Biomass Conversion and Biorefinery
Prof. Kaustubha Mohanty
Department of Chemical Engineering
Indian Institute of Technology - Guwahati

Lecture – 37
Life-Cycle Assessment

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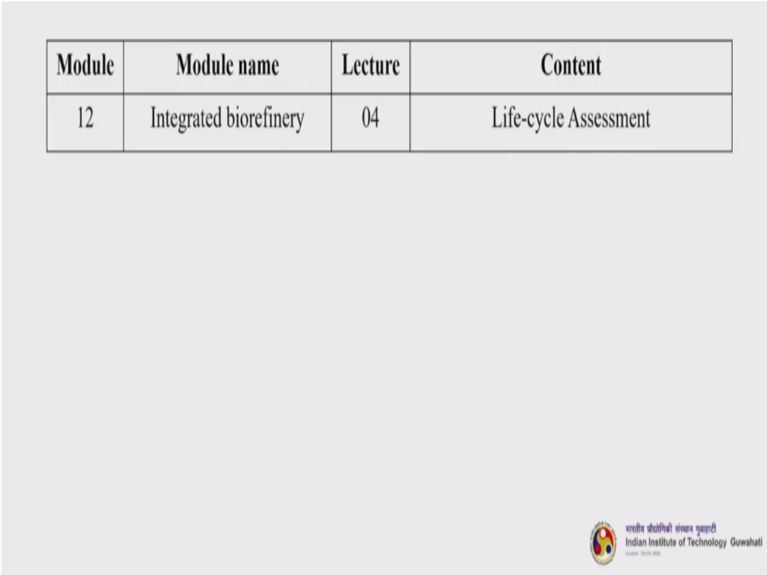

Module	Module name	Lecture	Content
12	Integrated biorefinery	04	Life-cycle Assessment

Good morning students. As you know, today is the last lecture of this module as well as for this entire course. And under this particular lecture, under this module named integrated biorefinery, we are going to discuss about the life cycle assessment with a case study. As you know that last class we have discussed about the techno-economical evaluation or assessment; even in one of our previous modules we have discussed briefly about the TEA and LCA.

But in this module we are going to discuss in detail about both TEA and LCA. TEA we have discussed, LCA we are going to discuss today. I will also take an example or we can say a case study that how LCA has been done or carried out for that particular biorefinery. So, let us begin.

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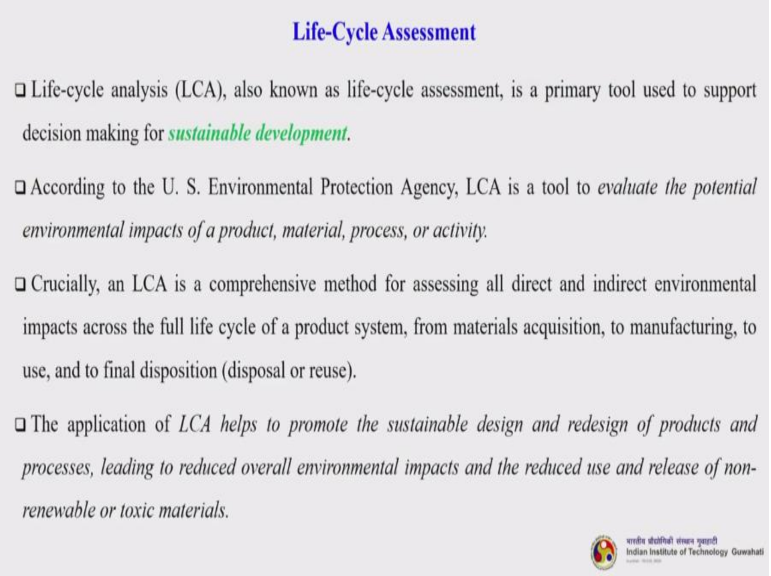

Life-cycle analysis also known as life-cycle assessment is a primary tool used to support the decision making for a sustainable development. According to the US Environmental Protection Agency, LCA is a tool to evaluate the potential environmental impacts of a product, material, process or activity. Crucially, an LCA is a comprehensive method for assessing all direct and indirect environmental impacts across the full life cycle of a product system, from materials acquisition, to manufacturing, to use, and to final disposition or you can say disposal or even reuse. The application of LCA helps to promote the sustainable design and redesign of products and processes leading to reduced overall environmental impacts and the reduced use and release of non-renewable or toxic materials.

So, if you recall our earlier discussions, LCA mostly relate itself to the environmental concerns; how a product which we are making in an industry, it can be any product, how it performs in its entire lifecycle. So that means we begin with the feedstock, then feedstock has been processed, converted to some product, it is purified, polished to a final product, then there are so many waste streams that comes out. Various types of waste, it can be solid, liquid gas. How those wastes are being actually treated? How those wastes are being recycled and reused? And all these things are being covered in a life cycle assessment. So, it tells us a comprehensive and overall view of how a product, once it is formed, is going to have a broad environmental impact during the use as well as after the use also.

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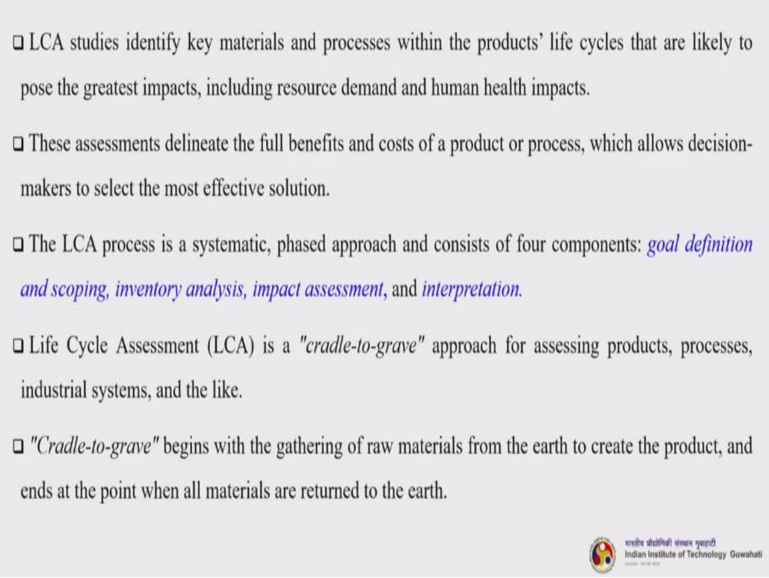

So, LCA studies identify key materials and processes within the products' life cycles that are likely to pose the greatest impacts including the resource demand and human health impacts. Now, these assessments delineate the full benefits and costs of a product or process which allows decision makers to select the most effective solution. The LCA process is a systematic, phased approach and consists of 4 components

What are those 4 components? The first and foremost one is the goal definition and scoping. What is the scope? And how you define it basically? Second is inventory analysis. Third is impact assessment and last one is the interpretation. Now, all these things we will discuss in subsequent slides today itself and when I take a case study, it will be more clear to you. So, life-cycle assessment is a cradle-to-grave approach for assessing products, processes, industrial systems, and the like.

