Biomass Conversion and Biorefinery
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Lecture 09
Economics and LCA

Good morning students, today is lecture 3 under module 3 and you know that we are discussing about biorefinery and concepts under this module. So today we will be discussing about the economics and the life cycle assessment of biorefineries. So, let us begin.

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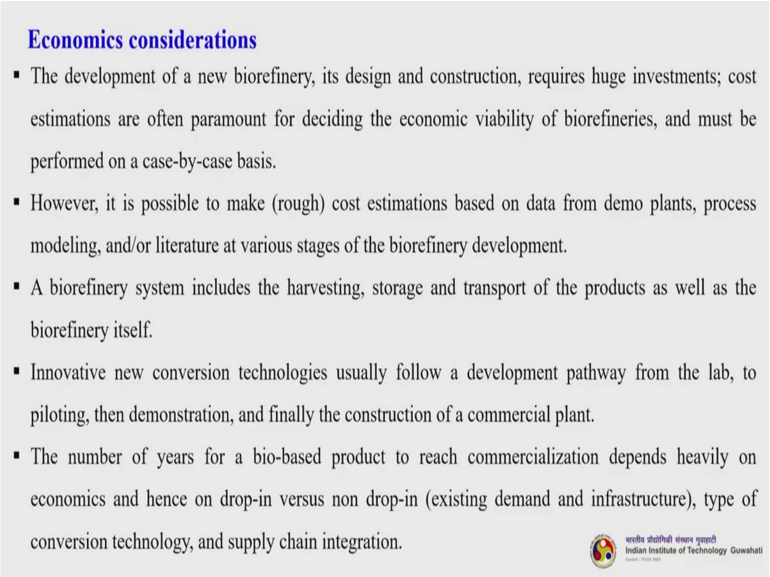

Economics considerations

- The development of a new biorefinery, its design and construction, requires huge investments; cost estimations are often paramount for deciding the economic viability of biorefineries, and must be performed on a case-by-case basis.
- However, it is possible to make (rough) cost estimations based on data from demo plants, process modeling, and/or literature at various stages of the biorefinery development.
- A biorefinery system includes the harvesting, storage and transport of the products as well as the biorefinery itself.
- Innovative new conversion technologies usually follow a development pathway from the lab, to piloting, then demonstration, and finally the construction of a commercial plant.
- The number of years for a bio-based product to reach commercialization depends heavily on economics and hence on drop-in versus non drop-in (existing demand and infrastructure), type of conversion technology, and supply chain integration.

The development of a new bio refinery, its design and construction, requires huge investments; cost estimation are often Paramount for deciding the economic viability of biorefineries and must be performed on a case-by-case basis. However, it is possible to make a rough estimation based and data from demo plants, process Modelling and/or literature at various stages of the biorefinery development. A Biorefinery system include the harvesting, storage and transport of the products as well as the biorefinery itself. Innovative new conversion Technologies usually follow a development pathway from the lab, to piloting, then demonstration and finally the construction of a commercial plant. The number of years for a bio-based product to reach commercialisation depends heavily on the economics and hence on drop-in versus non-drop-in (which means existing demand and infrastructure), type of conversion technology and supply chain integration.

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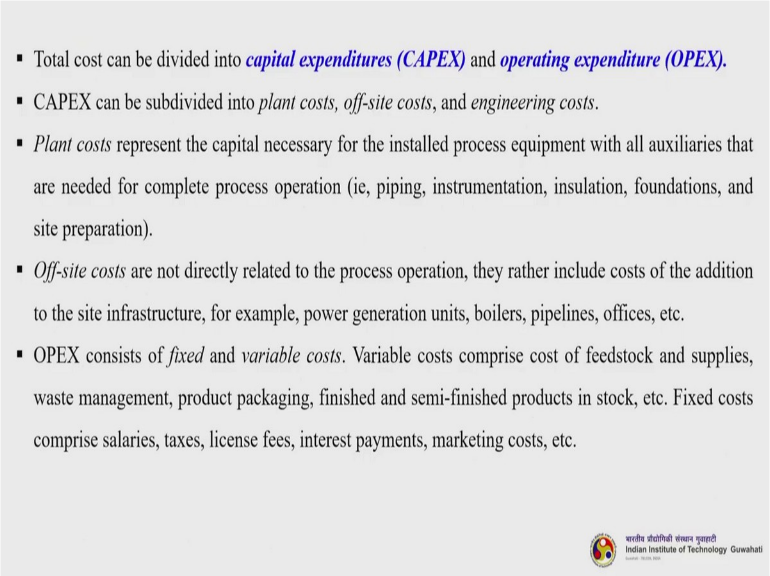

- Total cost can be divided into ***capital expenditures (CAPEX)*** and ***operating expenditure (OPEX).***
- CAPEX can be subdivided into *plant costs, off-site costs*, and *engineering costs*.
- *Plant costs* represent the capital necessary for the installed process equipment with all auxiliaries that are needed for complete process operation (ie, piping, instrumentation, insulation, foundations, and site preparation).
- *Off-site costs* are not directly related to the process operation, they rather include costs of the addition to the site infrastructure, for example, power generation units, boilers, pipelines, offices, etc.
- OPEX consists of *fixed* and *variable costs*. Variable costs comprise cost of feedstock and supplies, waste management, product packaging, finished and semi-finished products in stock, etc. Fixed costs comprise salaries, taxes, license fees, interest payments, marketing costs, etc.

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Total cost can be divided into two things: one is a capital expenditure, which is called as CAPEX and then the other one is the operating expenditure, which is called OPEX. CAPEX can be subdivided into mainly two things, one is plant cost and off-site cost and another cost also we can add on which is called engineering cost. So, the plant cost represents the capital necessary for the installed process equipment with all the auxiliary and accessories that are needed for the complete process operations. So, including from the piping, instrumentation, insulation, foundations, site preparation everything. Whereas off-site costs are not directly related to the process operation. They rather include costs of the addition of the site infrastructure, for example power generation units, boilers, pipelines, offices etc. OPEX consists of fixed and variable cost. Variable costs comprise cost of feedstock and supplies, waste management, product packaging, finished and semi-finished products in stock etc. Fixed cost comprises salaries, taxes, licence fees, interest payments, marketing cost etc. This gives us a rough idea about what are the different types of costs involved in a biorefinery.

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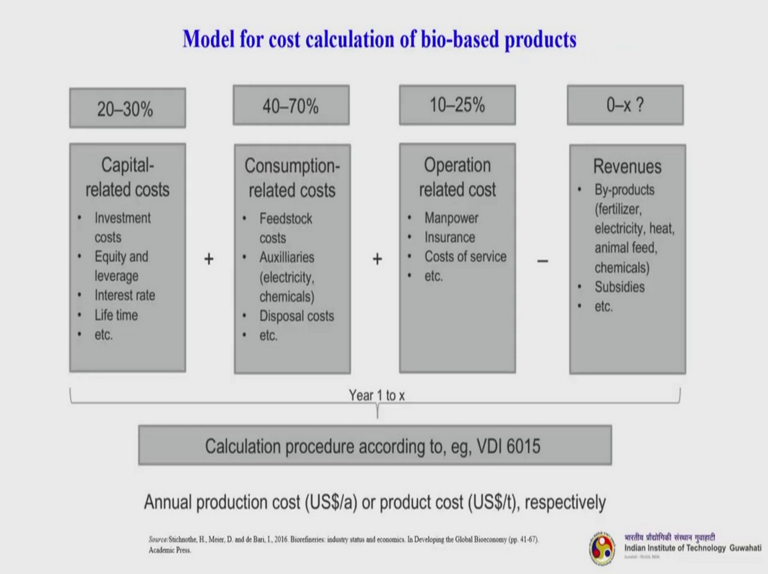

Model for cost calculation of bio-based products

Annual production cost (US$/a) or product cost (US$/t), respectively

Source: Stichnothe, H., Meier, D. and de Bari, I., 2016. Biorefineries: industry status and economics. In Developing the Global Bioeconomy (pp. 41-67). Academic Press.

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So, if you represent it in a schematic, we can understand in a better way, please have a look. You can see that 20% to 30% of the cost comes under the capital costs, which are investment cost basically. Equity, interest rate, life time etc. Then the major cost, 40% to 70%, is the consumption related cost. So, these are feedstock cost, auxiliaries (like electricity requirement - energy basically, chemicals), disposal cost etc.

Then the next is 10% to 25% is the operation related cost, which takes into account the manpower cost, insurance cost, cost of services etc. All these things, these three are basically the cost of the entire biorefinery process. So minus if you do the revenue, then that will become your profit.

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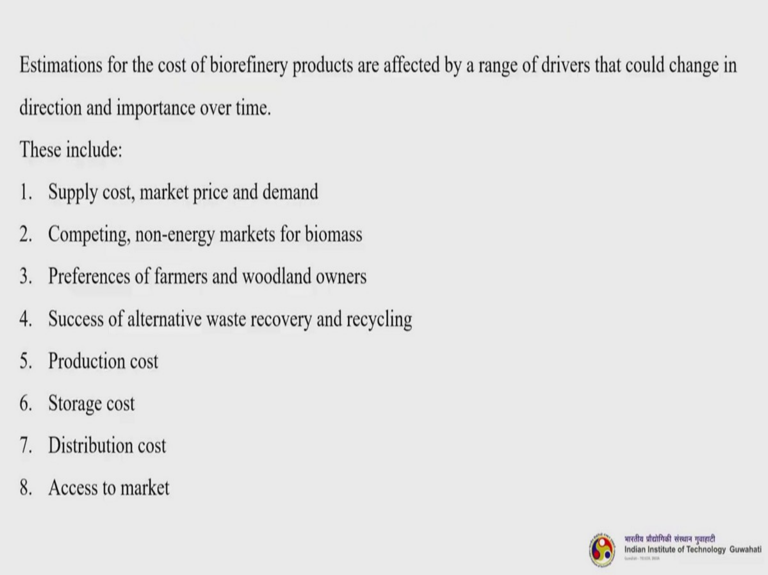

Estimations for the cost of biorefinery products are affected by a range of drivers that could change in direction and importance over time.

These include:

1. Supply cost, market price and demand
2. Competing, non-energy markets for biomass
3. Preferences of farmers and woodland owners
4. Success of alternative waste recovery and recycling
5. Production cost
6. Storage cost
7. Distribution cost
8. Access to market

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So, estimations for the cost of biorefinery products are affected by a range of drivers that could change in direction and importance over time. So, some of these include: supply cost, market price and demand, competing, non-energy markets for Biomass, preferences of farmers and Woodland owners, Success of alternative waste recovery and recycling, production cost, storage costs, distribution cost, access to market.

The first one, supply cost is basically feedstock supply cost. So how the feedstock is getting procured from the source and getting transported and all these things will come into that. Then again, the market price of the feedstock and market price of the product that you are eventually going to sell off all these things comes under that, with respect to demand for that particular product.

Then the second is, competing non-energy markets for the biomass. One of the most important thing that we need to understand at this point also that these bio-based products' acceptability has to be increased. So, a public awareness and campaigning is required to do that. So, right now even when somebody going to install a biorefinery, it is of paramount importance that they should also work on increasing the awareness of the bio-based products.

Then preferences of farmers and Woodland owners. So this is for both the things: one, is that feedstock procurement and all these things; then second, to whom you are selling the products. So, in both the cases farmers are of course stakeholders and the Woodland owners.

The next one is about the success of alternative waste recovery and recycling. As I told you in one of our class that recycle and reuse is one of the most important factors that is associated with the so-called bio refinery concept. So, unless and until we are looking for a value-based product from the waste that is getting generated from the biorefinery itself, we cannot have a sustainable economy. So that needs to be done. For that you have to develop the process technologies also. Production cost is of course very important that has to be taken care of, so then storage cost also important cost. You are you are going to store 2 things. First is that storing of the feedstocks; second is that storing of the finished products. And apart from that in between also storing of this waste and all, till they get recycled and converted. So then distribution cost and access to markets, all these will impact the entire costing of the biorefinery system.

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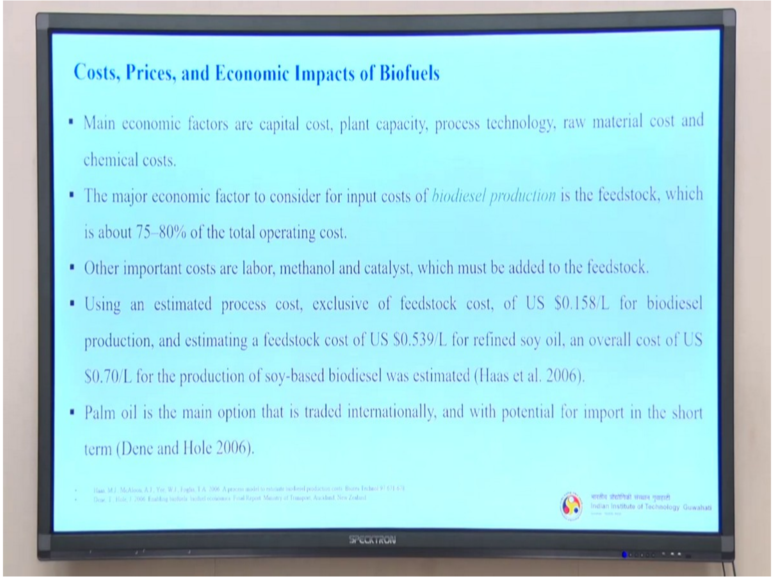

Costs, Prices, and Economic Impacts of Biofuels

- Main economic factors are capital cost, plant capacity, process technology, raw material cost and chemical costs.
- The major economic factor to consider for input costs of *biodiesel production* is the feedstock, which is about 75–80% of the total operating cost.
- Other important costs are labor, methanol and catalyst, which must be added to the feedstock.
- Using an estimated process cost, exclusive of feedstock cost, of US $0.158/L for biodiesel production, and estimating a feedstock cost of US $0.539/L for refined soy oil, an overall cost of US $0.70/L for the production of soy-based biodiesel was estimated (Haas et al. 2006).
- Palm oil is the main option that is traded internationally, and with potential for import in the short term (Dene and Hole 2006).

