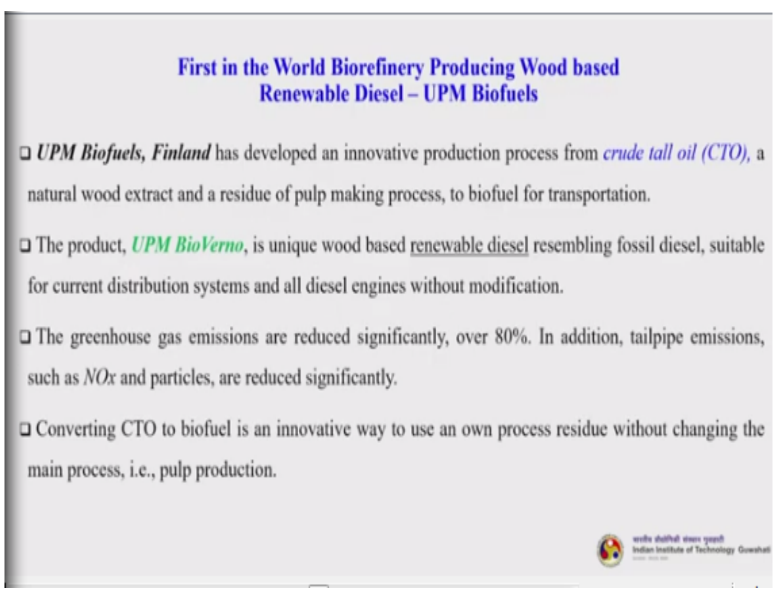

So, now we will see some of the commercial success stories. First in the world biorefinery producing wood based renewable biodiesel is the UPM biofuels. So, UPM biofuels is a big company in Finland, has developed an innovative production process from the crude tall oil, a natural wood extract and a residue of pulp making process, to biofuel for transportation. So, their product is known as UPM BioVerno, is a unique wood based renewable diesel resembling almost the fossil diesel, suitable for current distribution systems and all diesel engines without any modification. The greenhouse gas emissions are reduced significantly over 80%, it is a very significant result. And in addition, tailpipe emissions such as NOx and other particles are reduced significantly. Converting that crude tall oil - many times called Talal also - to biofuel is an innovative way to use an own process residue without changing the main process that is the pulp production.

So, this bio refinery has been integrated to the original pulp production unit, where you are using the pulp production waste and converting it to diesel.

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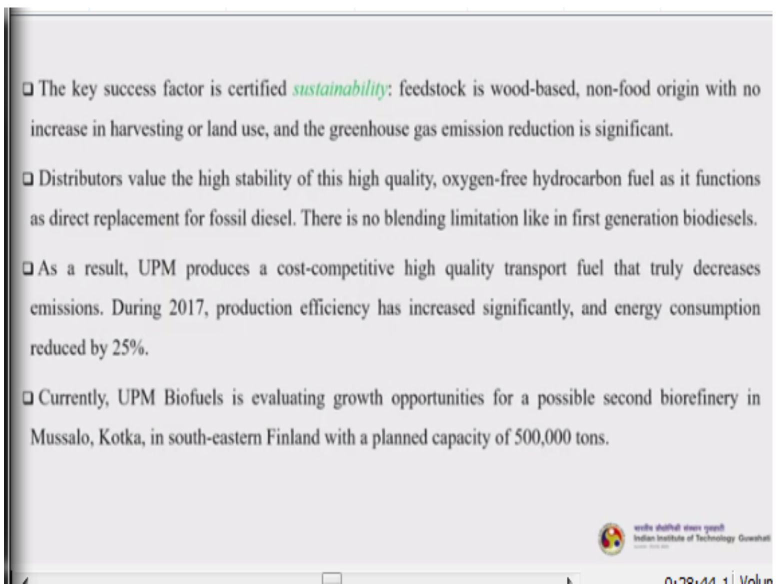

So, the key success factor is certified sustainability, it is very interesting. So, feedstock is wood based non food origin with no increase in harvesting or land use. So, no question of any food versus feed problem, and the greenhouse gas emission reduction is significant. Distributors value the high stability of this high quality oxygen free hydrocarbon fuel as it functions as direct replacement for fossil diesel.

There are no blending limitations like in the first generation bio diesels. As a result UPM produces a cost competitive high quality transport fuel that truly decreases emissions. During 2017, production efficiency has increased significantly and energy consumption was reduced by 25%. Another significant improvement in that entire integrated biorefinery technology. Currently, UPM biofuels is evaluating growth opportunities for a possible second biorefinery in Mussalo, that is in Kotka, in southeastern Finland with a planned capacity of 500,000 tons.

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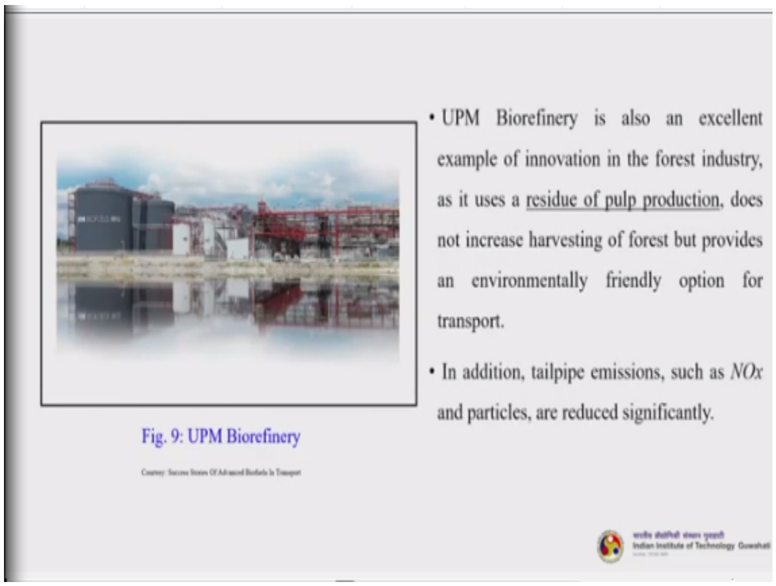

This is a photo of actually the UPM Biorefinery, UPM Biorefinery is also an excellent example of innovation in the forest industry, as it utilizes the residue of pulp production, does not increase harvesting of forest, but provides an environmentally friendly option for the transport. In addition, tailpipe emissions such as NOx and particles are reduced significantly, so it is a win-win story basically.