Cradle-to-grave begins with the gathering of raw materials from the earth to create the product and and ends the point when all materials are returned to the earth. So, this is a more holistic approach when you talk about cradle-to-grave. It starts from a point where it ends in the same point basically. So, it is a cycle.

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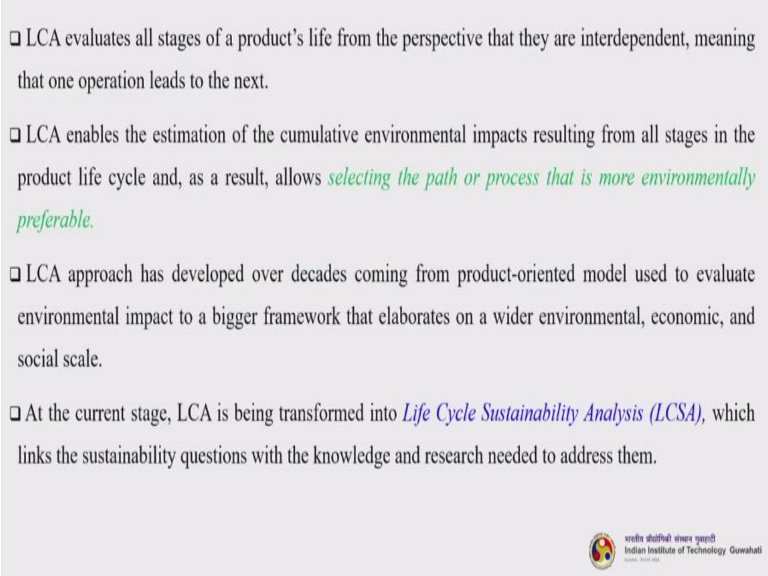

So LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle and as a result allows selecting the path or process that is more environmentally preferable. LCA approach has developed over decades coming from product-oriented model used to evaluate environmental impact to a bigger framework that elaborates on a wider environmental, economic as well as social scale. Social is also very important. Now at the current stage, LCA is being transferred into life cycle sustainability analysis which people call it a LCSA, which links the sustainability questions with the knowledge and research needed to address them.

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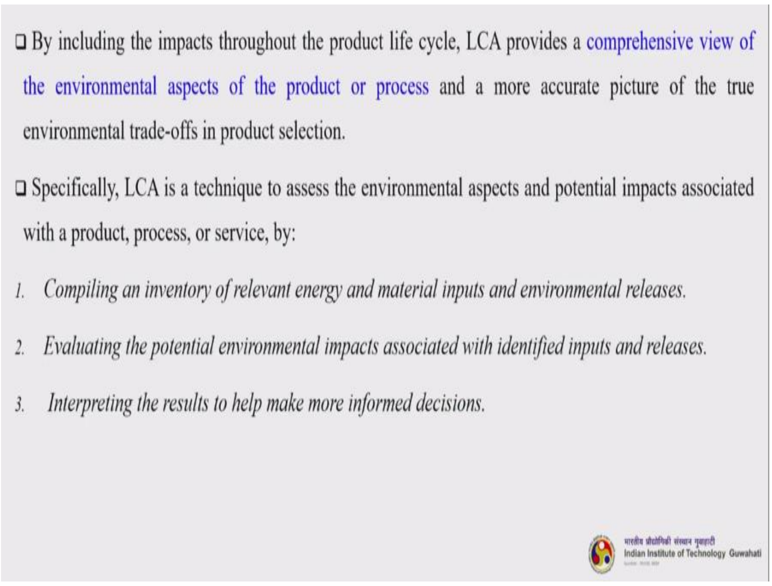

Now by including the impacts throughout the product life cycle, LCA provides a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product selection. Specifically, LCA is a technique to assess the environmental aspects and potential impacts associated with a product, process or service by: compiling an inventory of relevant energy and materials inputs as well as the environmental releases; Second, evaluating the potential environmental impacts associated with identified inputs and releases; Third is interpreting the results to help make more informed decisions. So, all these points are going to help us when we carry out this LCA or LCSA.

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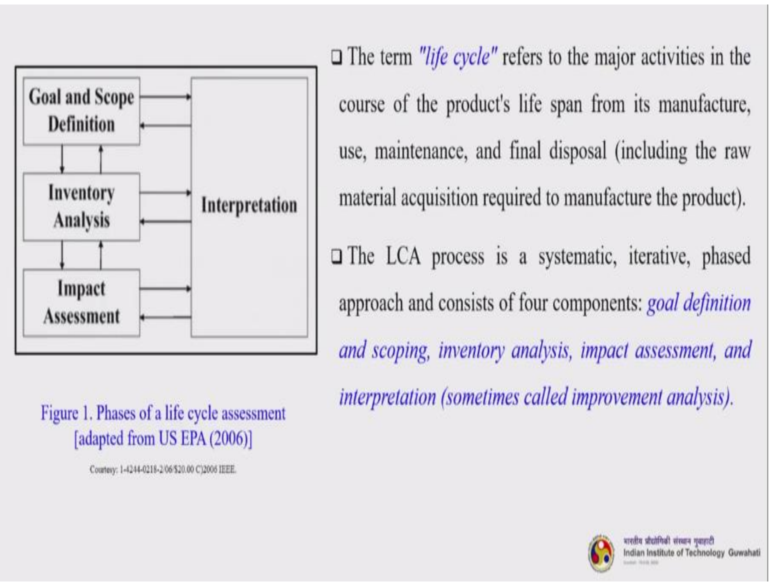

So, you can have a look at this figure 1. So, this describes the phases of a life cycle assessment. It was adapted from US EPA. So, goal, scope and definition, inventory analysis, impact assessment and interpretation. Now, all these things are interrelated with each other. So, that means once the goal and scope definition can be interpreted and then that same can be used by inventory analysis.