So, main economic factors are capital cost, Plant capacity, process technology, raw material cost and chemical costs. The major economic factor to consider for input cost of biodiesel production is the feedstock, which is about 75 to 80% of the total operating cost. This is for an example that let us understand that if biodiesel is a prime product or the main product from a particular bio refinery, then what is the situation.

So, other important costs of course labour, methanol and catalyst which must be added to the feedstock with respect to biodiesel. Using an estimated process cost exclusive of feedstock cost US dollar 0.158 per litre for biodiesel production and estimating a feedstock cost of US dollar 0.539 per litre for the refined soy oil and overall cost of US dollar 0.70 litre for the production of soy-based biodiesel was estimated. So, I have given the reference at the bottom you can refer to it later on.

Palm oil is the main option that is traded internationally and with potential for import in the short-term basis.

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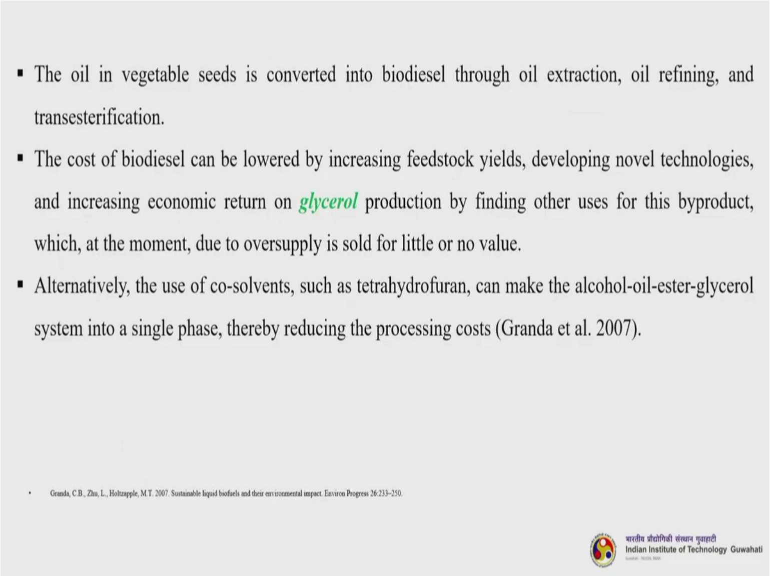

- The oil in vegetable seeds is converted into biodiesel through oil extraction, oil refining, and transesterification.
- The cost of biodiesel can be lowered by increasing feedstock yields, developing novel technologies, and increasing economic return on *glycerol* production by finding other uses for this byproduct, which, at the moment, due to oversupply is sold for little or no value.
- Alternatively, the use of co-solvents, such as tetrahydrofuran, can make the alcohol-oil-ester-glycerol system into a single phase, thereby reducing the processing costs (Granda et al. 2007).

- Granda, C.B., Zhu, L., Holtzapple, M.T. 2007. Sustainable liquid biofuels and their environmental impact. Environ Progress 26:233–250.

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So, the oil in vegetable seeds is converted into biodiesel through oil extraction, oil refining and transesterification. And as I told you in last class even last to last class, we have discussed that extraction technology should be developed in such a way that they are very efficient as well as they are low cost. And the cost of biodiesel can be lowered by increasing feedstock yields, developing novel technologies and increasing economic return on glycerol.

Please understand that glycerine is one of the most important by product from the transesterification reaction or biodiesel production. Glycerol is a very high value product but the problem right now is that the amount of glycerol that is produced across the globe and that is converted into useful products, there is a disparity. So you have huge surplus of glycerol. Unless and until we develop technologies to convert glycerine to other value added products rather than what is right now being used commercially then the sustainability of a bio diesel a based biorefinery is still in question.

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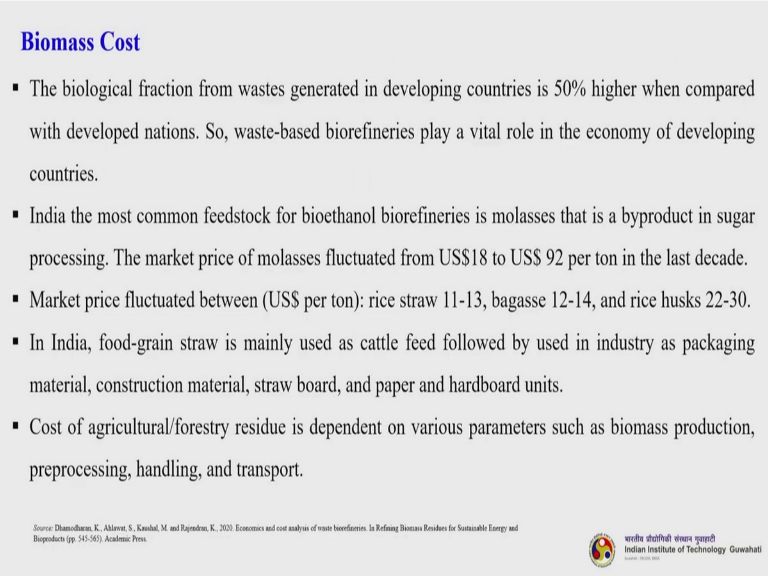

Biomass Cost

- The biological fraction from wastes generated in developing countries is 50% higher when compared with developed nations. So, waste-based biorefineries play a vital role in the economy of developing countries.
- India the most common feedstock for bioethanol biorefineries is molasses that is a byproduct in sugar processing. The market price of molasses fluctuated from US$18 to US$ 92 per ton in the last decade.
- Market price fluctuated between (US$ per ton): rice straw 11-13, bagasse 12-14, and rice husks 22-30.
- In India, food-grain straw is mainly used as cattle feed followed by used in industry as packaging material, construction material, straw board, and paper and hardboard units.
- Cost of agricultural/forestry residue is dependent on various parameters such as biomass production, preprocessing, handling, and transport.

Source: Dhamodharan, K., Ahlawat, S., Kaushal, M. and Rajendran, K., 2020. Economics and cost analysis of waste biorefineries. In Refining Biomass Residues for Sustainable Energy and Bioproducts (pp. 545-565). Academic Press.

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Let us look at Biomass cost which is one of the most significant cost associated with the biorefinery. The biological fraction from waste generated in developing countries is 50% higher when compared with developed nations. So, waste based biorefineries play a vital role in the economy of developing countries. In India the most common feedstock for bioethanol biorefineries is molasses.

Because there is a huge by-product that is coming from the sugar processing industries, mostly based on sugarcane. So, the market price of molasses fluctuated from 18 to 92 US dollar per tonne in the last decade. And market price fluctuated between US dollar per tonne for rice straw is between 11 to 13, bagasse 12 to 14 and rice husk is 22 to 30. Now in India food grain straw is mainly used as a cattle feed, followed by its use in industry as a packaging material, construction materials, straw board and paper and hardboard units. Cost of Agricultural and Forestry Residue is dependent on various parameters such as biomass production, pre-processing, handling and transportation. So, when you talk about biomass cost, all these costs are coming into picture.

Cost of residues fluctuated between 14 to 34 US dollar per tonne, minimum being for the bajra straw and the maximum for the arhar stalks. In another scenario when the travel distance was 100 KM from the farms cost fluctuated from US Dollar 36 to 55 per tonne for bajra straw and arhar stalks respectively highlighting the influence of transportation on market price of the residues.

We have discussed about this travel cost in one of our lectures previously that the transportation cost is a significant cost with respect to the Biomass procurement cost. The cost of the Biomass as it is will be very low because any way when it is getting procured from forest resources, agricultural field or anywhere, municipal waste also, its price or cost is very less. But when we keep on transporting it the transportation cost increases significantly due two things.

First is, where is the Plant located, how far it is from the source, that is source of procurement and what is the density and shape and size of this biomasses. If it is low dense, then it is basically very high-volume and transportation becomes difficult as well as it becomes costly.

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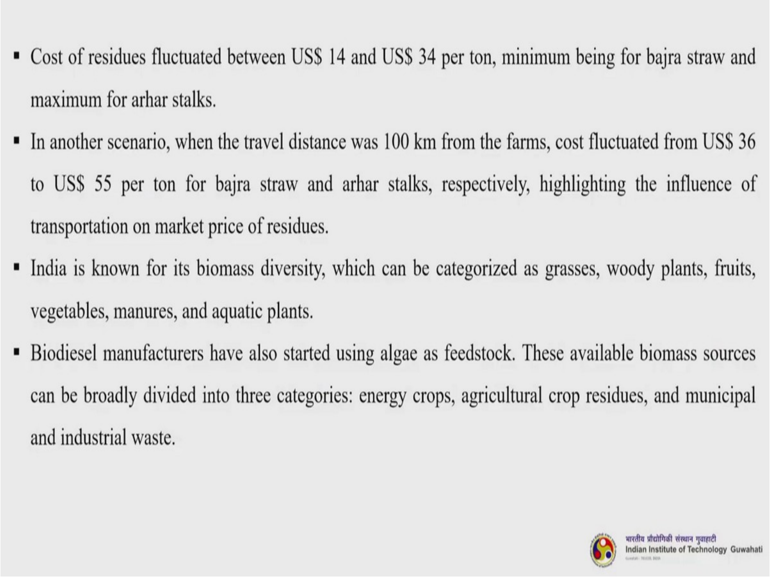

- Cost of residues fluctuated between US$ 14 and US$ 34 per ton, minimum being for bajra straw and maximum for arhar stalks.
- In another scenario, when the travel distance was 100 km from the farms, cost fluctuated from US$ 36 to US$ 55 per ton for bajra straw and arhar stalks, respectively, highlighting the influence of transportation on market price of residues.
- India is known for its biomass diversity, which can be categorized as grasses, woody plants, fruits, vegetables, manures, and aquatic plants.
- Biodiesel manufacturers have also started using algae as feedstock. These available biomass sources can be broadly divided into three categories: energy crops, agricultural crop residues, and municipal and industrial waste.

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So, India is known for its biomass diversity which can be categorised as grasses, woody plants, fruits, vegetables, manures, aquatic plants and what not there are so many. So, biodiesel manufacturers have also started using algae as feedstock. These available biomass sources can be broadly divided into three categories: energy crops, agricultural crop residues, municipal and industrial wastes. And we have already discussed this significantly in a few of our classes.

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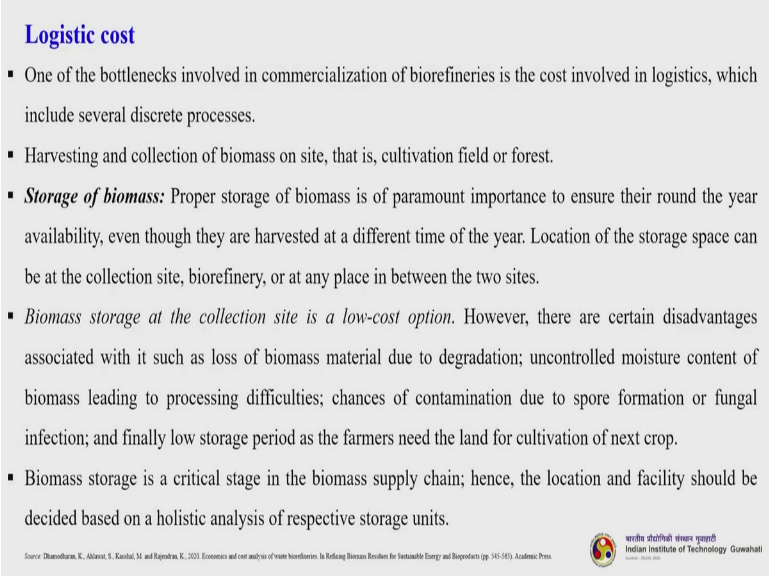

Logistic cost

- One of the bottlenecks involved in commercialization of biorefineries is the cost involved in logistics, which include several discrete processes.
- Harvesting and collection of biomass on site, that is, cultivation field or forest.
- ***Storage of biomass:*** Proper storage of biomass is of paramount importance to ensure their round the year availability, even though they are harvested at a different time of the year. Location of the storage space can be at the collection site, biorefinery, or at any place in between the two sites.
- *Biomass storage at the collection site is a low-cost option.* However, there are certain disadvantages associated with it such as loss of biomass material due to degradation; uncontrolled moisture content of biomass leading to processing difficulties; chances of contamination due to spore formation or fungal infection; and finally low storage period as the farmers need the land for cultivation of next crop.
- Biomass storage is a critical stage in the biomass supply chain; hence, the location and facility should be decided based on a holistic analysis of respective storage units.

Source: Dhamodharan, K., Ahlawat, S., Kaushal, M. and Rajendran, K., 2020. Economics and cost analysis of waste biorefineries. In Refining Biomass Residues for Sustainable Energy and Bioproducts (pp. 545-565). Academic Press.

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So, let us now understand what contributes to the logistics cost. So, one of the bottlenecks involved in commercialization of biorefinery is the cost involved in logistics, which include several discreet processes. Harvesting and collection of biomass and site that is from the cultivation field or forest. Storage of biomass is a significant cost, so proper storage of biomass is of paramount importance to ensure round the year availability even though they are harvested at different times of the year. Because most of the crops are seasonal. Location of the storage space can be at the collection site, biorefinery, or at any place in between the two sites. So the location will eventually decide about the transportation. Then biomass storage at the collection site is a low-cost option, but that is not always a Win-Win situation because there are certain disadvantages associated with it such as the loss of biomass material due to degradation; uncontrolled moisture content of biomass leading to processing difficulties; chances of contamination due to spore formation or fungal infection; and finally low storage period as the farmers need the land for cultivation of next crop. So, biomass storage is a critical stage in the biomass supply chain, hence, the location and facilities should be decided based on the holistic analysis of respective storage unit.