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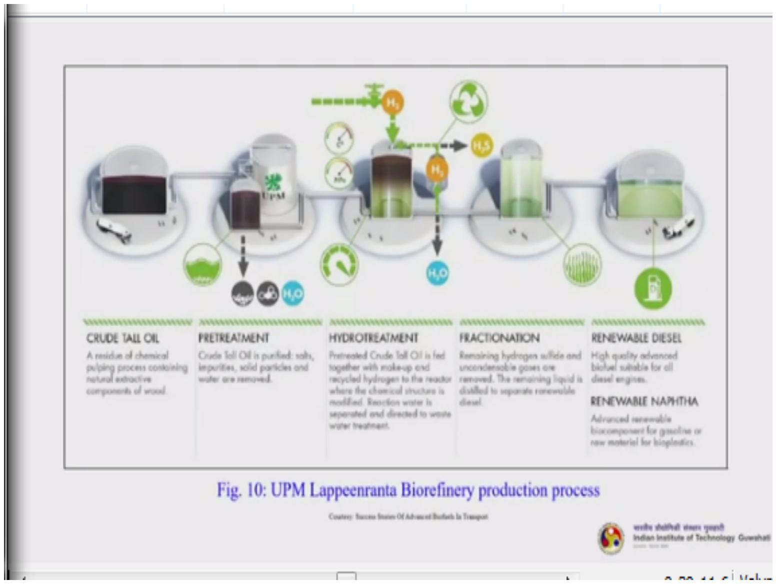

So, this is their refinery production process, let us quickly glance through it and understand, this is being given in a nutshell. So, this is the crude tall oil, a residue of chemical pulping process containing the natural extractive components of the wood which they have used as a feedstock. Now this goes to that pretreatment. So, crude tall oil is purified, so the salts, impurities, solid particles and water are removed.

And this is a quite energy intensive and cost intensive process, then it goes to the hydro treatment. So, in the hydro treatment pretreated crude tall oil is fed together with makeup and recycled hydrogen to the reactor where the chemical structure is modified. So, the reaction water is separated and directed to wastewater treatment plant. They have a very good in-house and very efficient wastewater treatment plan also, where they recycle water.

Then it goes to the fractionation, so here the remaining hydrogen sulfide and uncondensable gases are removed, the remaining liquid is distilled to separate renewable diesel. Then you get the renewable diesel and otherwise renewable naphtha both way they produce. So, fantastic technology and a very nice integrated biorefinery.

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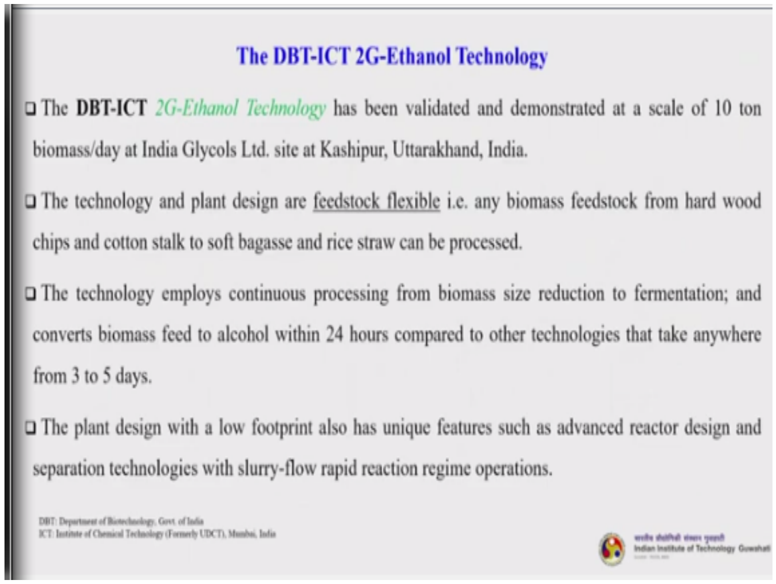

So, next is our own Indian success story. So that DBT-ICT, 2G Ethanol Technology, so DBT is the Department of biotechnology, Government of India and ICT, the Institute of Chemical Technology mostly, many of few may be knowing it as a UDCT it is in Mumbai, India. So, DBT-ICT 2G Ethanol Technology has been validated and demonstrated at a scale of 10 ton biomass per day at India Glycols limited site at Kashipur, Uttarakhand.

The technology and plant designed at feedstock flexible that is the beauty of this technology, any biomass feedstock from hardwood chips and cotton stock to soft bagasse and rice straw can be processed and has been processed. The technology employs continuous processing from biomass size reduction to fermentation and converts biomass feed to alcohol within 24 hours compared to other technologies that take anywhere from 3 to 5 days, another significant milestone achieved.

So, the plant design with a low footprint also has unique features such as advanced reactor design and separation technologies with slurry flow rapid reaction regime operations.

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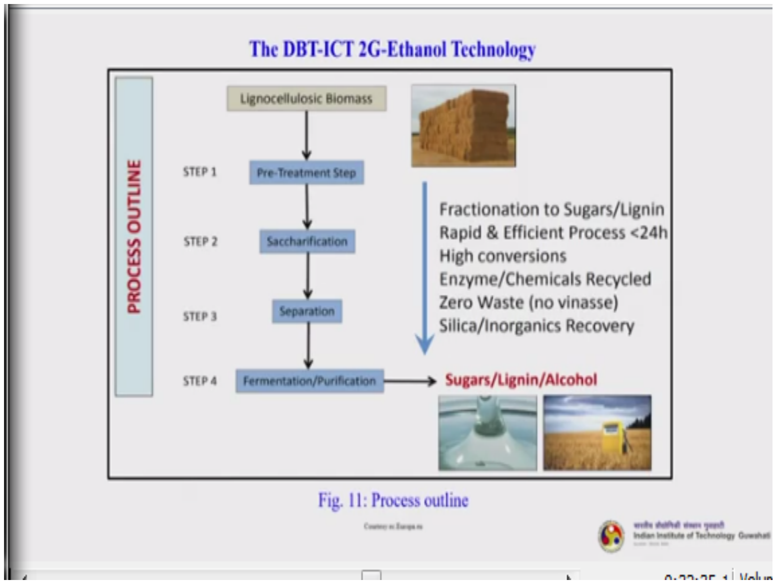

So, this is what in a nutshell we can describe it. The process outline, lignocellulosic biomass as I told any biomass soft, hard does not matter. It will be pretreated, the first step is always pretreatment, then it will goes to saccharification, that separation, fermentation and purification, you get sugars, lignin, alcohol can further be processed into other products.