Inventory analysis, data can be interpreted that same can be used to do the impact assessment. That means basically the meaning is that all these 3 parameters, the basic parameters, they are interdependent on each other. So, the term life cycle refers to the major activities in the course of product's life span from its manufacture, use, maintenance and final disposal. Now, the final disposal again as I told you earlier also that including the raw material acquisition required to manufacture the product.

The LCA process is a systematic, iterative, phased approach and consists of 4 components. Goal definition and scoping, inventory analysis, impact assessment and interpretation. Now, sometimes this also calls improvement analysis.

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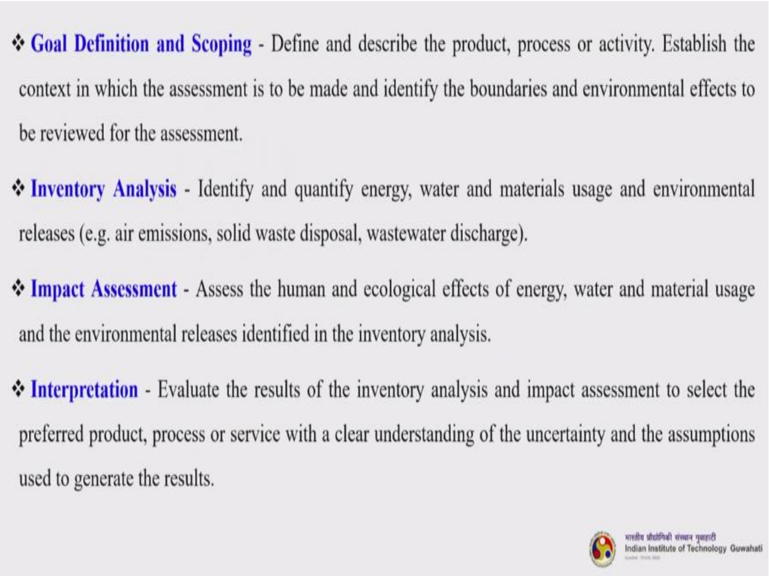

So, let us understand what are these 4 parameters. So, Goal definition and Scoping: now define and describe the product, process or activity. Establish the context in which the assessment is to be made and identify the boundaries and environmental impacts to be reviewed for the assessment. Then, next is the Inventory Analysis: Now here you identify and quantify the energy, water and materials usage and environmental releases. As for example air emissions, solid waste disposal, wastewater discharge, all these things. Then third is the Impact Assessment: Now, assess the human and ecological effects of energy, water and material usage and the environmental releases identified in the inventory analysis. And the last one is Interpretation: Now, here you evaluate the results of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

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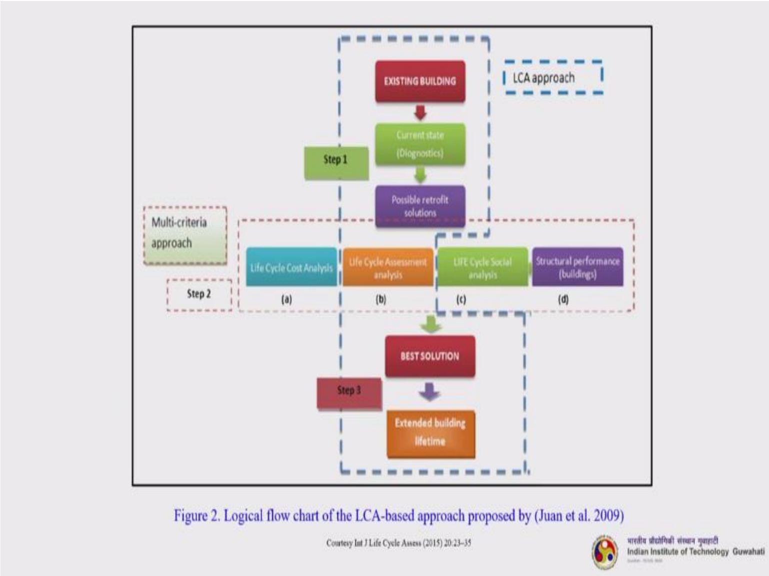

Now, please have a close look at figure 2, this is the logical flowchart of the LCA based approach proposed by Juan et al and this is International Journal of Life Cycle Assessment. So, this is being taken from one particular paper which is given below. So, what it says basically? So, it is telling us about the 3 different steps. So, step 1 which basically talks about the existing building, current state that is the diagnostic approach, then possible retrofit solutions.

Now, in the step 2, it is the multi-criteria approach. Here the life cycle cost analysis is there, life cycle assessment analysis, life cycle social analysis, and structural performance, again buildings. Now, the third one is, which out of all these, when we collect data and analyze them, analyze the impact, analyze how they are going to create problems for environmental effects and all these things, then we can think about the different types of solutions.

Now out of that you have to go for a best solution. Then extended building life time. And as you know that all these, again I am telling you, they are all interdependent on each other. One particular parameters' data will have an enormous impact on the subsequent conversion processes, subsequent wastewater treatment processes, subsequent energy requirement and all these things.

And from the upstream side also when you talk about procuring, raw material processing, then making into a particular shape, size, density so that it can be stored properly and can be used for further conversion. So all they are related to each other.

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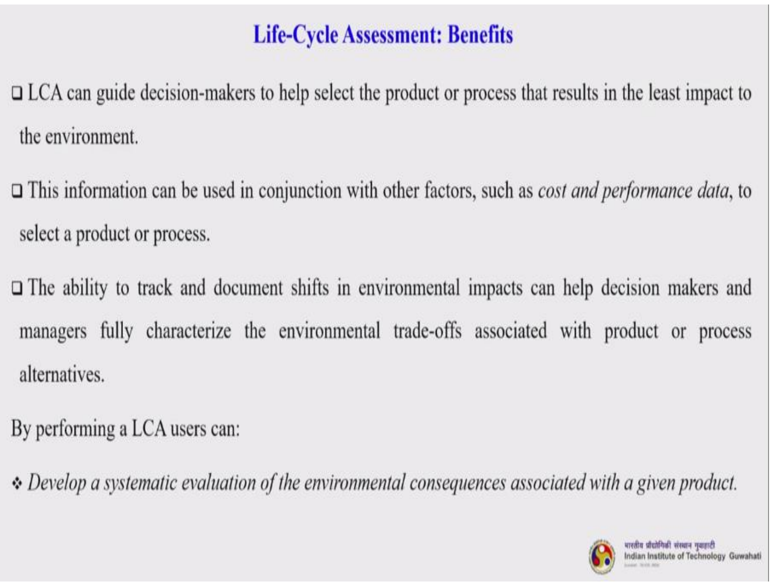

So let us understand the benefits of the life-cycle assessment. Now LCA can guide decision makers to help select the product or process that results in the least impact to the environment. Now, this information can be used in conjunction with other factors such as cost and performance data to select a product or process. Now again, I am telling you there are two important things.