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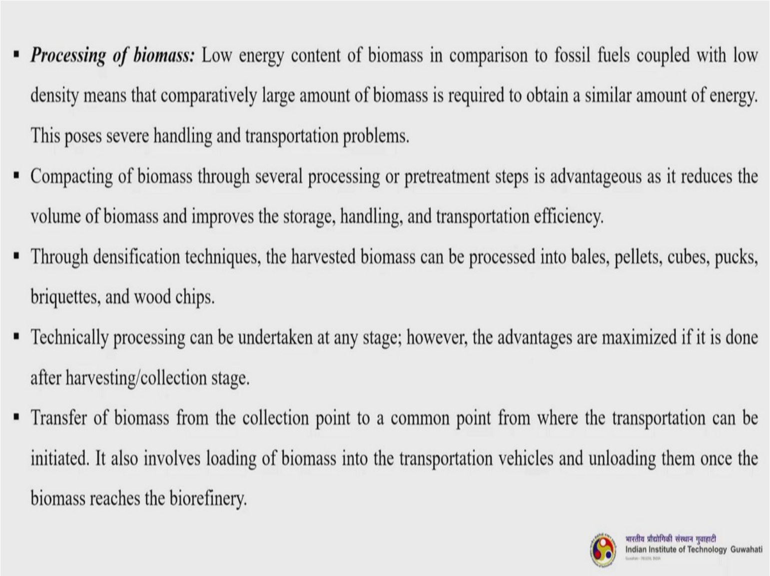

- ***Processing of biomass:*** Low energy content of biomass in comparison to fossil fuels coupled with low density means that comparatively large amount of biomass is required to obtain a similar amount of energy. This poses severe handling and transportation problems.
- Compacting of biomass through several processing or pretreatment steps is advantageous as it reduces the volume of biomass and improves the storage, handling, and transportation efficiency.
- Through densification techniques, the harvested biomass can be processed into bales, pellets, cubes, pucks, briquettes, and wood chips.
- Technically processing can be undertaken at any stage; however, the advantages are maximized if it is done after harvesting/collection stage.
- Transfer of biomass from the collection point to a common point from where the transportation can be initiated. It also involves loading of biomass into the transportation vehicles and unloading them once the biomass reaches the biorefinery.

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Processing of biomass: So, low energy content of Biomass in comparison to fossil fuels coupled with low density means that comparatively large amount of biomass is required to obtain a similar amount of energy. So, this poses severe handling and transportation problems. Compacting of biomass through several processing or pretreatment steps is advantageous as it reduces the volume of biomass as well as improve the storage, handling and transportation efficiency.

Though densification techniques (we have discussed that how do you densify this, you make into briquettes, pellets and all these things) the harvested biomass can be processed into bales, pellets, cubes, pucks, briquettes and wood chips. Technically processing can be undertaken at any stage. However, the advantages are maximized if it is done after harvesting or collection stage.

Transfer of biomass from the collection point to a common point from where the transportation can be initiated is also very important. It also involves loading of biomass into the transportation vehicles and unloading them once the Biomass reaches the biorefineries; so for each and every step there is a cost associated.

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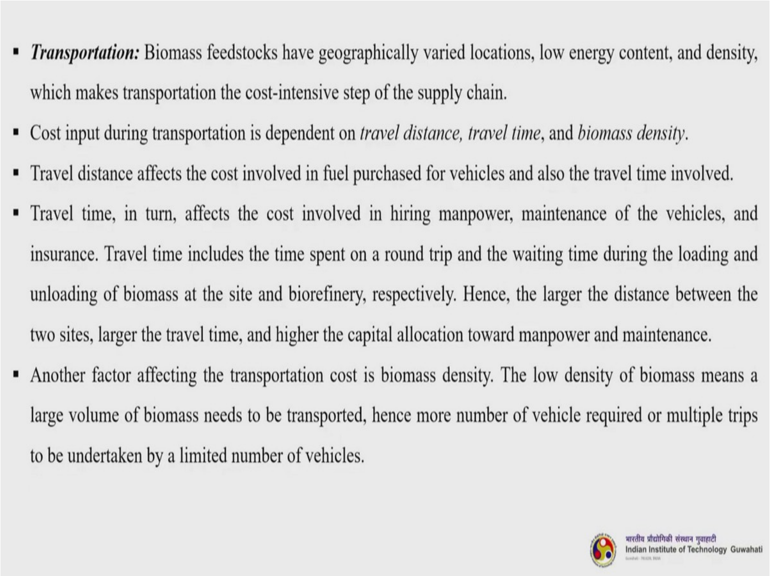

- ***Transportation:*** Biomass feedstocks have geographically varied locations, low energy content, and density, which makes transportation the cost-intensive step of the supply chain.
- Cost input during transportation is dependent on *travel distance, travel time*, and *biomass density*.
- Travel distance affects the cost involved in fuel purchased for vehicles and also the travel time involved.
- Travel time, in turn, affects the cost involved in hiring manpower, maintenance of the vehicles, and insurance. Travel time includes the time spent on a round trip and the waiting time during the loading and unloading of biomass at the site and biorefinery, respectively. Hence, the larger the distance between the two sites, larger the travel time, and higher the capital allocation toward manpower and maintenance.
- Another factor affecting the transportation cost is biomass density. The low density of biomass means a large volume of biomass needs to be transported, hence more number of vehicle required or multiple trips to be undertaken by a limited number of vehicles.

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Transportation: biomass feedstocks have geographically varied locations, low energy content and density, which makes transportation the cost-intensive step of the entire supply chain. Cost input during transportation is dependent on travel distance, travel time and bio mass density. Travel distance affects the cost involved in the fuel purchased for vehicles and also the travel time involved. Then travel time in turn affects the cost involved in hiring manpower, maintenance of the vehicles and insurance. Manpower is required for basically loading and unloading the Biomass in the transportation vehicles. So, travel time includes the time spent on a round trip and the waiting time during the loading and unloading of biomass at the site and biorefinery respectively. Hence, the larger the distance between the two sites, larger the travel time and higher is the capital allocation and manpower and maintenance; so these things needs to be optimised.

Another factor affecting the transportation cost is the Biomass density. The low density of biomass means a large volume of biomass needed to be transported, hence more number of vehicles required or multiple trips to be undertaken by limited number of vehicles.

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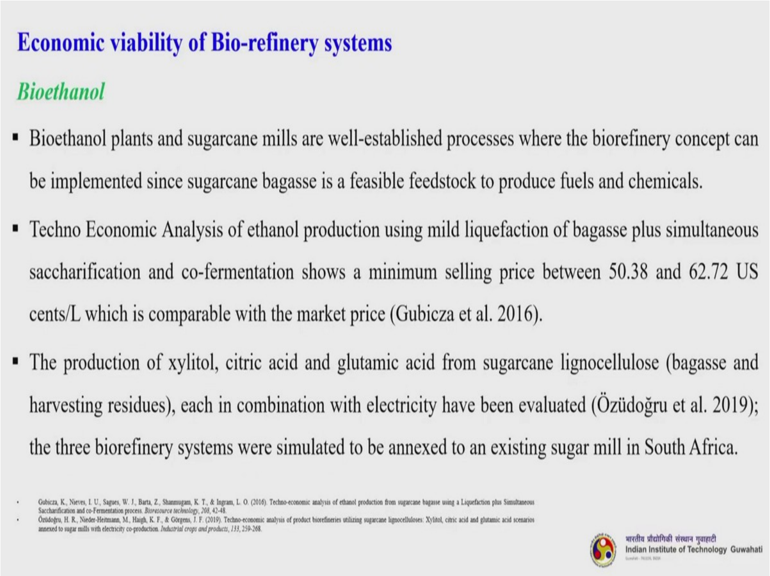

Economic viability of Bio-refinery systems

Bioethanol

- Bioethanol plants and sugarcane mills are well-established processes where the biorefinery concept can be implemented since sugarcane bagasse is a feasible feedstock to produce fuels and chemicals.
- Techno Economic Analysis of ethanol production using mild liquefaction of bagasse plus simultaneous saccharification and co-fermentation shows a minimum selling price between 50.38 and 62.72 US cents/L which is comparable with the market price (Gubicza et al. 2016).
- The production of xylitol, citric acid and glutamic acid from sugarcane lignocellulose (bagasse and harvesting residues), each in combination with electricity have been evaluated (Özüdoğru et al. 2019); the three biorefinery systems were simulated to be annexed to an existing sugar mill in South Africa.

- Gubicza, K., Nieves, I. U., Sagues, W. J., Barta, Z., Shanmugam, K. T., & Ingram, L. O. (2016). Techno-economic analysis of ethanol production from sugarcane bagasse using a Liquefaction plus Simultaneous Saccharification and co-Fermentation process. *Bioresource technology*, *208*, 42-48.
- Özüdoğru, H. R., Nieder-Heitmann, M., Haigh, K. F., & Görgens, J. F. (2019). Techno-economic analysis of product biorefineries utilizing sugarcane lignocelluloses: Xylitol, citric acid and glutamic acid scenarios annexed to sugar mills with electricity co-production. *Industrial crops and products*, *133*, 259-268.

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Economic viability of biorefinery system. So in economic viability of biorefinery systems, we will see a case study of bioethanol. Bioethanol plants and sugar cane mills are well established processes, where the biorefinery concept can be implemented little easily since sugarcane bagasse is a feasible feedstock to produce fuels as well as certain chemicals. Techno economic analysis of Ethanol production using mild liquefaction of bagasse plus simultaneous saccharification and co-fermentation shows a minimum selling price between 50.38 and 62.72 US cents per litre which is comparable with the market price.

The production of xylitol, citric acid and glutamic acid from sugarcane lignocellulose that includes bagasse and harvesting residues each in combination with electricity have been evaluated. The three biorefinery systems were simulated to be annexed to an existing sugar mill in South Africa. The case study is there, please read the references that have been given at the bottom. You can please refer to those and read in details from the manuscripts.

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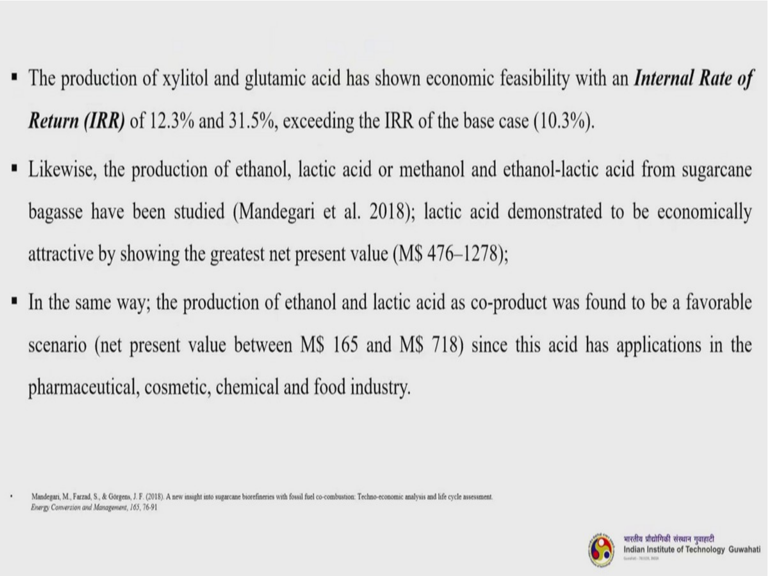

- The production of xylitol and glutamic acid has shown economic feasibility with an ***Internal Rate of Return (IRR)*** of 12.3% and 31.5%, exceeding the IRR of the base case (10.3%).
- Likewise, the production of ethanol, lactic acid or methanol and ethanol-lactic acid from sugarcane bagasse have been studied (Mandegari et al. 2018); lactic acid demonstrated to be economically attractive by showing the greatest net present value (M$ 476–1278);
- In the same way; the production of ethanol and lactic acid as co-product was found to be a favorable scenario (net present value between M$ 165 and M$ 718) since this acid has applications in the pharmaceutical, cosmetic, chemical and food industry.

- Mandegari, M., Farzad, S., & Görgens, J. F. (2018). A new insight into sugarcane biorefineries with fossil fuel co-combustion: Techno-economic analysis and life cycle assessment. *Energy Conversion and Management*, *165*, 76-91

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The production of xylitol and glutamic acid has shown economic feasibility with an internal rate of return of almost 12.3% and 31.5% exceeding the internal rate of return of the base case which is 10.3%. Likewise, the production of ethanol, lactic acid or methanol and ethanol-lactic acid from sugarcane bagasse have been studied. Lactic acid demonstrated to be economically attractive by showing the greatest net present value almost it ranges from 476 to 1276 million dollars.

In the same way the production of ethanol and lactic acid as co-product was found to be a favourable scenario. Since this acid has applications in pharmaceutical, cosmetic, chemical, and food industry.

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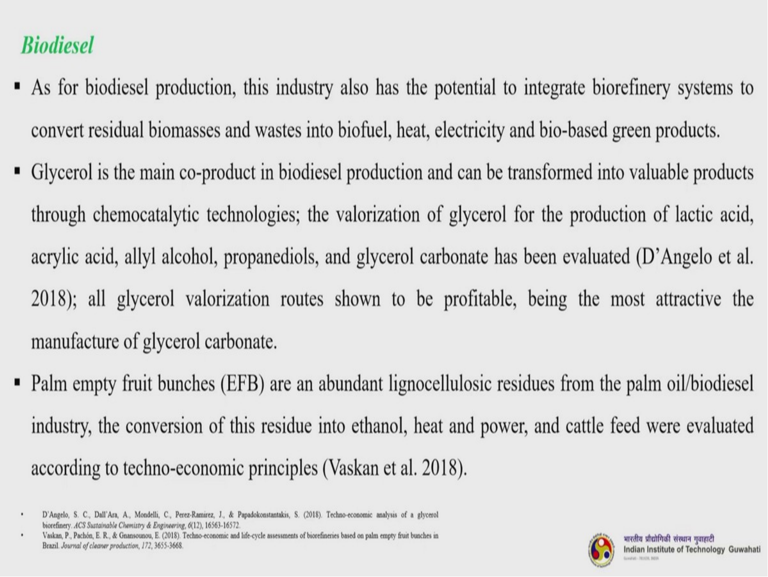

Biodiesel

- As for biodiesel production, this industry also has the potential to integrate biorefinery systems to convert residual biomasses and wastes into biofuel, heat, electricity and bio-based green products.
- Glycerol is the main co-product in biodiesel production and can be transformed into valuable products through chemocatalytic technologies; the valorization of glycerol for the production of lactic acid, acrylic acid, allyl alcohol, propanediols, and glycerol carbonate has been evaluated (D'Angelo et al. 2018); all glycerol valorization routes shown to be profitable, being the most attractive the manufacture of glycerol carbonate.
- Palm empty fruit bunches (EFB) are an abundant lignocellulosic residues from the palm oil/biodiesel industry, the conversion of this residue into ethanol, heat and power, and cattle feed were evaluated according to techno-economic principles (Vaskan et al. 2018).