So, fractionation to sugars, lignin, rapid and efficient process less than 24 hours, high conversion, enzyme and chemical that is whatever being used are recycled. So, zero waste almost zero waste technology we can say and silica and inorganic recovery is also being carried out, especially when you are using this rice husk and other bagasses which contains some amount of silica in it, so excellent technology.

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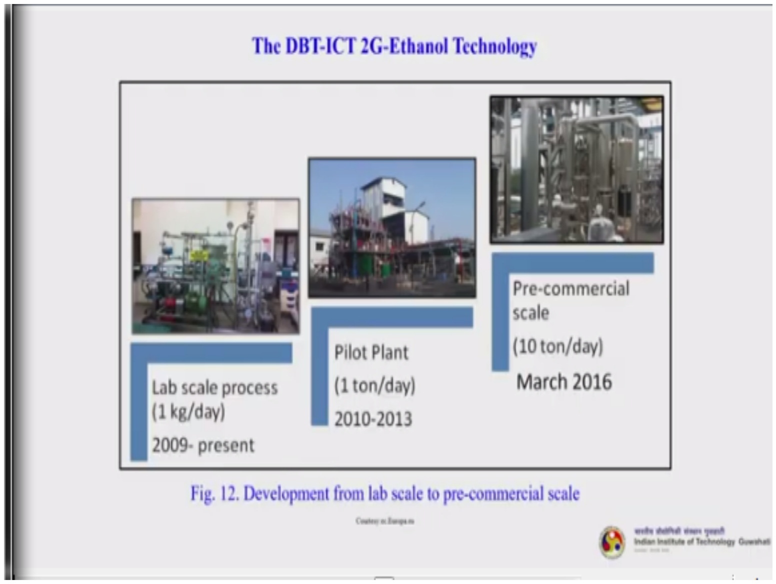

So, this is how they have processed, this you see lab scale process 1 kg per day, 2009 it was developed in the lab scale in ICT. So, then it goes to a pilot scale 1 ton per day in 2010 to 13 that they have tested. And then it goes to a pre commercial scale 10 ton per day in March 2016, now it is a full scale plant.

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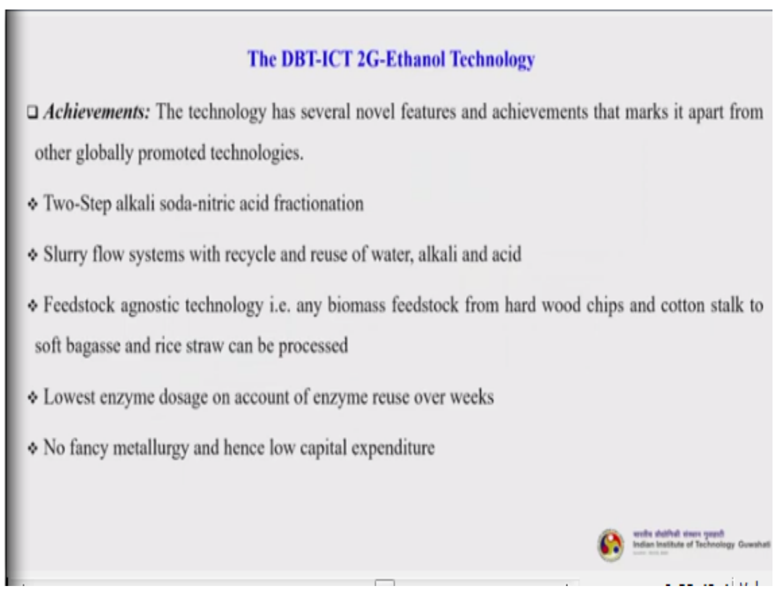

So, the achievements, if you talk about achievements, that technology has several novel features and achievements, that marks it apart from other globally promoted technologies. The first is 2 steps alkali soda-nitric acid fractionation. Second, slurry flow systems with recycle and reuse of water, alkali and acid. Then next feedstock agnostic technology, this is the most beautiful part of this entire technology. Any biomass feedstock from hardwood chips and cotton stalk to soft bagasse and rice straw can be processed. Lowest enzyme dosage on account of enzyme reuse over weeks. No fancy metallurgy hence low capital expenditure.

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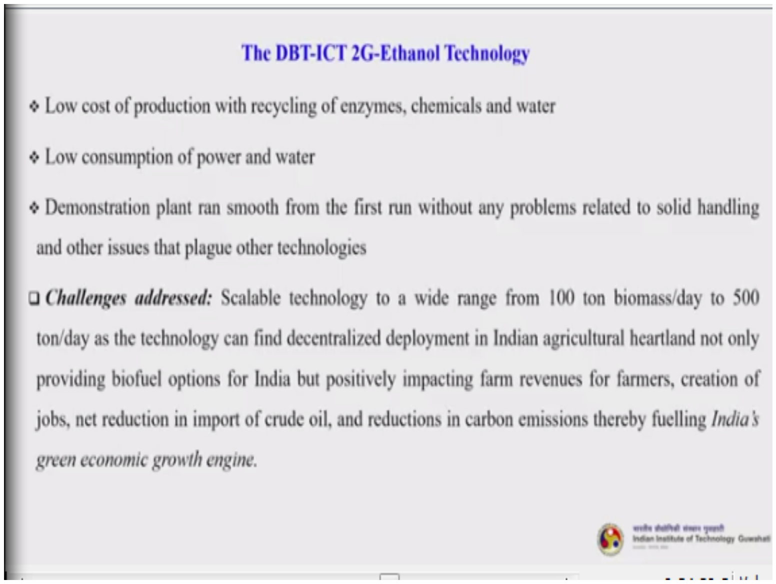

Low cost of production with recycling of enzymes, chemicals and water, low consumption of power and water. And demonstration plant ran smoothly from the first run without any problem related to solid handling and other issues that plague other technologies, so excellent technology. So, challenges that this technology addressed are scalable technology to a wide range from 100 tons biomass per day to 500 ton per day as the technology can find decentralized deployment in the Indian agricultural heartland not only providing biofuel options for India, but positively impacting farm revenues for farmers. Creation of jobs, net reduction in import of crude oil and reduction in carbon emissions, thereby fuelling India's green economic growth engine, so it is a fantastic technology.