If you remember in our TEA discussion I was telling you, it is very important to understand that if somebody goes for development of a process and technology, then find out whether it is technically valuable or not that is the technical part. Then the second is that whether it is techno economically valuable or not or sustainable or not and third is the life-cycle assessment. So, all these 3 things you have to do.

First is technical challenge, second is the techno-economical challenge or let us say the cost of the product and the process and third is the life cycle which takes into account also a part of that processes which I have discussed earlier. So, all these things will be taken into consideration when somebody goes for building up a new biorefinery or refinery or any process industries or any industry per se.

So, the ability to track and document shifts in the environmental impacts can help decision makers and managers fully characterize the environmental trade-offs associated with the product or process alternatives. Now, by performing an LCA users can, what they can do? Basically it is listed out. Now develop a systematic evaluation of the environmental consequences associated with a given product.

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Then analyse the environmental trade-offs associated with one or more specific product or process to help gain stakeholders as for example state, community acceptance for a planned action. Third is quantify environmental releases to air, water and land in relation to each life cycle stages and/or major contributing process. Fourth is assist in identifying significant shifts in environmental impacts between life cycle stages and environmental media.

Then next is assess the human and ecological effects of the material consumption and environmental releases to the local community, region as well as the world. Next is compare the health and ecological impacts between two or more rival products/processes or identify the impacts of a specific product or processes. And the last one is identify impacts to one or more specific environmental areas of concern.

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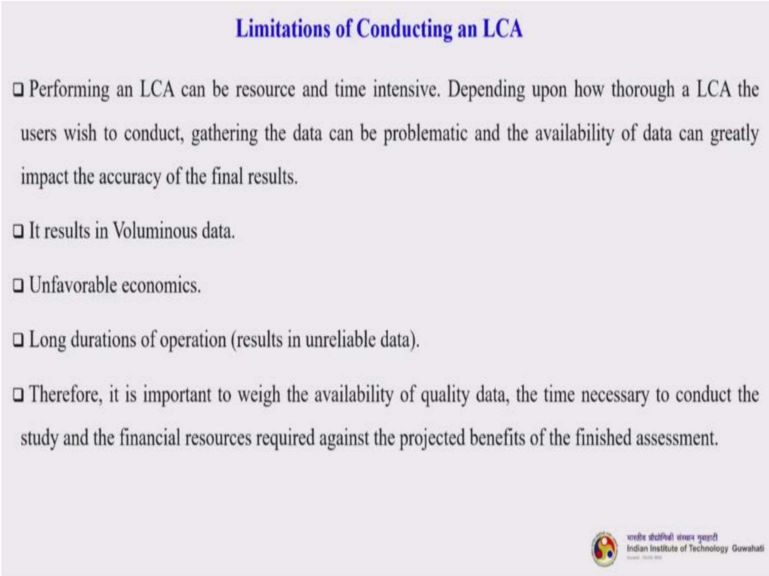

Now, let us talk about the limitations of conducting an LCA. Now performing an LCA can be resource or time intensive. Depending upon how thorough a LCA the users wish to conduct, gathering the data can be problematic and the availability of data can greatly impact the accuracy of the final results. So it results in voluminous data.

There are unfavorable economical conditions that needs to be taken into consideration, long durations of operation basically that results in unreliable data. Therefore, it is important to weigh the availability of quality data, the time necessary to conduct the study and the financial resources required against the projected benefits of the finished assessment.

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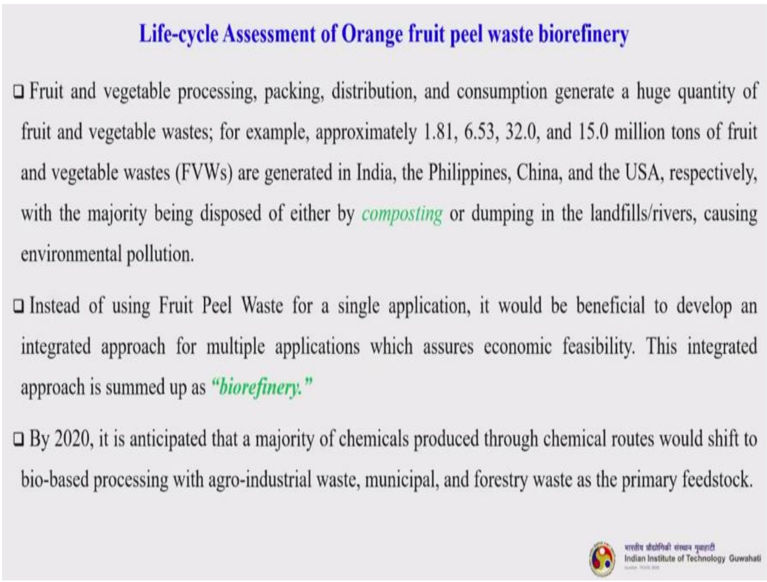

Now, let us take a case study. So here, I have taken a life cycle assessment of orange fruit peel waste biorefinery. You remember we had also taken a case study when we discussed about the technico-economical assessment in our last class. So, let us see how LCA has been carried out for this particular waste biorefinery. So fruit and vegetable processing, packing, distribution and consumption generate a huge quantity of fruit and vegetable waste.

For example, approximately 1.81, 6.53, 32.0 and 15.0 million tons of fruit and vegetable waste are generated in India, the Philippines, China and the United States respectively with the majority being disposed of either by composting or dumping in the landfills and rivers causing environmental pollution because many components leach out. Then they also produce toxic gases.

Now, instead of using fruit peel waste for a single application, it would be beneficial to develop an integrated approach for multiple applications, which assures economical feasibility. Now, this integrated approach is summed up as biorefinery and we have been discussing about biorefinery in many of our classes. So by 2020, it is anticipated that a majority of chemicals produced through chemical routes would shift to bio-based processing with agro industrial waste, municipal and forestry waste as the primary feedstock.