- D'Angelo, S. C., Dall'Ara, A., Mondelli, C., Perez-Ramirez, J., & Papadokonstantakis, S. (2018). Techno-economic analysis of a glycerol biorefinery. *ACS Sustainable Chemistry & Engineering*, *6*(12), 16563-16572.
- Vaskan, P., Pachón, E. R., & Gnansounou, E. (2018). Techno-economic and life-cycle assessments of biorefineries based on palm empty fruit bunches in Brazil. *Journal of cleaner production*, *172*, 3655-3668.

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Let us now understand the biodiesel. So as for biodiesel production this industry also has the potential to integrate bio refinery system to convert residual biomasses and waste into biofuel, heat, electricity and bio-based green products. Glycerol is the main co-product in biodiesel production and can be transferred into valuable products through chemo catalytic technologies.

The valorization of glycerol for the production of lactic acid, acrylic acid, allyl alcohol propanediols and glycerol carbonate has been evaluated; all glycerol valorization routes shown to be profitable, being the most attractive the manufacture of glycerol carbonate. Palm empty fruit bunches are abundant lignocellulosic residues from the palm oil biodiesel industry. The conversion of this residue into ethanol, heat and power, and cattle feed were evaluated according to the techno economic principles.

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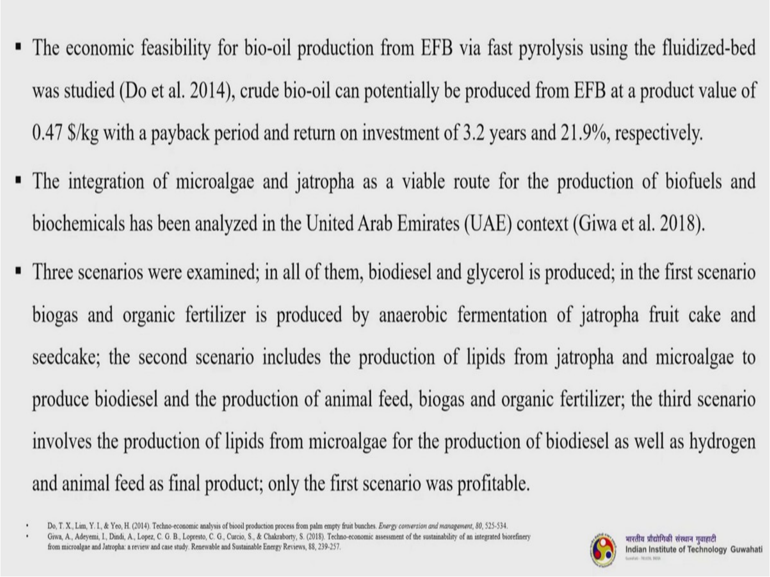

- The economic feasibility for bio-oil production from EFB via fast pyrolysis using the fluidized-bed was studied (Do et al. 2014), crude bio-oil can potentially be produced from EFB at a product value of 0.47 $/kg with a payback period and return on investment of 3.2 years and 21.9%, respectively.
- The integration of microalgae and jatropha as a viable route for the production of biofuels and biochemicals has been analyzed in the United Arab Emirates (UAE) context (Giwa et al. 2018).
- Three scenarios were examined; in all of them, biodiesel and glycerol is produced; in the first scenario biogas and organic fertilizer is produced by anaerobic fermentation of jatropha fruit cake and seedcake; the second scenario includes the production of lipids from jatropha and microalgae to produce biodiesel and the production of animal feed, biogas and organic fertilizer; the third scenario involves the production of lipids from microalgae for the production of biodiesel as well as hydrogen and animal feed as final product; only the first scenario was profitable.

- Do, T. X., Lim, Y. I., & Yeo, H. (2014). Techno-economic analysis of biooil production process from palm empty fruit bunches. *Energy conversion and management*, *80*, 525-534.
- Giwa, A., Adeyemi, I., Dindi, A., Lopez, C. G. B., Lopresto, C. G., Curcio, S., & Chakraborty, S. (2018). Techno-economic assessment of the sustainability of an integrated biorefinery from microalgae and Jatropha: a review and case study. Renewable and Sustainable Energy Reviews, 88, 239-257.

So, the economic feasibility of bio oil production from the EFB via fast pyrolysis using a fluidized bed technology was studied. Crude bio oil can potentially be produced from the EFB at a product value of 0.47 dollar per kg with a payback period and return on investment of 3.2 years and 21.9% respectively, which is considered as almost a moderate range. So, the integration of microalgae and Jatropha as viable route for the production of biofuels and biochemical has also been analysed in the United Arab Emirates context.

Three scenarios were examined; in all of them, biodiesel and glycerol is produced; in the first scenario biogas and organic fertilizer is produced by anaerobic fermentation of Jatropha fruit cake and seedcake. And in the second scenario the production of lipids from Jatropha and microalgae to produce biodiesel was evaluated and the production of animal feed, biogas and organic fertilizer was also integrated. In the third scenario that involves the production of lipids from microalgae for the production of biodiesel, as well as hydrogen and animal feed as final product (from the lipid extracted from algae basically); so this is the first scenario which was almost profitable compared to other scenarios.

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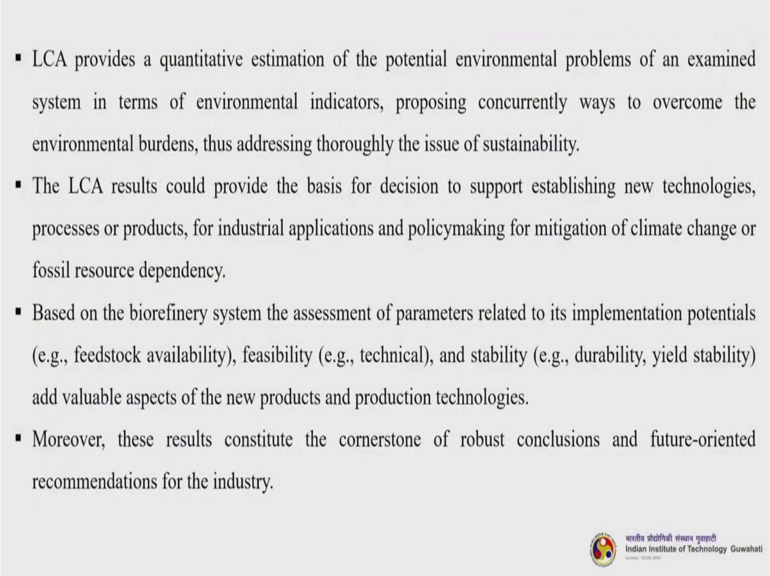

- LCA provides a quantitative estimation of the potential environmental problems of an examined system in terms of environmental indicators, proposing concurrently ways to overcome the environmental burdens, thus addressing thoroughly the issue of sustainability.
- The LCA results could provide the basis for decision to support establishing new technologies, processes or products, for industrial applications and policymaking for mitigation of climate change or fossil resource dependency.
- Based on the biorefinery system the assessment of parameters related to its implementation potentials (e.g., feedstock availability), feasibility (e.g., technical), and stability (e.g., durability, yield stability) add valuable aspects of the new products and production technologies.
- Moreover, these results constitute the cornerstone of robust conclusions and future-oriented recommendations for the industry.

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So now we will understand about the life cycle assessment. Now, whenever we are going to develop a process technology or let us say refinery, biorefinery or any industry whether it is a waste biomass-based industry or any other feedstock-based industry we need to carry out a life cycle assessment plus the techno economic evaluation. So, we have discussed about the cost, in a nutshell we understand what are the different types of cost that are associated in setting up a biorefinery. Now we will try to understand what is the meaning of a life cycle assessment (LCA).

LCA provides a quantitative estimation of the potential environmental problems of an examined system in terms of environmental indicators proposing concurrently ways to overcome the environmental burdens thus addressing thoroughly the issue of sustainability. The LCA results could provide the basis for decision to support establishing new technologies, processes or products for industrial applications and policy-making for mitigation of Climate Change or fossils resources dependency.

Based on the biorefinery system the assessment of parameters related to its implementation potentials (for example feedstock availability), feasibility and stability add valuable aspects of the new products and production Technologies. Moreover, these results constitute the cornerstone of robust conclusions and future oriented recommendations for the industries.

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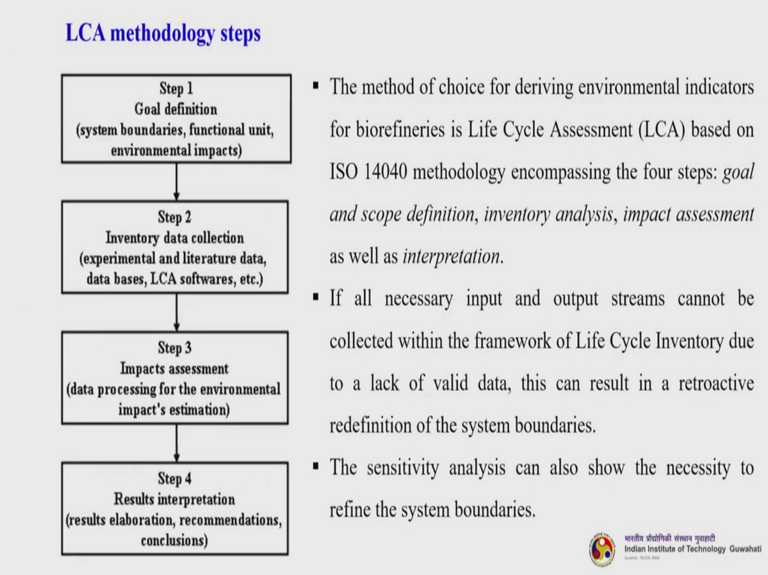

LCA methodology steps

Step 1
Goal definition
(system boundaries, functional unit, environmental impacts)

Step 2
Inventory data collection
(experimental and literature data, data bases, LCA softwares, etc.)

Step 3
Impacts assessment
(data processing for the environmental impact's estimation)

Step 4
Results interpretation
(results elaboration, recommendations, conclusions)

- The method of choice for deriving environmental indicators for biorefineries is Life Cycle Assessment (LCA) based on ISO 14040 methodology encompassing the four steps: *goal and scope definition*, *inventory analysis*, *impact assessment* as well as *interpretation*.
- If all necessary input and output streams cannot be collected within the framework of Life Cycle Inventory due to a lack of valid data, this can result in a retroactive redefinition of the system boundaries.
- The sensitivity analysis can also show the necessity to refine the system boundaries.

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So, let us understand how it happens actually. So in step 1, we have to define the goals. So in the step 2 we will talk about the inventory data collection. In step 3 it is the impact assessment and in step 4 it is the results interpretation. So, the method of choice for deriving environmental indicators for biorefinery is life cycle assessment based on the ISO 14040 methodology encompassing the 4 steps as mentioned here (refer slide).

So, if all necessary input and output streams cannot be collected within the framework of life cycle inventory due to a lack of valid data, this can result in a retroactive redefinition of the system boundaries. The sensitivity analysis can also show the necessity to refine the system boundaries.

When you define the goal in the step 1 basically you are talking about the system boundaries. You define the system boundaries, functional units, and what are the environmental impacts, that is going to arise from the processing of the feedstocks, handling them and when you convert them to value added products. In the second step it is about inventory Data Collection where experimental and literature data will be collected and stored, then databases will be accessed and you have to take the help of certain LCA software.

In the third step, it is impact assessment, where the data processing for the environmental impact will be basically carried out to understand whether there are any environmental effects at all from the biorefinery perspective when you are processing the Biomass and converting them to the value-added products. And in the final step, that is the result interpretation, you basically elaborate what are the results we have actually received. Then, based on that, what are the recommendations for reducing the environmental impact and/or mitigation. So, these are the essential 4 steps which are required to carry out the basic LCA study. There are so many other things also but, in a nutshell, let us try to understand what is LCA.

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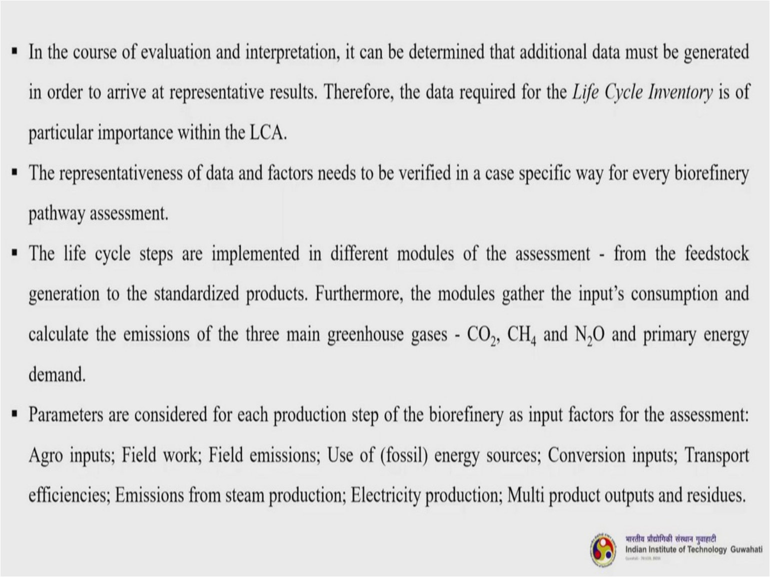

- In the course of evaluation and interpretation, it can be determined that additional data must be generated in order to arrive at representative results. Therefore, the data required for the *Life Cycle Inventory* is of particular importance within the LCA.
- The representativeness of data and factors needs to be verified in a case specific way for every biorefinery pathway assessment.
- The life cycle steps are implemented in different modules of the assessment - from the feedstock generation to the standardized products. Furthermore, the modules gather the input's consumption and calculate the emissions of the three main greenhouse gases - CO_2, CH_4 and N_2O and primary energy demand.
- Parameters are considered for each production step of the biorefinery as input factors for the assessment: Agro inputs; Field work; Field emissions; Use of (fossil) energy sources; Conversion inputs; Transport efficiencies; Emissions from steam production; Electricity production; Multi product outputs and residues.