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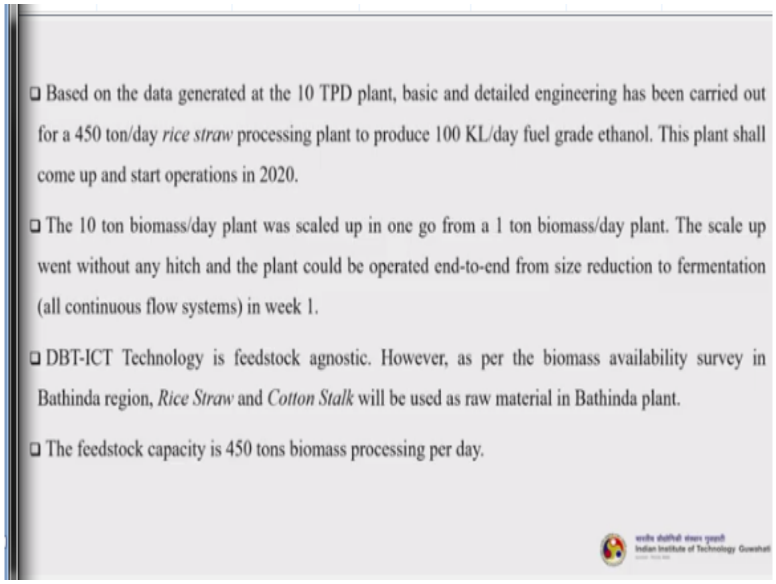

So, based on the data generated at the 10 tons per day plant basic and detailed engineering has been carried out for a 450 ton per day rice straw processing plant to produce 100 kilo liter per day fuel grade ethanol. This plant shall come up and start operations in 2020. The 10-ton biomass per day plant was scaled up in one go from a 1-ton biomass per day plant. The scale up went without any hitch and the plant could be operated end to end from size reduction to fermentation, including all the continuous flow system in a single week.

So, DBT-ICT technology is feedstock agnostic, however as per the biomass availability survey in Bathinda region rice straw and cotton stalk will be used as raw material in their Bathinda plant. So, feedstock capacity is 450 tons biomass processing per day.

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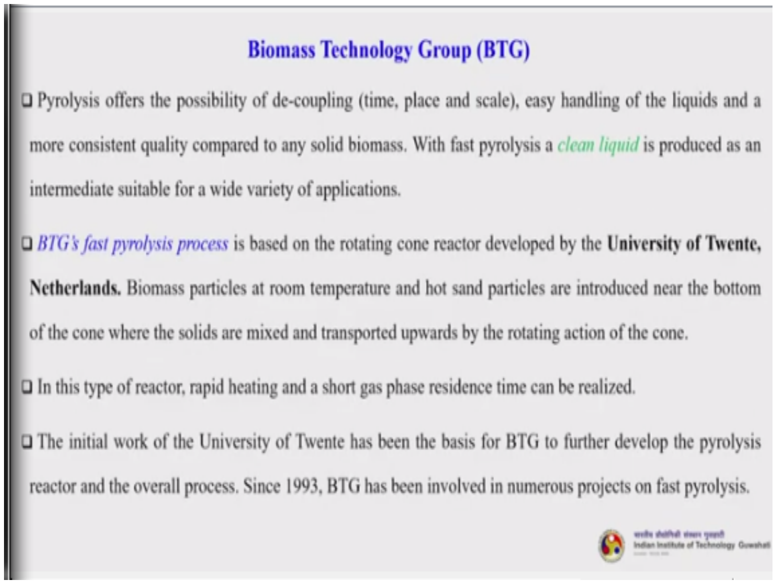

Next such commercial adaptation is the biomass technology group BTG. So, here the pyrolysis has been adapted. Pyrolysis offers the possibility of decoupling, time, place and scale, easy handling of the liquids and a more consistent quality compared to any solid biomass. With fast pyrolysis a clean liquid is produced as an intermediate suitable for a wide variety of applications. BTG's fast pyrolysis process is based on the rotating cone reactor developed by the University of Twente in Netherlands.

Biomass particles at room temperature and hot sand particles are introduced near the bottom of the cone where the solids are mixed and transported upwards by the rotating action of the cone. In this type of reactor rapid heating, and a short gas phase residence time can be realized. The initial work of the University of Twente has been the basis for BTG to further develop pyrolysis reactor and the overall process. Since 1993, BTG has been involved in numerous projects on fast pyrolysis.

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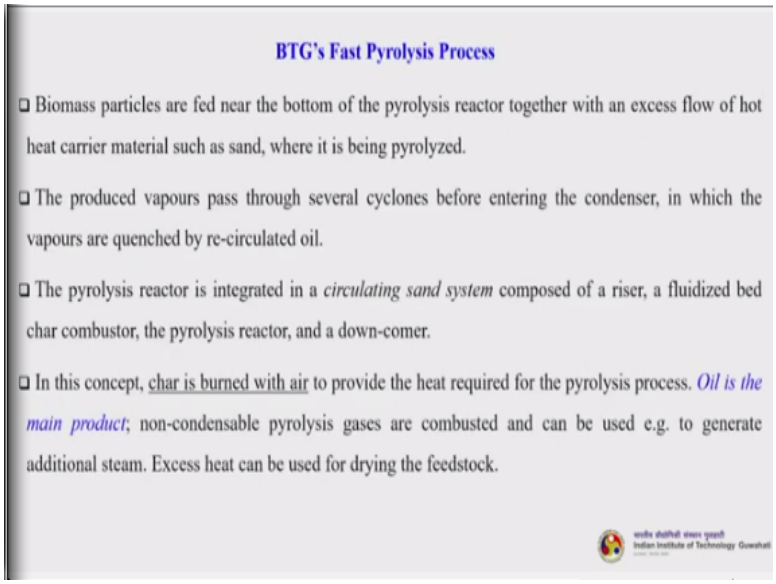

Biomass particles are fed near the bottom of the pyrolysis reactor together with an excess flow of hot heat carrier material such as sand where it is being pyrolyzed. We have already seen that how sand can be used as a heat carrier. So, the produced vapors pass through several cyclones before entering the condenser, in which the vapors are quenched by re-circulated oil.

The pyrolysis reactor is integrated in a circulating sand system composed of a riser, a fluidized bed char combustor, the pyrolysis reactor and a down-comer. So, these are the parts of the unit. Now in this concept char is burned with air to provide the heat required for the pyrolysis process. Oil is the main product, non condensable pyrolysis gases are combusted and can be used as for example to generate additional steam. Now excess heat can be used for drying the feedstock.