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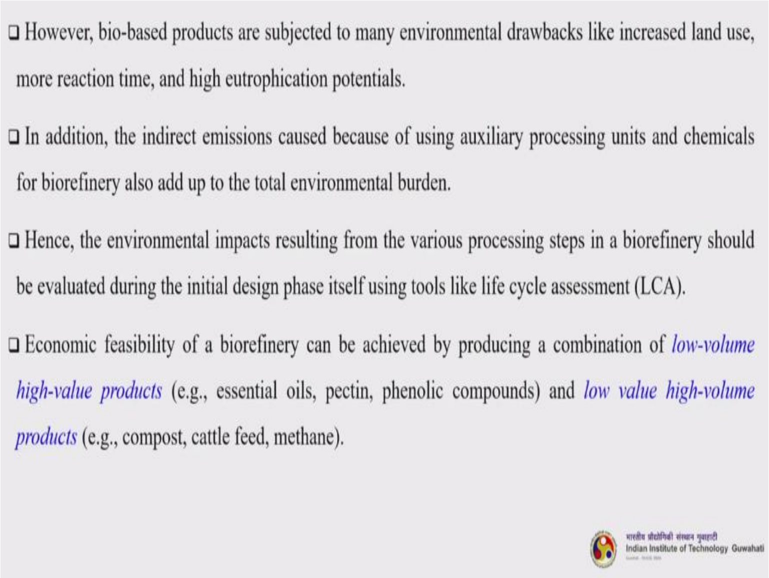

However, bio-based products are subjected to many environmental drawbacks like increased land use, more reaction time and high eutrophication potentials. In addition, the indirect emissions caused because of using auxiliary processing units and chemicals for biorefinery also add up to the total environmental burden. Hence, the environmental impacts resulting from the various processing step in a biorefinery should be evaluated during the initial design phase itself using tools like life cycle assessment.

Economic feasibility of a biorefinery can be achieved by producing a combination of low-volume high-value products. As for example, essential oils, pectin, phenolic compounds. And also low value high volume products as per example compost, cattle feed, methane which are produced in high volume or large volume.

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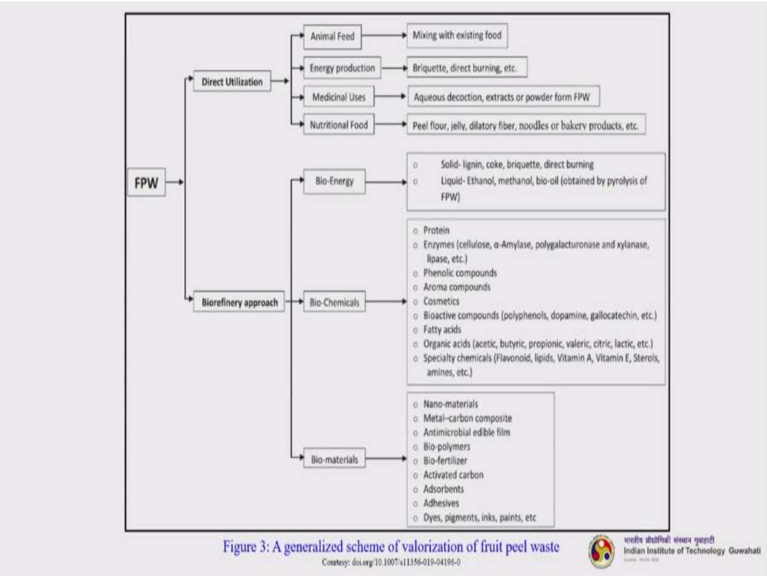

Figure 3: A generalized scheme of valorization of fruit peel waste
Courtesy: doi.org/10.1007/s11356-019-04196-0

So this figure 3 gives us a generalized scheme of the valorization of the fruit peel waste. It is a generalized scheme. It has been divided into 2 approaches. First is a direct approach or direct utilization, second is the biorefinery approach. Let us see what is the difference. If you go for a direct utilization you can have animal feed, you can have energy production, you can have some sort of medicinal uses and nutritional food components.

So, mixing with existing food, briquette, then there are different things which are noted down. So, if you talk about the biorefinery approach, then we go for various types of multiple products. So, it is again divided into 3 distinct groups. First is bio-energy, biochemicals and then bio-materials. In bio-energy we can have solid lignin, coke, briquette, direct burning of solid fuel basically. So, you can have liquid ethanol, methanol as well as bio-oil which comes from pyrolysis. So, this is under bio-energy.

Let us see about (bio)chemicals. Now you can have proteins, enzymes, phenolic compounds, aroma compounds, different types of cosmetics. Then bioactive compounds like polyphenols, dopamine, etc. Fatty acids, organic acids and some speciality chemicals like flavonoids. Now bio-materials, we can have different types of nano-materials. We can have metal-carbon composite. We can have bio-polymers, we can have bio-fertilizer, we can have activated carbon and adsorbents, adhesives, dyes, pigments, inks, so many things. You can see the list is endless actually in a biorefinery perspective. And we have learned in this particular course that whenever you talk about biorefinery, it should have multiple feedstocks, it should have also multiple products, then only it will become sustainable.

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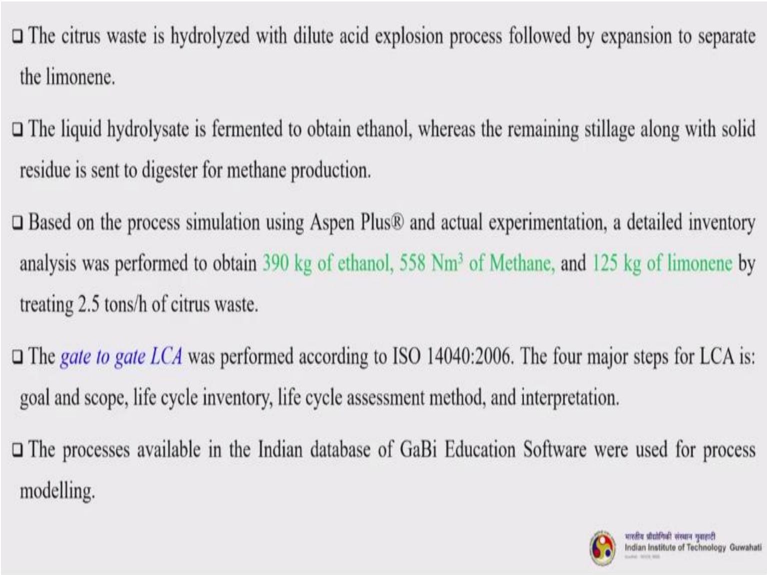

The citrus waste is hydrolyzed with dilute acid explosion process followed by expansion to separate the limonene. Now I am just going to discuss that how this has been carried out that means how the biorefinery study has been done and what are the assumptions has been taken all these things we are going to discuss. So, the liquid hydrolysate is fermented to obtain ethanol.