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So, in the course of evaluation and interpretation, it can be determined that additional data must be generated in order to arrive at a representative result. Therefore, the data required for the life cycle inventory is of particular importance within the LCA. The representativeness of data and factors needs to be verified in a case specific way for every biorefinery pathway assessment.

The life cycle steps are implemented in different modules of the assessment - From the feedstock generation to the standardized products. Furthermore, the modules gather the input's consumption and calculate the emissions of the three main greenhouse gases - carbon dioxide, Methane and Nitrous oxide and primary energy demand. So, the parameters that are considered for each production step of the biorefinery as input factors for the assessment are: agro inputs, field work, field emission, use of the Fossil energy resources, conversion inputs transport efficiencies, emissions from steam production, Electricity production, multi product outputs and the residues.

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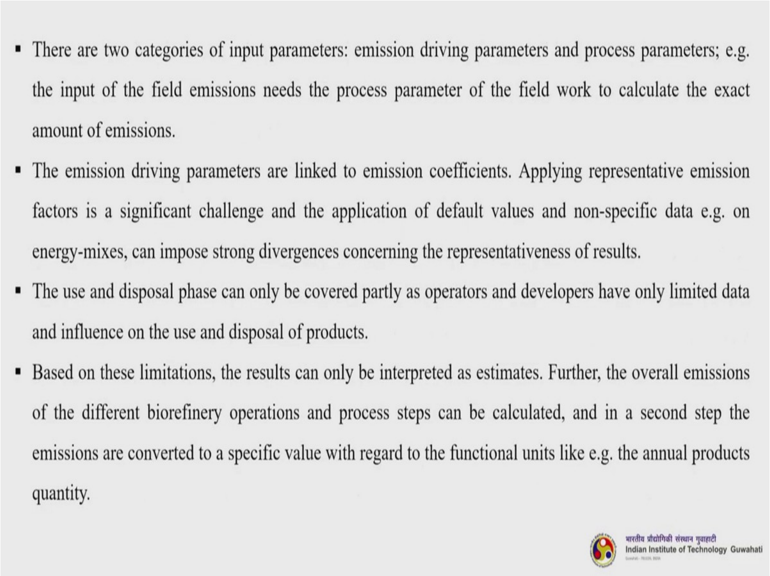

- There are two categories of input parameters: emission driving parameters and process parameters; e.g. the input of the field emissions needs the process parameter of the field work to calculate the exact amount of emissions.
- The emission driving parameters are linked to emission coefficients. Applying representative emission factors is a significant challenge and the application of default values and non-specific data e.g. on energy-mixes, can impose strong divergences concerning the representativeness of results.
- The use and disposal phase can only be covered partly as operators and developers have only limited data and influence on the use and disposal of products.
- Based on these limitations, the results can only be interpreted as estimates. Further, the overall emissions of the different biorefinery operations and process steps can be calculated, and in a second step the emissions are converted to a specific value with regard to the functional units like e.g. the annual products quantity.

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So, two categories of input parameters: emission driving parameters and process parameters. For example, the input of the field emission needs the process parameter of the field work to calculate the exact amount of emissions. So, you have to basically collect so much of field data and then analyse them to understand the value of emission. The emission driving parameters are linked to emission coefficients. Applying representative emission factors is a significant challenge and application of default values and non-specific data, for example on energy-mixes, can impose strong divergences concerning the representativeness of results. The use and disposal phase can only be partly covered as operators and developers have only limited data and influence on the use and disposal of products. Based on these limitations, the results can only be interpreted as estimates. Further, the overall emissions of the different biorefinery operations and process steps can be calculated, and a second step the emissions are converted to a specific value with regard to the functional units like for example the annual product quantity.

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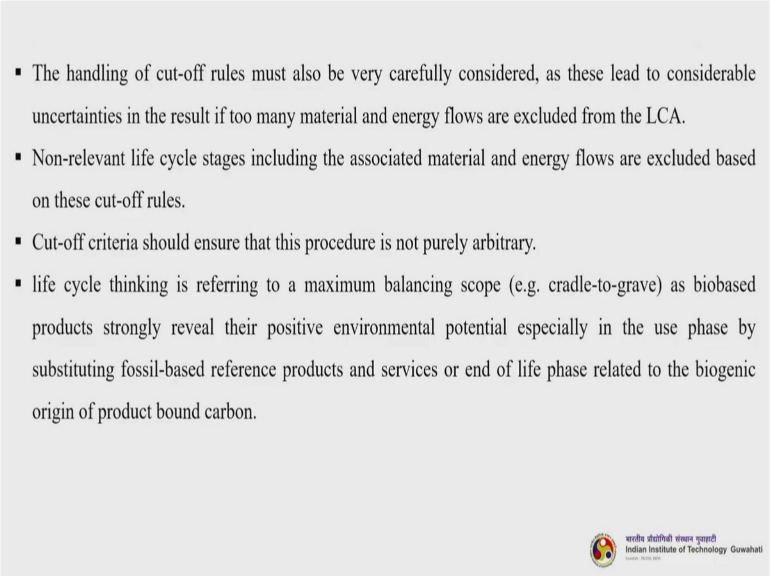

- The handling of cut-off rules must also be very carefully considered, as these lead to considerable uncertainties in the result if too many material and energy flows are excluded from the LCA.
- Non-relevant life cycle stages including the associated material and energy flows are excluded based on these cut-off rules.
- Cut-off criteria should ensure that this procedure is not purely arbitrary.
- life cycle thinking is referring to a maximum balancing scope (e.g. cradle-to-grave) as biobased products strongly reveal their positive environmental potential especially in the use phase by substituting fossil-based reference products and services or end of life phase related to the biogenic origin of product bound carbon.

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The handling of cut-off rules must also be very carefully considered as these lead to considerable uncertainties in the result if too many material and energy flows are excluded from the LCA. So non-relevant life cycle stages, including the associated material and energy flows are excluded based on these cut-off rules. Cut-off criteria should ensure that this procedure is not purely arbitrary.

Life cycle thinking is referring to a maximum balancing scope, for example cradle-to-grave (the meaning of cradle to grave here is basically you start from the feedstock and end up in the finished goods or finished product. The entire lifecycle, so that is basically from cradle-to-grave. That’s what it means.), as bio-based products strongly reveal their positive environmental potential especially in the use phase by substituting Fossil-based reference products and services or end of life phase related to the biogenic origin of product bound carbon.

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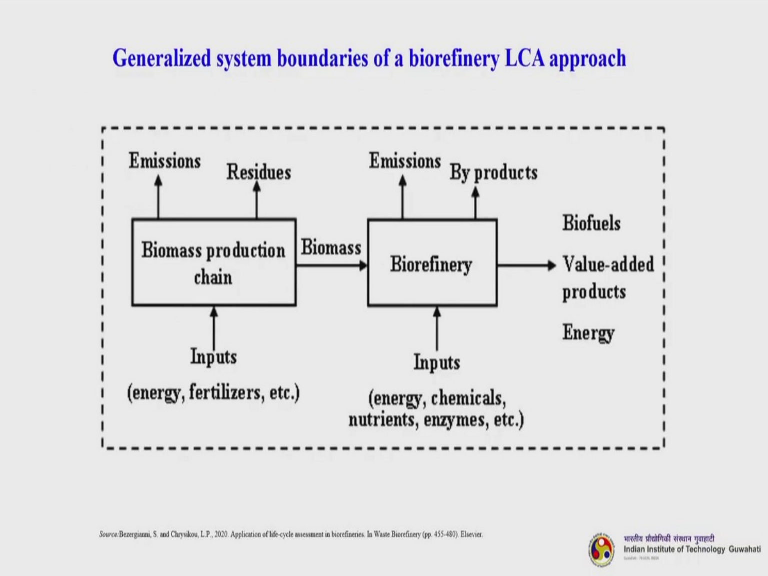

Generalized system boundaries of a biorefinery LCA approach

Source: Bezergianni, S. and Chrysikou, L.P., 2020. Application of life-cycle assessment in biorefineries. In Waste Biorefinery (pp. 455-480). Elsevier.

So, let us look at this, particular generalized system boundaries of a biorefinery LCA approach. This is a complete system boundary that is defined for a particular value-added biofuel based biorefinery. So, you start with the Biomass production chain basically, inputs, energy, fertilizer etc. to grow biomass, procure, transport, process. Then in that case there will be emissions and that will be the residues.

Now to make a sustainable biorefinery we also should convert these residues into value added products that is basically the recycling of the waste. Then the biomass goes to the Processing Unit, the plant, in which you are processing into value added products. So, when you are doing that there is an enormous amount of emissions that is coming out. And of course, again another set of by-product.

That by-product also should be taken into consideration to convert to value added products and basically minimise the waste and recycle them. Inputs are energy, Chemicals, nutrients and enzymes and there may be many things and the biofuels and other value-added products in terms of energy, electricity, and platform chemical. So, this is the complete system boundary and it’s an entire system.

Now I can take some small boundaries here also (*refer to the corresponding slide for explanation @time 28:05 min*). This is a generalized one. So, I can take one by one processes, one system boundaries, find out what are the emissions and also, we can do the techno economic assessment also by defining the system boundaries. So, this is how actually the boundaries have been defined for a biorefinery LCA approach.

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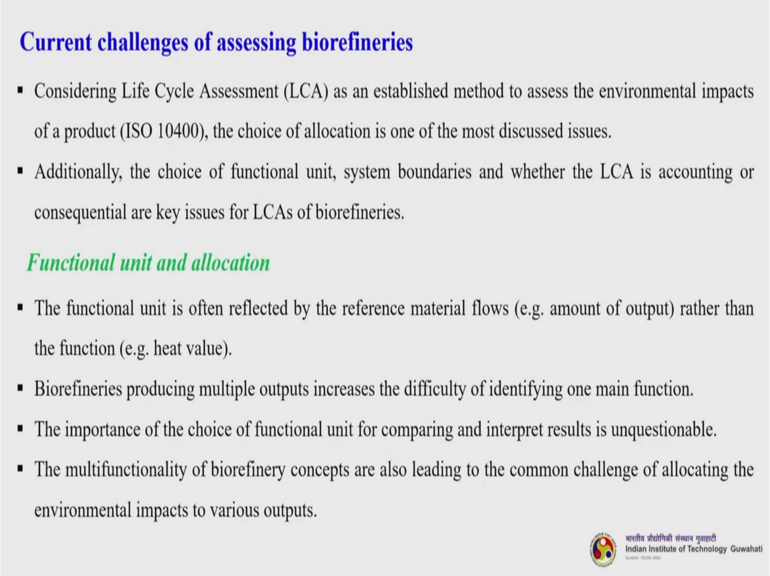

Current challenges of assessing biorefineries

- Considering Life Cycle Assessment (LCA) as an established method to assess the environmental impacts of a product (ISO 10400), the choice of allocation is one of the most discussed issues.
- Additionally, the choice of functional unit, system boundaries and whether the LCA is accounting or consequential are key issues for LCAs of biorefineries.

Functional unit and allocation

- The functional unit is often reflected by the reference material flows (e.g. amount of output) rather than the function (e.g. heat value).
- Biorefineries producing multiple outputs increases the difficulty of identifying one main function.
- The importance of the choice of functional unit for comparing and interpret results is unquestionable.
- The multifunctionality of biorefinery concepts are also leading to the common challenge of allocating the environmental impacts to various outputs.

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Let us now understand the current challenges of assessing biorefineries. Considering life cycle assessment as an established method, to assess the environmental impacts of a product, based on the ISO 10400 criteria, the choice of allocation is one of the most discussed issues. Additionally, the choice of functional unit, system boundaries and whether the LCA is accounting or consequential are the key issues for the LCAs of biorefineries.

So, functional unit and allocation: Let us understand what it means. So, the functional unit is often reflected by reference material flows (for example, the amount of output) rather than the function (for example, the heat value). Biorefineries producing multiple outputs increases the difficulty of identifying one main function. The importance of the choice of functional unit for comparing and interpret results is unquestionable. Multifunctionality of biorefinery concepts are also leading to the common challenge of allocating the environmental impacts to various outputs.

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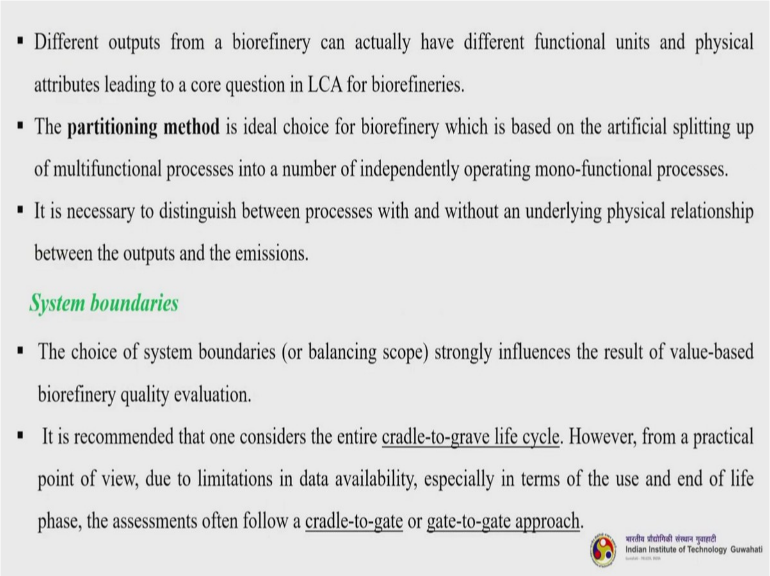

- Different outputs from a biorefinery can actually have different functional units and physical attributes leading to a core question in LCA for biorefineries.
- The **partitioning method** is ideal choice for biorefinery which is based on the artificial splitting up of multifunctional processes into a number of independently operating mono-functional processes.
- It is necessary to distinguish between processes with and without an underlying physical relationship between the outputs and the emissions.

System boundaries

- The choice of system boundaries (or balancing scope) strongly influences the result of value-based biorefinery quality evaluation.
- It is recommended that one considers the entire cradle-to-grave life cycle. However, from a practical point of view, due to limitations in data availability, especially in terms of the use and end of life phase, the assessments often follow a cradle-to-gate or gate-to-gate approach.