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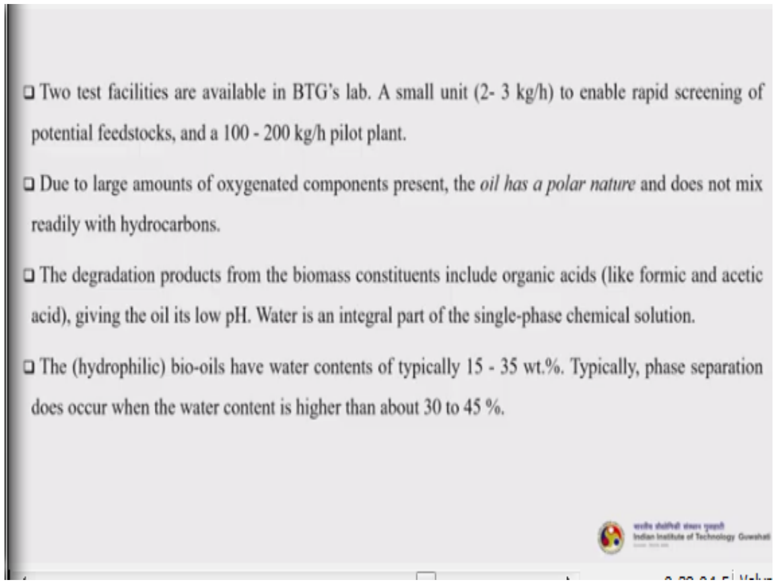

Two test facilities are available in BTG's lab, a small unit 2 to 3 kg per hour to enable rapid screening of potential feedstock and a 100 to 200 kg per hour pilot plant. Due to large amounts of oxygenated compounds present the oil has a polar nature and does not mix readily with hydrocarbons. The degradation products from the biomass constituents include organic acids like formic acid, acetic acid, giving the oil its low pH.

Water is an integral part of the single phase chemical solution. The hydrophilic bio oils have a water content of typically 15 to 35 weight percent. Again as you know that this depends upon what feedstock you are using and how much initial moisture content that feedstock is having. So, typically phase separation does occur when the water content is higher than that of the 30 to 45%.

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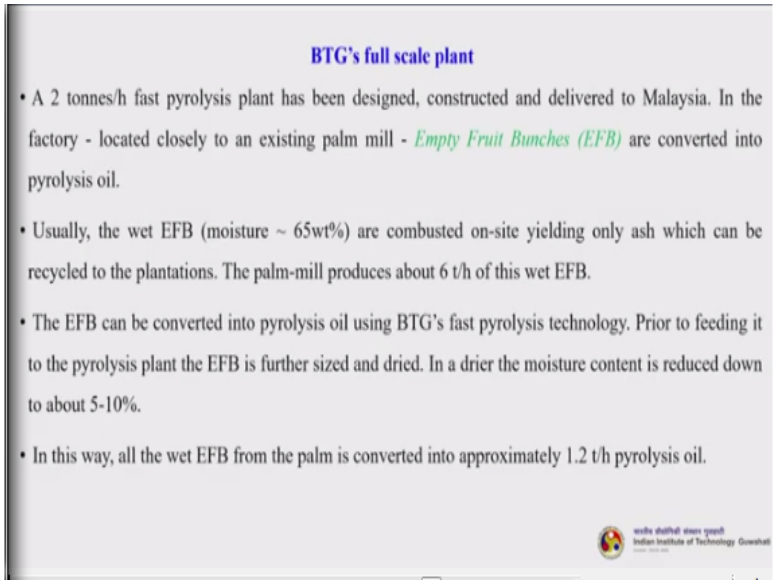

So, BTG's full scale plant takes into account 2 tons per hour fast pyrolysis process and it was constructed, designed and delivered to Malaysia. In the factory located closely to an existing palm mill where what they are using actually the empty fruit bunches or you can say the empty palm fruit bunches are converted into the pyrolysis oil. Usually the wet EFB where the moisture is about 65% are combusted on-site yielding only ash which can be recycled to the plantations.

The palm mill produces about 6 ton per hour of this wet EFB, empty fruit bunches. So, the empty fruit bunches can be converted into pyrolysis oil using BTG's fast pyrolysis technology. Prior to feeding it to the pyrolysis plant the EFB is further sized and dried. In a dryer the moisture content is reduced down to about 5 to 10%. In this way, all the wet EFB from the palm is converted into approximately 1.2 ton per hour pyrolysis oil.

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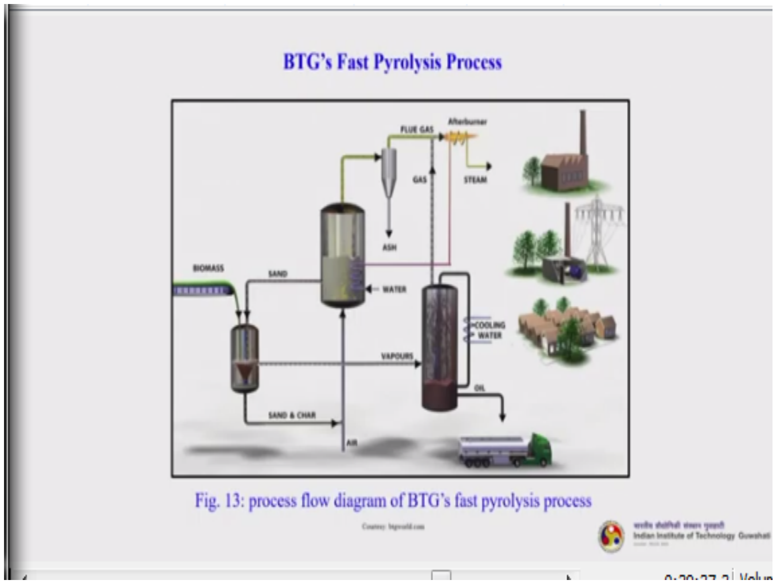

Fig. 13: process flow diagram of BTG's fast pyrolysis process

This is their technology, very simple technology, but nicely integrated, so that the yield of the pyrolytic oil is very high. You can see this biomass is fed to this circulated sand based reactor where actually the pyrolysis is happening here**.** So, the gas or the vapors, what is coming out of the pyrolysis is being feed to a tower which is basically cooler **,** where it is the condensable part is condensed and you get the oil here.

Now what about non condensable gases - that can be collected and burnt. Similarly you can see that the sand along with the char whatever left out is from the pyrolysis reactor is being fed to another unit where the sand has been recovered and again can be processed or fed back to the main pyrolyzer or the pyrolysis reactor. And whatever the gas is still left out that can be fed to another cyclone, where the ash can be collected. Because of the due to the density difference and that gas can go to steam production. So, you can see this is a very nice integrated approach.