Whereas the remaining stillage along with the solid residue is sent to digester for methane production, basically anaerobic digestion. Now, based on the process simulation using Aspen Plus and actual experimentation, a detailed inventory analysis was performed to obtain 390 kg of ethanol, 558 Nm cube of methane and 125 kg of limonene by treating 2.5 tons per hour of citrus waste.

Now, the *gate to gate* LCA was performed according to the ISO 14040:2006. The 4 major steps for LCA is goal and scope, life cycle inventory, life cycle assessment and interpretation. This we have already discussed. Now, the processes available in the Indian database of the GaBi Education Software were used for the process modeling.

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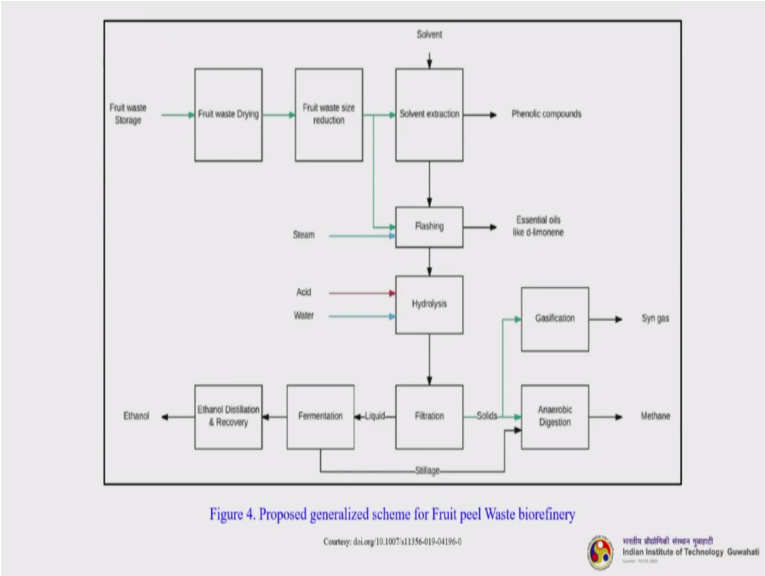

Figure 4. Proposed generalized scheme for Fruit peel Waste biorefinery

Courtesy: doi.org/10.1007/s11356-019-04196-0

Now, this is the proposed generalized scheme for the fruit peel waste biorefinery. Now, you can see that the fruit waste storage, it goes to drying, then size reduction - mechanical operation basically. Then you go for solvent extraction where you take out the phenolic compounds. Then whatever left out that goes to flashing. So, again you get essential oils as a byproduct from that side.

You steam here, then it goes for the hydrolysis part. Here we you use acid and water and then you filter it. Once you filter there is a liquid part, there is a solid part. The solid part goes to anaerobic digestion, you get methane. Part of that can also be gasified to produce syngas. Now the liquid product can be fermented then you get ethanol distillation and recovery, basically you are producing ethanol, distill it; finally ethanol.

Then part of the fermentation broth, the stillage can be fed to anaerobic digestion. It has so many valuable components which can be used as source of nutrient during anaerobic digestion. So, this is a simplified schematic representation of the fruit peel waste biorefinery.

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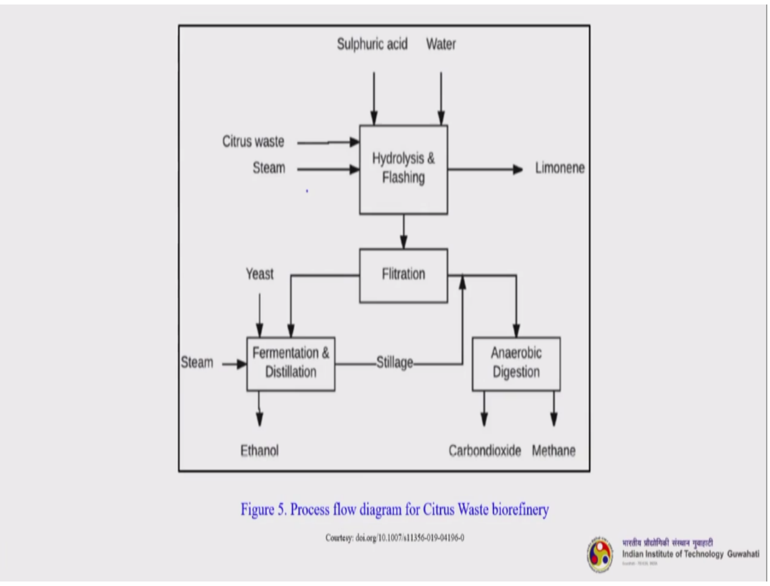

Now, this process flow diagram tells us about the citrus waste biorefinery. Here you can see that hydrolysis and flashing, it has just been expanded little from that side. Citrus waste, steam, your acid and water - dilute sulphuric acid treatment. You carry out hydrolysis and flashing, you get limonene one of the major component of this particular waste biorefinery. Then whatever left out has been filtered. The solid goes to anaerobic digestion, the liquid goes to fermentation, distillation, ethanol using the yeast *Saccharomyces cerevisiae*.

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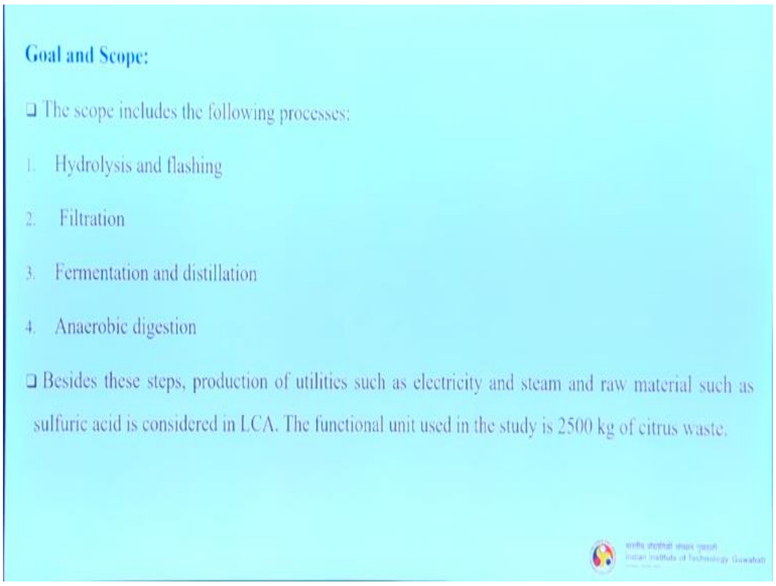

Now, let us talk about the goal and scope for this particular waste biorefinery. Now, the scope includes the following processes. Hydrolysis and flashing, filtration, fermentation and distillation, then anaerobic digestion. The 4 major processes. Now besides these steps, production of utilities such as electricity and steam, and raw materials such as sulfuric acid is considered in the LCA. The functional unit used in the study is 2500 kg of citrus waste.