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Different outputs from a biorefinery can actually have different functional units and physical attributes leading to a core question in the LCA for biorefineries. The partitioning method is an ideal choice for biorefinery which is based on artificial splitting up of multifunctional processes into a number of independently operating monofunctional process. So, it is easier to assess basically if you do like that. It is necessary to distinguish between processes with or without an underlying physical relationship between the outputs and the emissions.

Now, let us understand system boundaries. So, the choice of system boundaries or balancing the scope strongly influences the result of value based biorefinery quality evaluation. So, you can go for an entire cradle to grave life cycle. However, from a practical point view due to limitations in data availability especially in terms of the use and the end of life phase, the assessments of one follow cradle-to-gate or gate-to-gate approach. So these are midsegment approaches.

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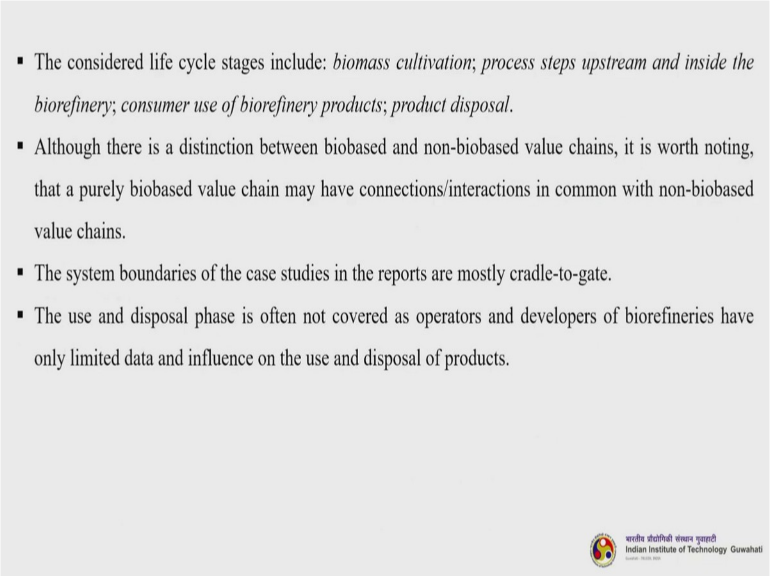

- The considered life cycle stages include: *biomass cultivation*; *process steps upstream and inside the biorefinery*; *consumer use of biorefinery products*; *product disposal*.
- Although there is a distinction between biobased and non-biobased value chains, it is worth noting, that a purely biobased value chain may have connections/interactions in common with non-biobased value chains.
- The system boundaries of the case studies in the reports are mostly cradle-to-gate.
- The use and disposal phase is often not covered as operators and developers of biorefineries have only limited data and influence on the use and disposal of products.

The considered life cycle stages include: Biomass cultivation; process steps upstream and inside the biorefinery; consumer use of biorefinery products; and product disposal. Although there is a distinction between bio based and non-bio-based value chains, it is worth noting that a purely bio-based value chain may have connections and interactions in common with non-bio-based value chain. The system boundaries of the case studies in the reports are mostly cradle-to-gate.

The use and disposal phase is often not covered as operators and developers of biorefineries have only limited data and influence on the use and disposal of products.

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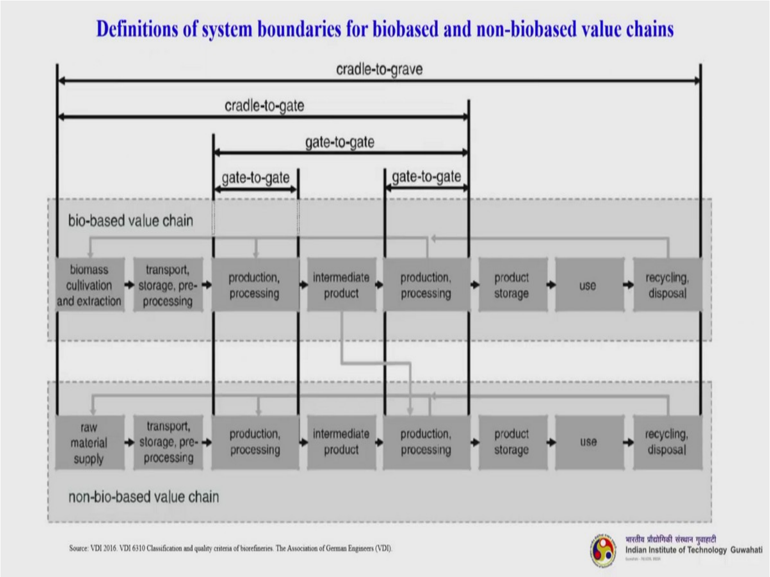

Definitions of system boundaries for biobased and non-biobased value chains

Source: VDI 2016. VDI 6310 Classification and quality criteria of biorefineries. The Association of German Engineers (VDI).

This is an interesting slide where we can understand, what is this cradle-to-Grave, cradle-to-gate and gate-to-gate system boundaries under LCA concept. Look at the Cradle-to-Grave, so it starts from the Biomass cultivation and extraction everything to recycling and disposal you get it? So it is the entire bio refinery system. Now let us understand cradle-to-gate which is intermediate boundary. It starts from Biomass cultivation and extraction, let us go to the production, processing, intermediate product and let us say till production or processing. It is not sacrosanctly defined like this. You can either take it that side or you can bring it this side also. You can end anywhere. It depends upon what type of data is available with you and how easily you can proceed with the availability of the data basically. Then, if you understand about gate-to-gate it is basically a single process. Let us see this. Production and processing of the biomass. This is one gate-to-gate approach. It can be production and processing of the intermediate product. Again, gate-to-gate approach. So, this is how the system boundaries has been defined for LCA analysis. So, the second one is a non-bio-based value chain and top one is the bio-based value chain.

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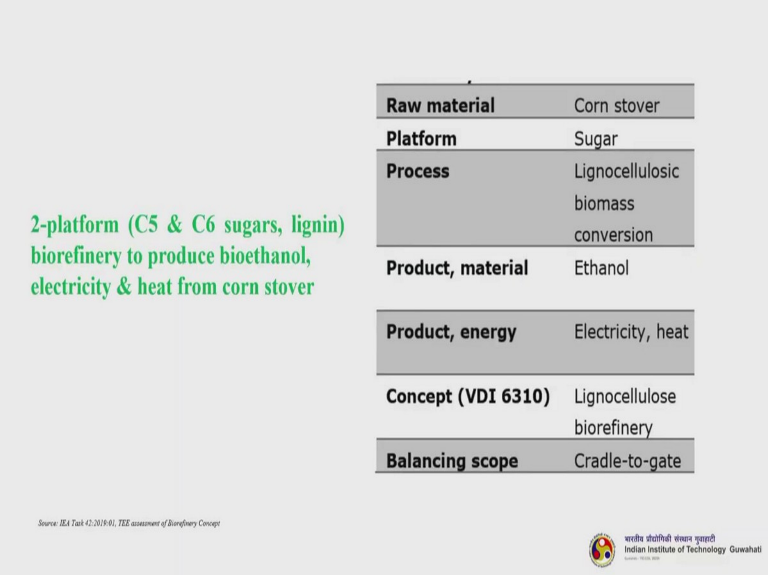

2-platform (C5 & C6 sugars, lignin) biorefinery to produce bioethanol, electricity & heat from corn stover

Raw material	Corn stover
Platform	Sugar
Process	Lignocellulosic biomass conversion
Product, material	Ethanol
Product, energy	Electricity, heat
Concept (VDI 6310)	Lignocellulose biorefinery
Balancing scope	Cradle-to-gate

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

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So, now let us take a case study of the technical, economic and environmental assessment of a biorefinery. So, we are talking about a 2-platform biorefinery, where there is a C5 and C6 sugar platform to convert it to bioethanol and the Biomass is corn stover. So, the raw material is corn stover, the platform is the sugar platform, both C5 and C6, the process is a lignocellulosic biomass conversion.

The product and the major end material is ethanol. There may be the other by-products also. Product energy is electricity and heat. Concept according to the VDI 6310 is the lignocellulosic biorefinery and the balancing scope is cradle-to-gate.

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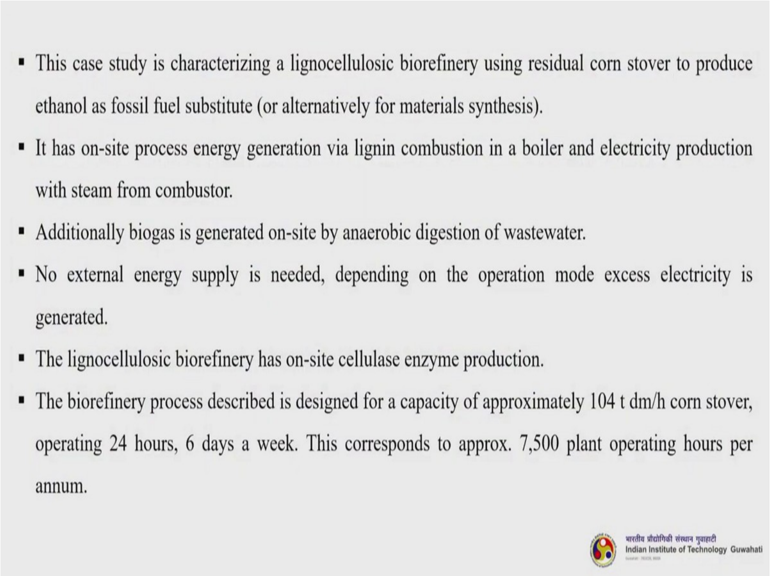

- This case study is characterizing a lignocellulosic biorefinery using residual corn stover to produce ethanol as fossil fuel substitute (or alternatively for materials synthesis).
- It has on-site process energy generation via lignin combustion in a boiler and electricity production with steam from combustor.
- Additionally biogas is generated on-site by anaerobic digestion of wastewater.
- No external energy supply is needed, depending on the operation mode excess electricity is generated.
- The lignocellulosic biorefinery has on-site cellulase enzyme production.
- The biorefinery process described is designed for a capacity of approximately 104 t dm/h corn stover, operating 24 hours, 6 days a week. This corresponds to approx. 7,500 plant operating hours per annum.

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This case study is characterizing a lignocellulosic biorefinery using residual corn stover to produce ethanol as fossil fuels substitute. So, it has on-site process energy generation via Lignin combustion in a boiler and Electricity production with steam from combustor. So, the inherent meaning of this particular sentence is that whatever lignin is getting generated during the pretreatment or delignification of the Biomass is getting burnt to produce electricity.

Additionally, biogas is generated on-site by the anaerobic digestion of wastewater. No external energy supply is needed, every energy that is required for the biorefinery is getting generated on-site. So, the lignocellulosic bio refinery has on-site cellulase enzyme production facility also. So, the bio refinery process described is designed for a capacity of approximately 104 tonne corn stover operating 24 hours 6 days a week. This corresponds to approximately 7,500 plant operating hours per annum.

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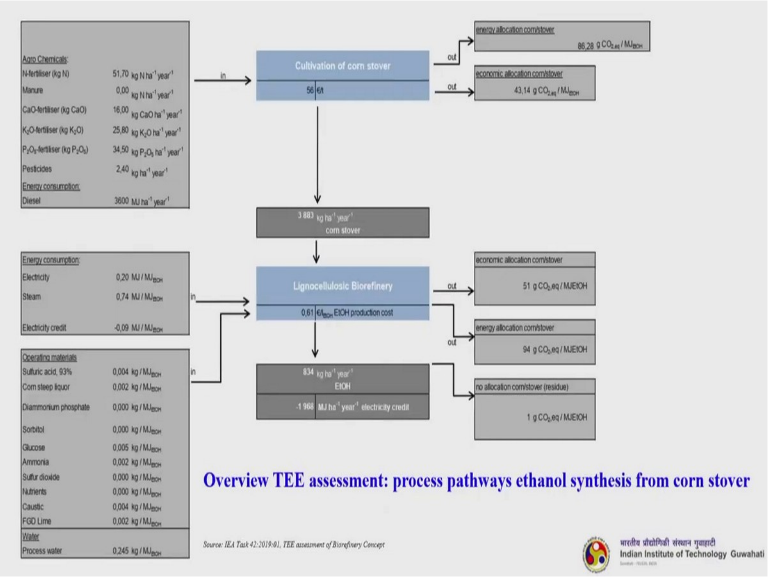

Agro Chemicals:		
N-fertiliser (kg N)	51,70	kg N ha^{-1} $year^{-1}$
Manure	0,00	kg N ha^{-1} $year^{-1}$
CaO-fertiliser (kg CaO)	16,00	kg CaO ha^{-1} $year^{-1}$
K_2O-fertiliser (kg K_2O)	25,80	kg K_2O ha^{-1} $year^{-1}$
P_2O_5-fertiliser (kg P_2O_5)	34,50	kg P_2O_5 ha^{-1} $year^{-1}$
Pesticides	2,40	kg ha^{-1} $year^{-1}$
Energy consumption:		
Diesel	3600	MJ ha^{-1} $year^{-1}$

in

Cultivation of corn stover

56 €/t

out

energy allocation corn/stover

86,28 g $CO_{2,eq}$ / MJ_{EtOH}

out

economic allocation corn/stover

43,14 g $CO_{2,eq}$ / MJ_{EtOH}

3 883 kg ha^{-1} $year^{-1}$
corn stover

Energy consumption:		
Electricity	0,20	MJ / MJ_{EtOH}
Steam	0,74	MJ / MJ_{EtOH}
Electricity credit	-0,09	MJ / MJ_{EtOH}

in

Operating materials		
Sulfuric acid, 93%	0,004	kg / MJ_{EtOH}
Corn steep liquor	0,002	kg / MJ_{EtOH}
Diammonium phosphate	0,000	kg / MJ_{EtOH}
Sorbitol	0,000	kg / MJ_{EtOH}
Glucose	0,005	kg / MJ_{EtOH}
Ammonia	0,002	kg / MJ_{EtOH}
Sulfur dioxide	0,000	kg / MJ_{EtOH}
Nutrients	0,000	kg / MJ_{EtOH}
Caustic	0,004	kg / MJ_{EtOH}
FGD Lime	0,002	kg / MJ_{EtOH}
Water		
Process water	0,245	kg / MJ_{EtOH}

in

Lignocellulosic Biorefinery

0,61 €/l_{EtOH} EtOH production cost

out

economic allocation corn/stover

51 g CO_2,eq / MJEtOH

out

energy allocation corn/stover

94 g CO_2,eq / MJEtOH

834 kg ha^{-1} $year^{-1}$
EtOH

-1 968 MJ ha^{-1} $year^{-1}$ electricity credit

no allocation corn/stover (residue)

1 g CO_2,eq / MJEtOH

Overview TEE assessment: process pathways ethanol synthesis from corn stover

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

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So, this is the overview of the techno economical assessment: the process pathways of ethanol synthesis from corn stover. So, these are the agrochemicals requirement. How much it is required it is written there. The energy, how much it is getting consumed in the form of electricity, steam and how much electricity credit you are generating. Then the operating materials like cost of the corn steep liquor, sulphuric acid, diammonium phosphate, some other solvents all these things and of course, the water (it is a huge requirement and a huge cost).