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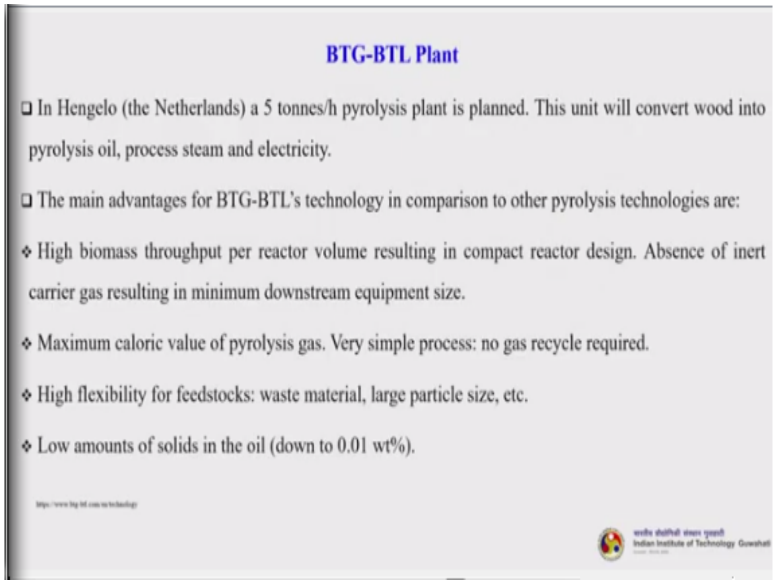

So, in Hengelo, the Netherlands a 5 tons per hour pyrolysis plant is planned. This unit will convert wood into pyrolysis oil, process steam and electricity. The main advantages for the BTG-BTL's technology in comparison to other pyrolysis technologies are: high biomass throughput per reactor volume resulting in compact reactor design. Absence of inert carrier gas resulting in minimum downstream equipment size.

Maximum calorific value of pyrolysis gas actually, very simple process, no gas cycle required. High flexibility for feedstocks, so waste material, large particle size, all these feedstocks can be actually processed. Low amount of solids in the oil.

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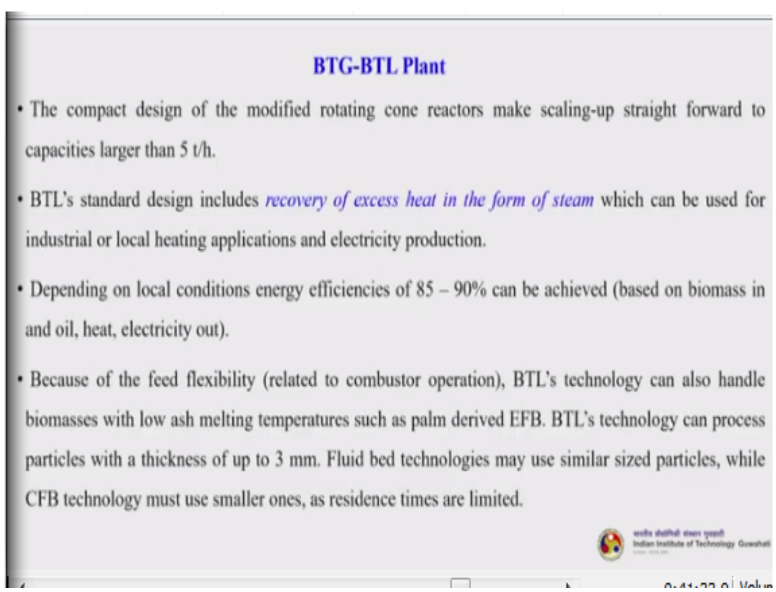

The compact design of the modified rotating cone reactor makes scaling up straight forward to capacities larger than 5 tons per hour. Now BTL standard design includes recovery of excess heat in the form of steam which can be used for the industrial or local heating applications and electricity production. Now depending on local conditions, energy efficiencies of 85 to 90% can be achieved, so that is based on biomass and oil, heat, electricity out.

So, because of the feed flexibility, BTL's technology can also handle biomasses with low ash melting temperature, such as palm derived EFB's. Now BTL's technology can process particles with a thickness of up to 3 mm. So, 2 beautiful things about this particular technology is that it can just like our DBT-ICT 2G ethanol technology. Now this technology also can process different types of feedstock materials not only different types of feedstock also different size of feedstock also.

Fluid bed technologies may use similar sized particles, while CFB technology must use smaller ones as a residence times are limited, CFB with the circulating fluidized bed technology.

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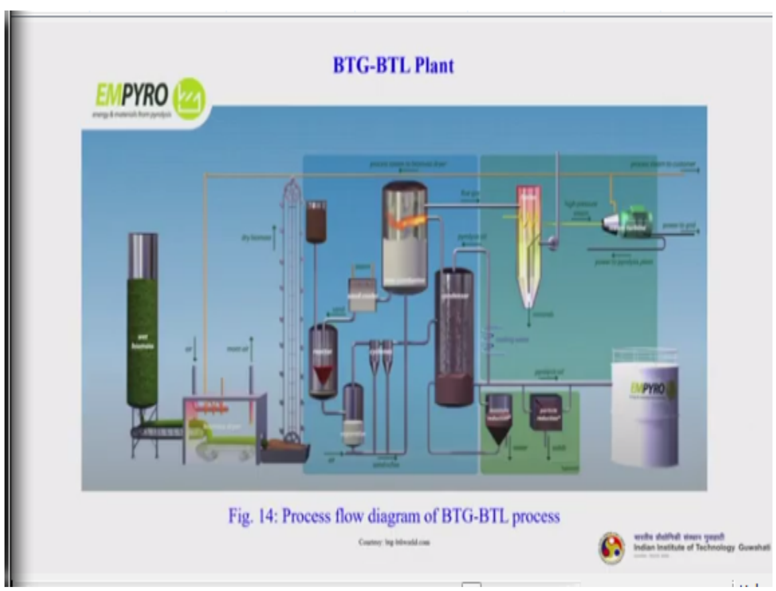

Fig. 14: Process flow diagram of BTG-BTL process

So, this is the BTG-BTL plant process flow diagram. So, you can see that wet biomass right now, once it comes it is being fed to some sort of dryer where air is being used and the moisture is taken out. So, the biomass is getting dried then it is collected somewhere. Now here there is a conveyer system you can see that which is basically taking the biomass up and put it in the somewhere in the top where there is the feeder.

From here the biomass is slowly fed to the main reactor, here the pyrolysis is happening. Now from the main reactor, it goes to the separator and air is being fed also here. So, what it is separating is the sand and char, the solid part. So, the sand and char is being separated and char is being fed to the char combustor, where the flue gas is being taken away from the top and is being used for steam generation and some other purposes.