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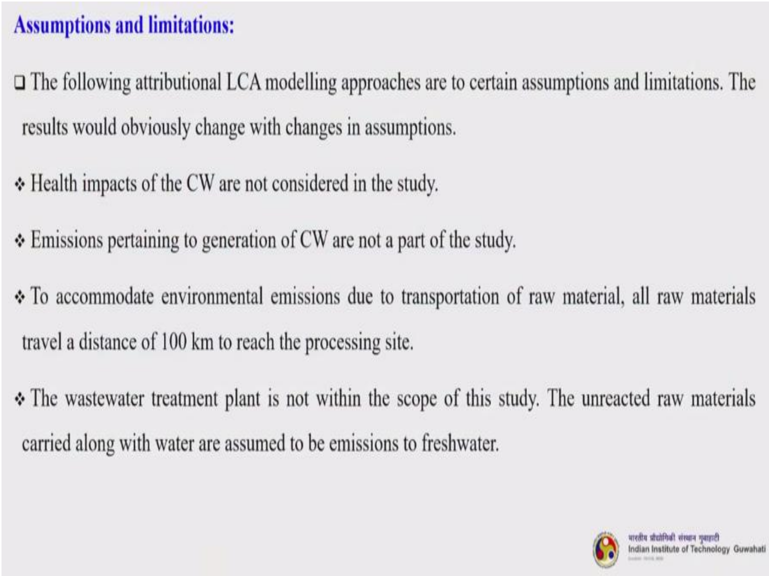

Now, assumptions and limitations. The following attributional LCA modeling approaches are to certain assumptions and limitations. The results would obviously change with the change in assumptions. First is the health impacts of the CW are not considered in this study. Second, emissions pertaining to the generation of CW are not a part of the study.

Third, to accommodate environmental emissions due to transportation of the raw materials, all raw materials travel a distance of only 100 kilometer to reach the processing site. Fourth, the wastewater treatment plant is not within the scope of the study, the ETP, effluent treatment plant. The unreacted raw materials carried along with water are assumed to be emissions to freshwater.

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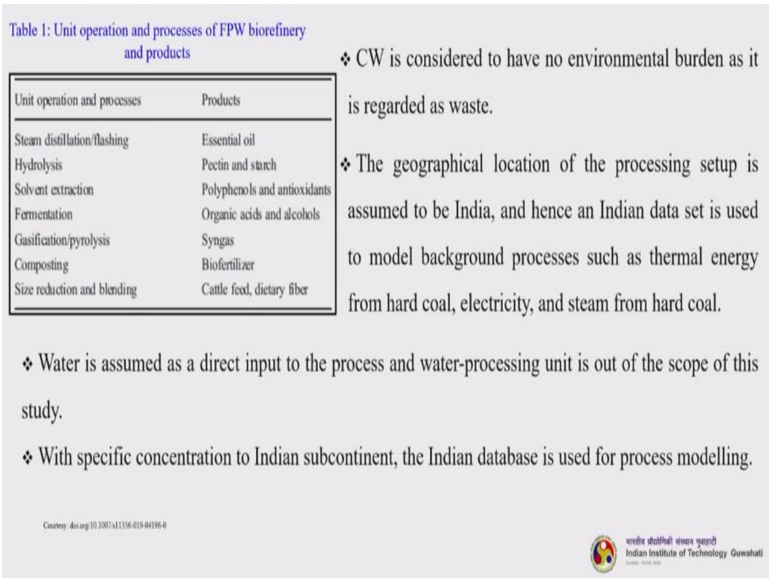

So, the table lists the different types of unit operations and processes of the FPW biorefinery and products. If you talk about steam distillation/flashing, the product is essential oil. Hydrolysis, the product is pectin and starch. Solvent extraction, we get polyphenols and antioxidants. Fermentation, we get organic acids and alcohols like ethanol. Gasification and pyrolysis we get syngas. Composting we get biofertilizer. Size reduction and blending, we get cattle feed and dietary fiber.

Now, CW is considered to have no environmental burden as it is regarded as waste. The geographical location of the processing setup is assumed to be India and hence an Indian data set is used to model background processes such as thermal energy from hard coal, electricity and steam from hard coal. Water is assumed as the direct input to the process and water processing unit is out of the scope of this study. With specific concentration to Indian subcontinent, the Indian database is used for process modeling.

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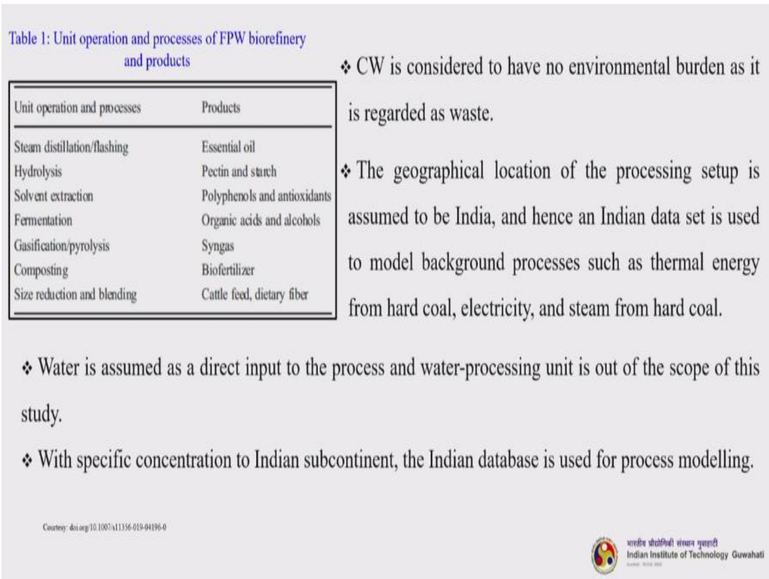

Then let us talk about the life cycle inventory. The first one is feedstock. Now the citrus waste generated after extraction of juice has 20% dry matter with significant amounts of pectin 25%, hexosans almost 26% and pectosans 7%. The CW thus obtained is used for further processing without any drying or grinding. Hence drying and grinding processes are out of the scope of this particular study.