So, then it goes to the cultivation of the corn stover, you get let us say 3883 kilograms per hectare per year and it goes to the lignocellulosic biorefinery (biomass productivity), comes to the biorefinery and you get almost 834 kilograms per hectare per year of the ethanol. Then of course there are other things. So you can refer it and get an understanding that how that TEE looks like.

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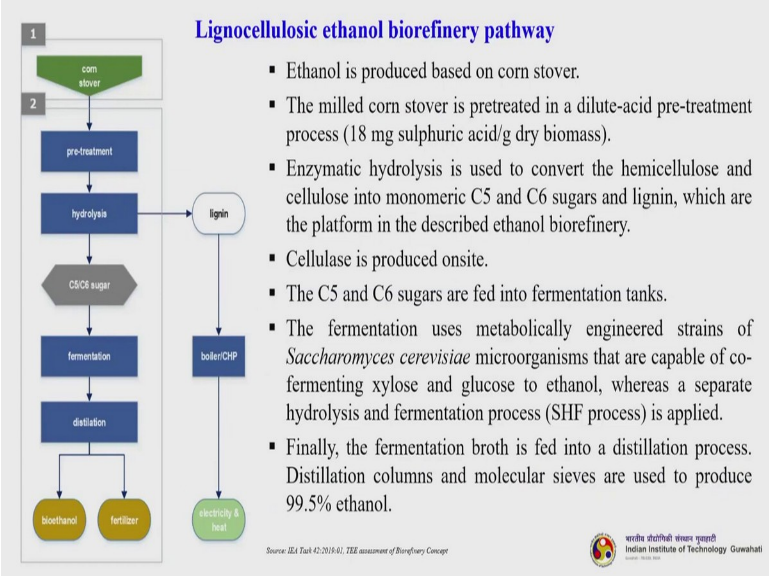

Lignocellulosic ethanol biorefinery pathway

- Ethanol is produced based on corn stover.
- The milled corn stover is pretreated in a dilute-acid pre-treatment process (18 mg sulphuric acid/g dry biomass).
- Enzymatic hydrolysis is used to convert the hemicellulose and cellulose into monomeric C5 and C6 sugars and lignin, which are the platform in the described ethanol biorefinery.
- Cellulase is produced onsite.
- The C5 and C6 sugars are fed into fermentation tanks.
- The fermentation uses metabolically engineered strains of *Saccharomyces cerevisiae* microorganisms that are capable of co-fermenting xylose and glucose to ethanol, whereas a separate hydrolysis and fermentation process (SHF process) is applied.
- Finally, the fermentation broth is fed into a distillation process. Distillation columns and molecular sieves are used to produce 99.5% ethanol.

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

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So then lignocellulosic ethanol biorefinery pathway. Ethanol is produced based on corn stover. The milled corn stover is pre-treated in a dilute acid pretreatment process. So, 18 milligrams of sulphuric acid per gram of dry mass is optimised requirement. Enzymatic Hydrolysis is used to convert the hemicellulose and cellulose into monomeric C5 and C6 Sugars and lignin which are the platform inside the described ethanol biorefinery.

Cellulase is produced on site. The C5 and C6 sugars are fed into fermentation tanks. The fermentation uses metabolically engineered strains of the *Saccharomyces cerevisiae* microorganisms that are capable of co-fermenting xylose and glucose to ethanol. So, this particular *Saccharomyces cerevisiae*, which is the engineered strain, can co-ferment both C5 and C6 Sugars to ethanol whereas, a separate hydrolysis and fermentation processes applied, SHF process.

So finally, the fermentation broth is fed into a distillation process. Distillation columns and Molecular sieves are used to produce 99.5% ethanol. It is a very great purity. So again, you can see here, whatever Lignin is coming from this hydrolysis after the delignification step, is being fed to the boiler. So, lignin is burnt basically and you generate electricity and heat in a CHP platform.

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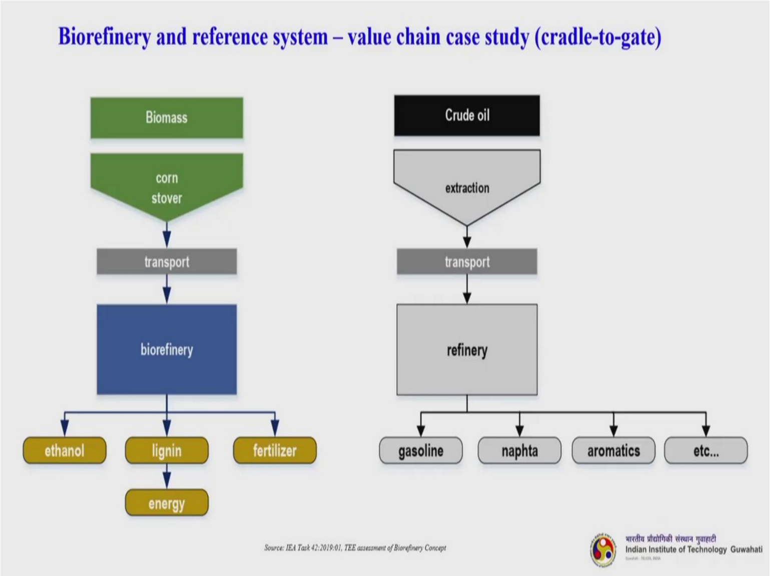

Biorefinery and reference system – value chain case study (cradle-to-gate)

Biomass → corn stover → transport → biorefinery → ethanol, lignin, fertilizer; lignin → energy

Crude oil → extraction → transport → refinery → gasoline, naphta, aromatics, etc...

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

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So, this is the biorefinery and reference system – a value chain case study with reference to cradle-to-gate approach. So, the Biomass - corn stover – transport - biorefinery - we get ethanol, Lignin - converted to energy, whatever left out can be converted to fertilizer. It is not that fertilizer is the only thing, it can be any other things also. So crude oil – extraction – transport – refinery - gasoline, naphtha, aromatic etc. This is your general refinery. This is a bio refinery.

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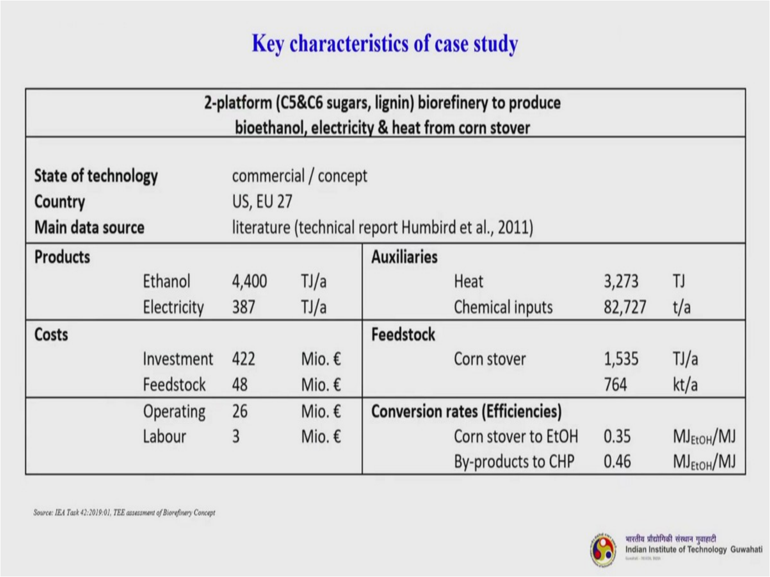

Key characteristics of case study

2-platform (C5&C6 sugars, lignin) biorefinery to produce bioethanol, electricity & heat from corn stover							
State of technology	commercial / concept						
Country	US, EU 27						
Main data source	literature (technical report Humbird et al., 2011)						
Products				**Auxiliaries**			
	Ethanol	4,400	TJ/a		Heat	3,273	TJ
	Electricity	387	TJ/a		Chemical inputs	82,727	t/a
Costs				**Feedstock**			
	Investment	422	Mio. €		Corn stover	1,535	TJ/a
	Feedstock	48	Mio. €			764	kt/a
	Operating	26	Mio. €	**Conversion rates (Efficiencies)**			
	Labour	3	Mio. €		Corn stover to EtOH	0.35	MJ_{EtOH}/MJ
					By-products to CHP	0.46	MJ_{EtOH}/MJ

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

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So, the key characteristics of the case study based on the 2 platform C5, C6 sugars and Lignin bio refinery to produce bioethanol, electricity and heat from corn stover is that; so, the state of technology is almost commercial. Country is United States; the main data source is from literature. The products are ethanol and Electricity, these are the costs given in a million

Euros - investment, feedstock, operating, labour and all these costs and then auxiliaries, feedstock, conversion rates are also given.

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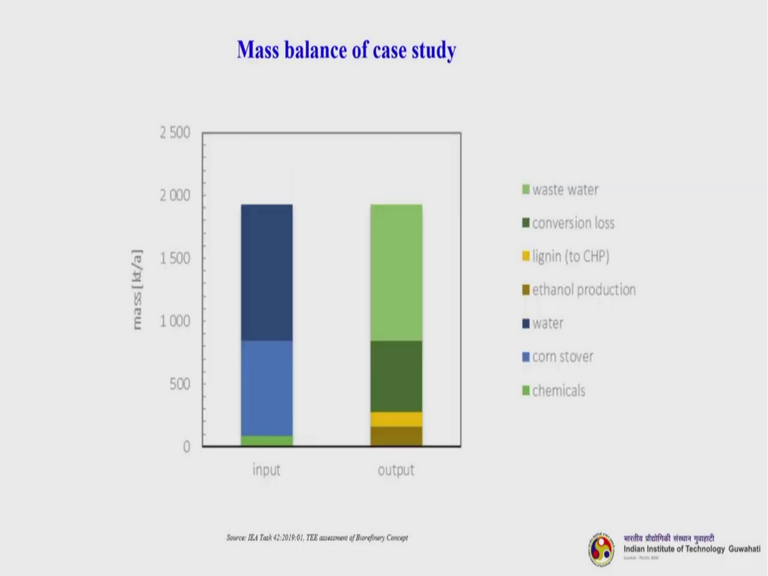

Mass balance of case study

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

So, if you look the mass balance case study; so you can see, these are the different things - waste water, conversion loss, Lignin (converted to CHP), ethanol, water, corn stover, and Chemicals. Have a look here, the input - the major input cost is of course that of the water, followed by the Biomass that is corn stover, and the small amount is due to the Chemicals. Now, if you talk about the output, so the major cost is wastewater.

So, this was what I was mentioning that waste water needs to be treated. Recycle in-house so that our dependency of freshwater will come down. Followed by the conversion losses, huge amount of conversion that is getting lost and then this yellow (z)one you can see, that is the lignin - of course it is value added because it is getting converted to electricity and heat; followed by this brown (z)one, which is the ethanol production. See the cost in terms of the mass balance.

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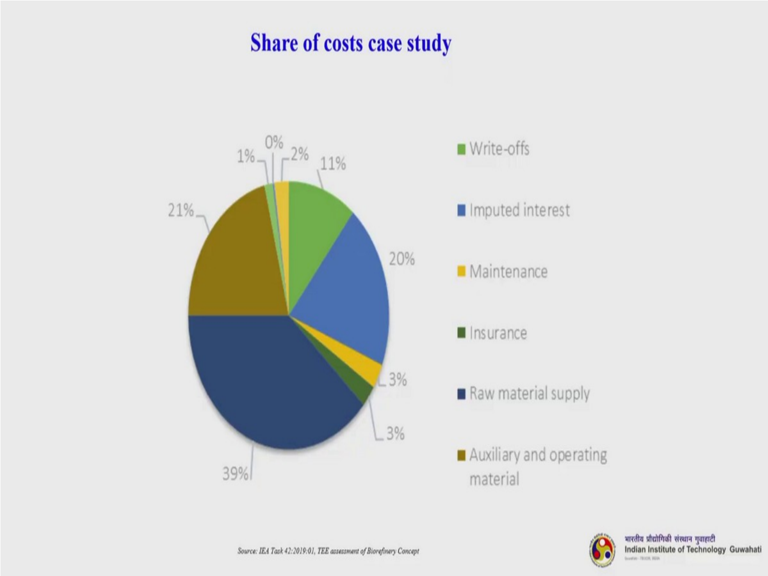

Share of costs case study

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

So, when you talk about the sharing of the cost, it is again in the same manner - raw material supply, followed by auxiliary and operating material, followed by the imputed interest, then the next is the write-off cost and there are some other costs like insurance and auxiliary and operating material.

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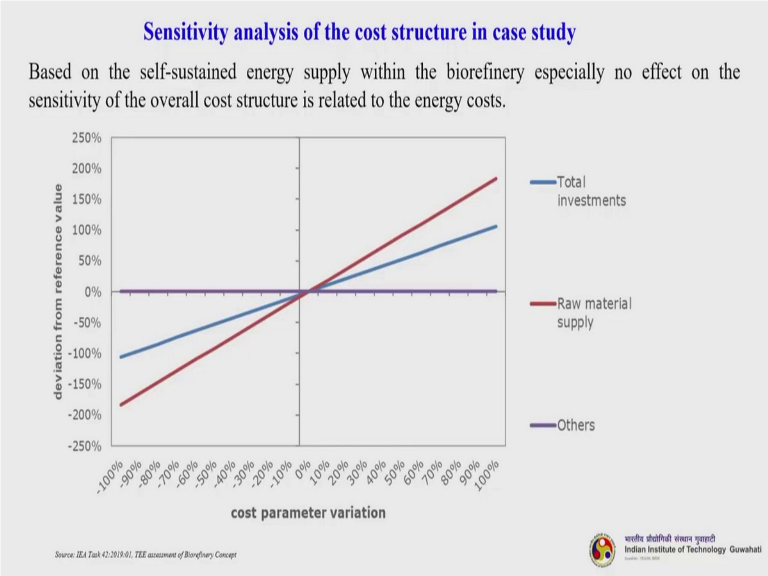

Sensitivity analysis of the cost structure in case study

Based on the self-sustained energy supply within the biorefinery especially no effect on the sensitivity of the overall cost structure is related to the energy costs.