And the oil whatever it is getting converted from here the condensable part that goes straight to the condenser, where the oil is getting condensed and collected and further processed. So, this is a simple and nicely integrated technology by the BTG-BTL technology, and the yield is very high. And as we have already discussed that it can process any type of feedstock as well as different sizes of the feedstock particles also.

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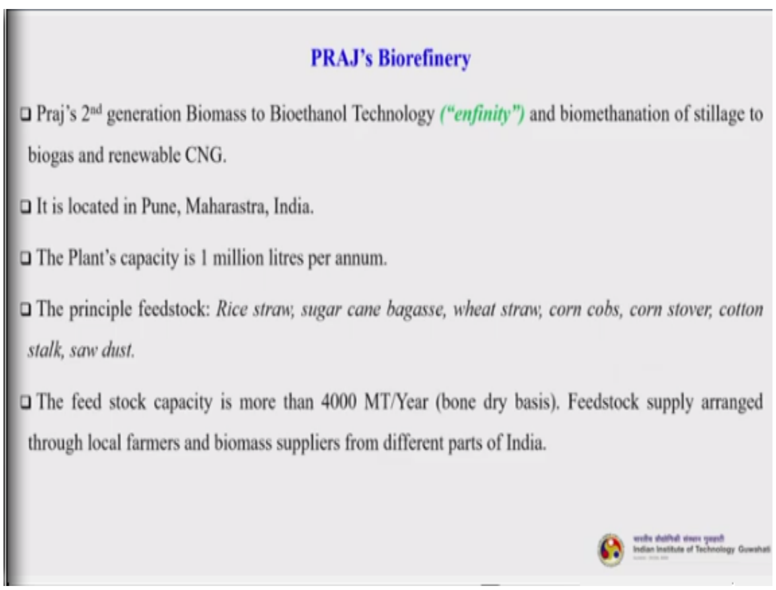

So, the next is again an Indian success story it is about the Praj biorefinery, so Praj second generation biomass to bioethanol technology which is named as ***enfinity*** and biomethanation of stillage to biogas and renewable CNG, is a beautiful technology which is actually being praised by most of the western countries also. So, it is located in Pune, Maharashtra, and the plant's capacity is 1 million liters per annum.

The principle feedstocks are rice straw, sugar cane bagasse, wheat straw, corn cobs, corn stover, cotton stalk and saw dust, and please understand there are many more also, these are the principle feedstock of course. The feedstock capacity is more than 4000 metric tons per year on a bone dry basis. So, feedstock supply arranged through local farmers and biomass suppliers from different parts of India.

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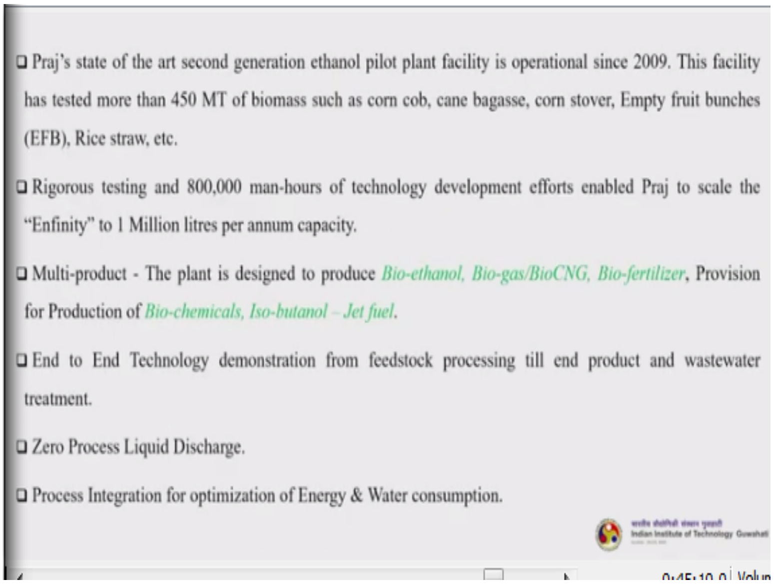

Praj's state of the art second generation ethanol pilot plant facility is operational since 2009. This facility has tested more than 450 metric ton of biomass such as corn cob, cane bagasse and other things. Empty fruit bunches, rice straw also has been processed. Rigorous testing and 800,000 man hours of technology development efforts enabled Praj to scale the Enfinity to 1 million liters per annum capacity.

Multi-product, so the plant is designed to produce bio-ethanol, bio-gas or bioCNG, bio-fertilizer and there is also provision for production of biochemicals, Iso-butanol to jet fuel. End to end technology demonstration from feedstock processing till end product and wastewater treatment. Zero process liquid discharge, that is very interesting actually. Process integration for optimization of energy and water consumption.

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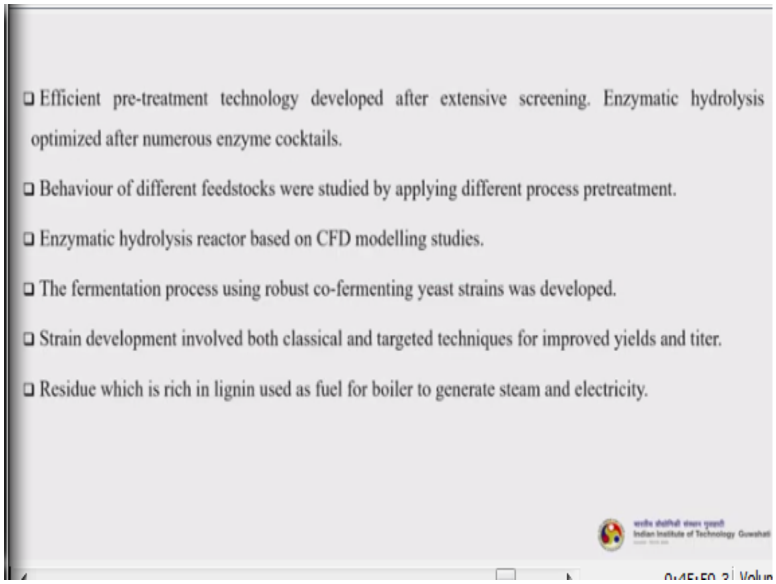

Efficient pretreatment technology developed after extensive screening, enzymatic hydrolysis optimized after numerous cocktails. Behavior of different feedstocks were studied by applying different process treatment. Enzymatic hydrolysis reactor based on CFD modeling studies, the fermentation process using robust co-fermenting yeast strain was developed. Strain development involved both classical and targeted techniques for improved yields and titer. Residue which is rich in lignin used as fuel for boiler to generate steam and electricity.

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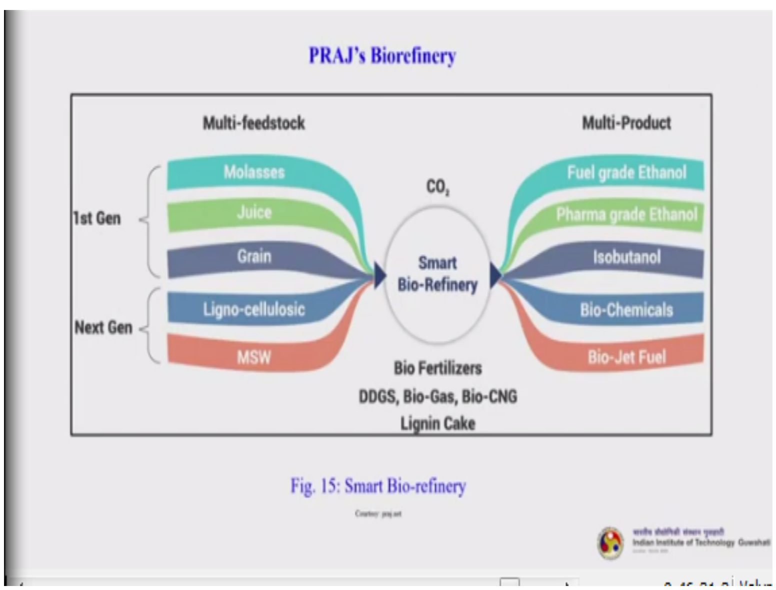

So, this is Praj's smart biorefinery concept, so the first generation and second generation it has both it is taking to account. Molasses, juice, grain, lignocellulosic, municipal solid waste**.** So, it goes to the smart biorefinery processing where we get this multiple products such as fuel grade ethanol, pharma grade ethanol also, then iso-butanol, biochemicals and bio jet fuel. And left out can be used as biofertilizers, biogas it can be converted to biogas, bio CNG and lignin cake, lignin cake can be further pyrolysed also.

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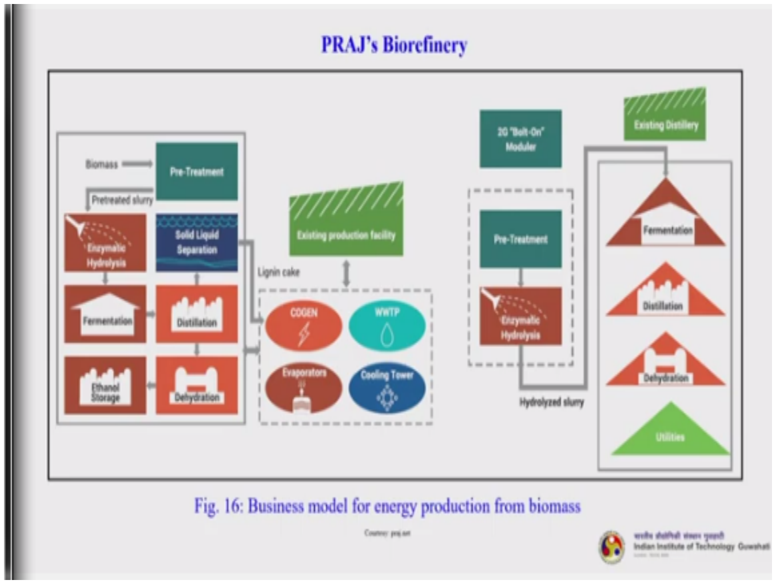

So, this is the entire schematic process, this is the business model for their energy production from biomass. So, the biomass pretreated, pretreated slurry coming to enzymatic hydrolysis, it is getting fermented, you get purification distillation process, dehydration you get the ethanol, ethanol is stored here. So, the lignin cake from here the liquid solid separation process can be processed in this platform. It is a co-generation platform where you can use gasification, pyrolysis any other things to again generate the power, in a CHP platform module. And that is you can see the utility of the existing distillery process and the 2G bolt on moduler, here it is pretreatment, enzymatic hydrolysis. This is hydrolyzed slurry that goes to fermentation process, so this is a very nice and beautiful technology which was developed by Praj.

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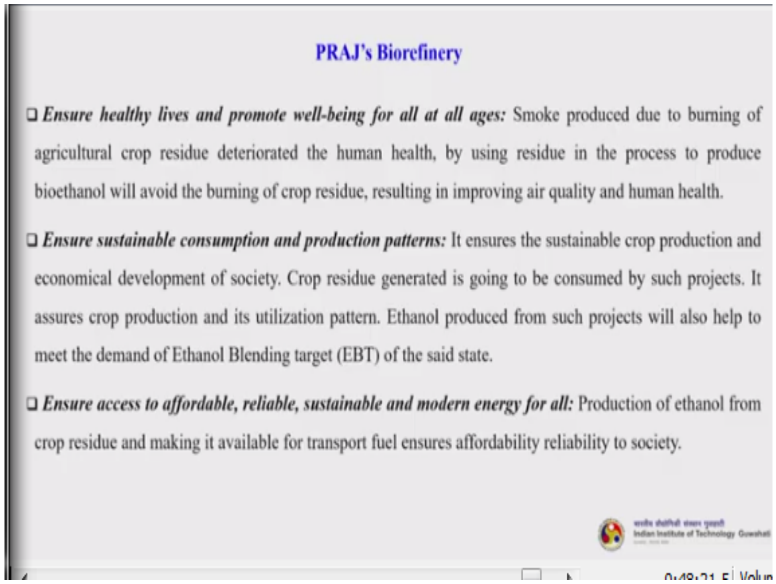

So, the Praj process actually it ensures healthy lives and promote well-being of all at all ages: Smoke produced due to the burning of the agricultural crop residue deteriorated the human health, by using residue in the process to produce bioethanol will avoid the burning of crop residue, resulting in improving air quality and human health, one of the most important aspect.

Second is, they ensure a sustainable consumption and production patterns. It ensures the sustainable crop production and economical development of the society. Crop residue generated is going to be consumed by such projects, it assures crop production and its utilization pattern. Ethanol produced from such projects will also help to meet the demand of ethanol blending target of the said state.

So, it further ensures access to affordable, reliable, sustainable and modern energy for all. So, production of ethanol from crop residues and making it available for transport fuel ensures affordability reliability to the society.

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So, with this I end my today's lecture. So, if you have any queries please feel free to register your query in the swayam portal or else you can drop a mail to me at kmohanty@iitg.ac.in. So, in the next module that is module 6 we will discuss the microbial conversion process, so thank you very much.