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

So, if you look at the sensitivity analysis of the cost structure in a case study, you can see this red one is the raw material supply and the blue one is the total investment (the entire investment cost) and the line which is horizontal you can see that is the other costs. So, based on the self-sustained energy supply within the biorefinery, especially no effect on the sensitivity of the overall cost structure is related to the energy cost. So that is what is understood from this particular slide.

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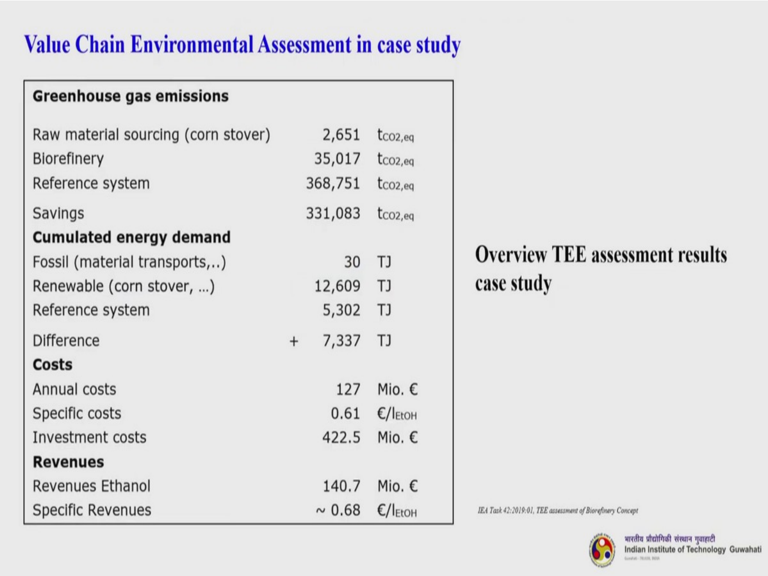

Value Chain Environmental Assessment in case study

Greenhouse gas emissions		
Raw material sourcing (corn stover)	2,651	$t_{CO2,eq}$
Biorefinery	35,017	$t_{CO2,eq}$
Reference system	368,751	$t_{CO2,eq}$
Savings	331,083	$t_{CO2,eq}$
Cumulated energy demand		
Fossil (material transports,..)	30	TJ
Renewable (corn stover, ...)	12,609	TJ
Reference system	5,302	TJ
Difference	+ 7,337	TJ
Costs		
Annual costs	127	Mio. €
Specific costs	0.61	€/l_{EtOH}
Investment costs	422.5	Mio. €
Revenues		
Revenues Ethanol	140.7	Mio. €
Specific Revenues	~ 0.68	€/l_{EtOH}

Overview TEE assessment results case study

IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

So, value chain environmental assessment in case study. So, this is an overview of the TEE assessment results cases study. So, the greenhouse gas emissions. This was estimated after the LCA study or TEE study. Raw material sourcing corn stover is almost 2651 tons of carbon dioxide equivalent; so the biorefinery 35017, reference system 368751 tonnes and savings is 331083 tonnes. Then this is the cumulated energy demand in terms of the terra-joule, then these are the other costs in terms of the million euros.

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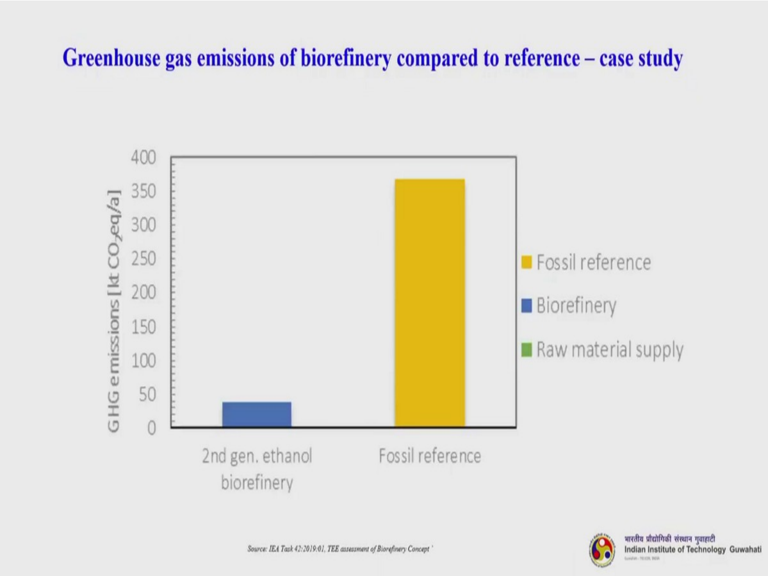

Greenhouse gas emissions of biorefinery compared to reference – case study

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept

If we talk about the greenhouse gas emissions of biorefinery compared to reference case study, you see, this is the second-generation ethanol biorefinery. And this is the greenhouse gas emission. You see the gas (emission), this is nothing when you compared to the fossil reference. So, this is quite understood from this particular slide, when you talk about biorefinery concept that Greenhouse gas emissions is far less compared to the Fossil fuel emissions.

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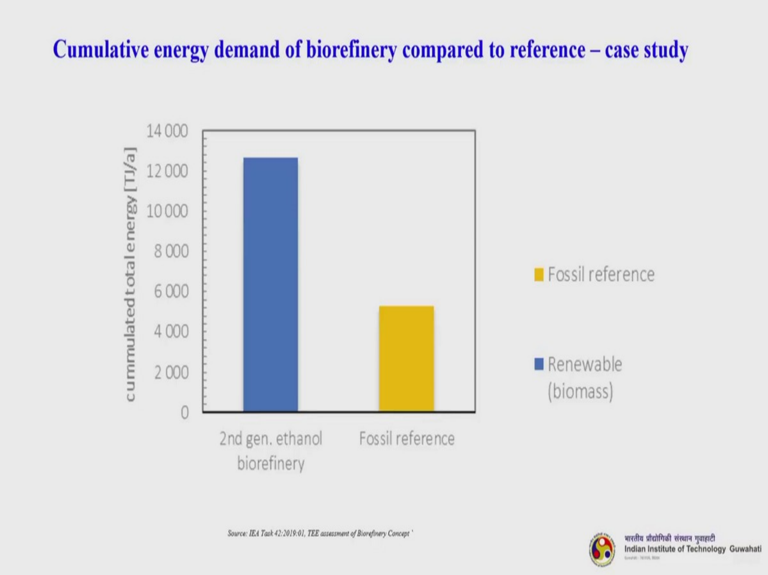

Cumulative energy demand of biorefinery compared to reference – case study

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept '

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So, the next is cumulative energy demand of biorefinery compared to reference. So again you can see that the energy demand for biorefinery compared to the fossil fuel reference, with respect to renewables, it is little higher. But then you have to understand, what is the output in terms of every aspect including the environmental aspect. It is not about only the energy demand or energy requirement.

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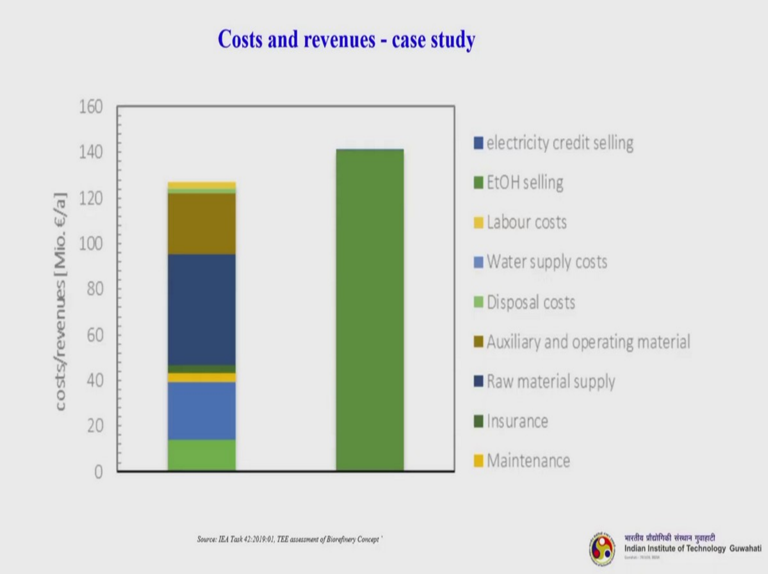

Costs and revenues - case study

Source: IEA Task 42:2019:01, TEE assessment of Biorefinery Concept '

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This is the cost and revenue, the final one. You can see, this is the input cost basically and this is the final value of the ethanol selling price. So, you can see that it is marginally higher than all the input cost and everything is being accounted here, whether it is water supply, disposal, raw material, insurance, maintenance, everything. So, we can understand from this particular slide that, the ethanol cost (the annual selling price) of the total amount that is produced is higher than the input cost or the production costs. That means we are in profit.

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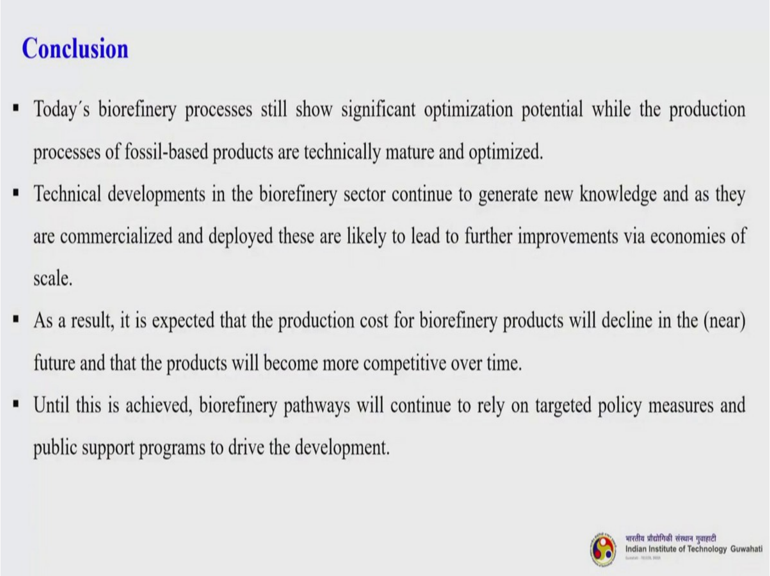

Conclusion

- Today´s biorefinery processes still show significant optimization potential while the production processes of fossil-based products are technically mature and optimized.
- Technical developments in the biorefinery sector continue to generate new knowledge and as they are commercialized and deployed these are likely to lead to further improvements via economies of scale.
- As a result, it is expected that the production cost for biorefinery products will decline in the (near) future and that the products will become more competitive over time.
- Until this is achieved, biorefinery pathways will continue to rely on targeted policy measures and public support programs to drive the development.

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So, let us conclude this LCA discussion. So, today's biorefinery processes still show significant optimisation potential while the production processes of fossils-based products are technically mature and optimised. Technical developments in the biorefinery sector continue to generate new knowledge and as they are commercialized and deployed, these are likely to lead to further improvements via economies of scale. As a result, it is expected that the production cost for bio refinery products will decline in the near future and that the product will become more competitive over time. Until this is achieved, bio refinery pathways will continue to rely on targeted policy measures and public transport programs to drive the development.

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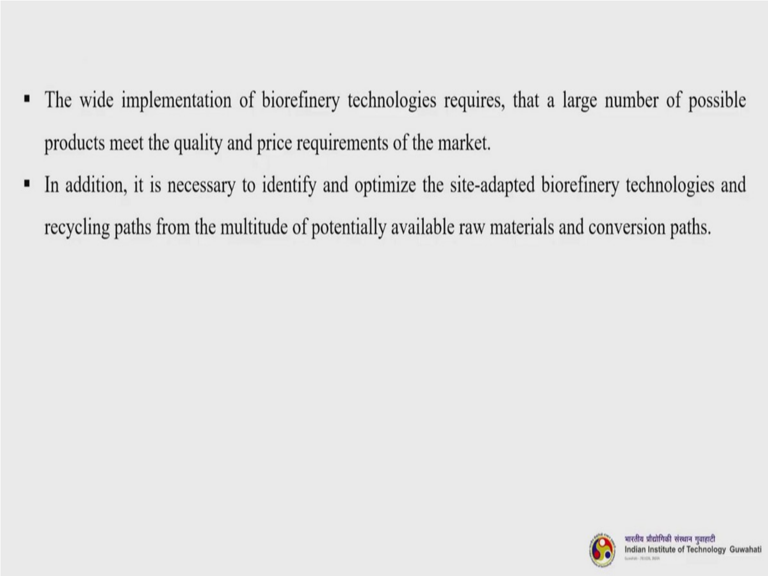

- The wide implementation of biorefinery technologies requires, that a large number of possible products meet the quality and price requirements of the market.
- In addition, it is necessary to identify and optimize the site-adapted biorefinery technologies and recycling paths from the multitude of potentially available raw materials and conversion paths.

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The wide implementation of biorefinery technologies requires that a large number of possible products meet the quality and price requirement of the market. So, basically price is one factor, another is the awareness of the bio based products and their acceptability by the end users. So in addition it is necessary to identify and optimise the site-adapted biorefinery technologies and recycling paths from the multitude of potentially available raw materials and conversion paths.

So, with this I wind up today's lecture; in case you have any query, please feel free to write to me at kmohanty@iitg.ac.in or post your query in the Swayam portal itself I will definitely answer those. In the next module we will be discussing about the biomass pre-treatment technologies. What are the different types of biomass pretreatment techniques that is available? What are their pros and cons and how they can be carried out? So, thank you very much.