The feedstock is sourced from nearby area as it would decrease the cost of procurement and reduce the chances of its degradation before processing. Hence the feedstock and other raw materials are assumed to travel a distance of 100 kilometer to reach the processing site to incorporate transportation emissions in the study.

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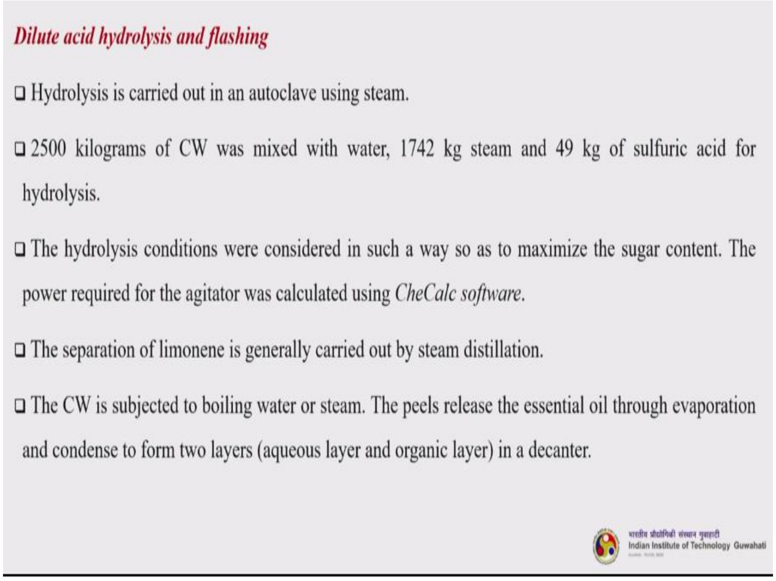

Then, the next method is dilute acid hydrolysis and flashing. Now hydrolysis is carried out in an autoclave using steam. 2500 kilogram of CW was mixed with water, 1742 kilogram of steam and 49 kilogram of sulfuric acid for hydrolysis. The hydrolysis conditions were considered in such a way so as to maximize the sugar content. The power required for the agitator was calculated using the *CheCalc* software.

The separation of limonene is generally carried out by steam distillation. The CW is subjected to boiling water or steam. The peels release the essential oil through evaporation and condense to form two layers, aqueous layer and organic layer in a decanter.

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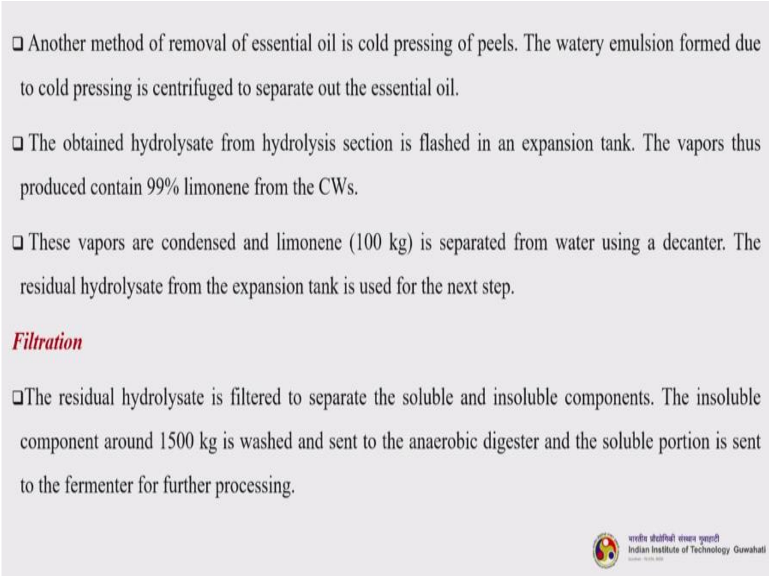

Another method of removal of essential oil is cold pressing of peels. The watery emulsion formed due to cold pressing is centrifuged to separate out the essential oil. The obtained hydrolysate from hydrolysis section is flashed in an expansion tank. The vapors thus produced content 99% limonene from the CWs. Now, these vapors are condensed and limonene that is 100 kg is separated from water using a decanter. The residual hydrolysate from the expansion tank is used for the next step.

Filtration: The residual hydrolysate is filtered to separate the soluble and insoluble components. The insoluble component around 1500 kilogram is washed and sent to the anaerobic digester and the soluble portion is sent to fermenter for further processing for anaerobic digestion to be carried out actually.

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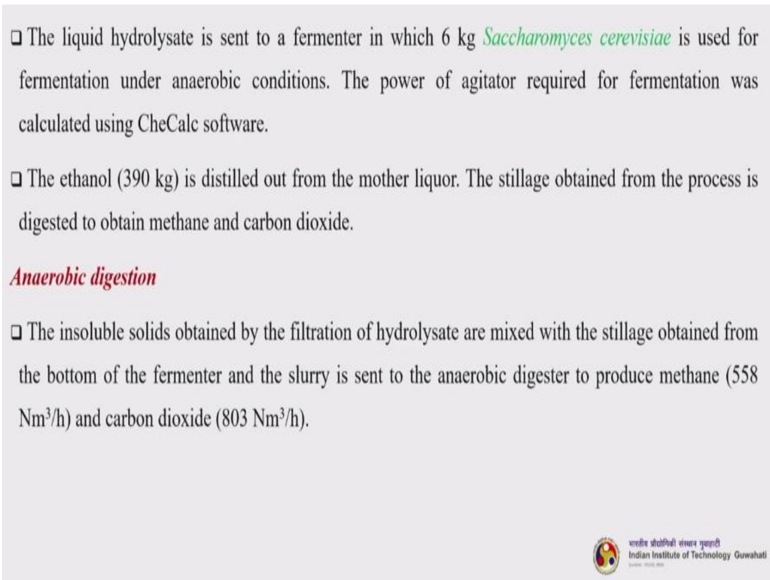

Now, the liquid hydrolysate is sent to a fermenter in which 6 kilograms of *Saccharomyces cerevisiae* is used for fermentation under anaerobic conditions. The power of agitator required for fermentation was calculated using the *CheCalc* software. The ethanol that is 390 kg is distilled out from the mother liquor. The stillage obtained from the process is digested to obtain methane and carbon dioxide.

Then the next one is the anaerobic digestion. The insoluble solids obtained by the filtration of hydrolysate are mixed with the stillage obtained from the bottom of the fermenter and the slurry is sent to the anaerobic digester to produce methane, 558 Nm cube per hour and carbon dioxide is almost 803 Nm cube per hour.

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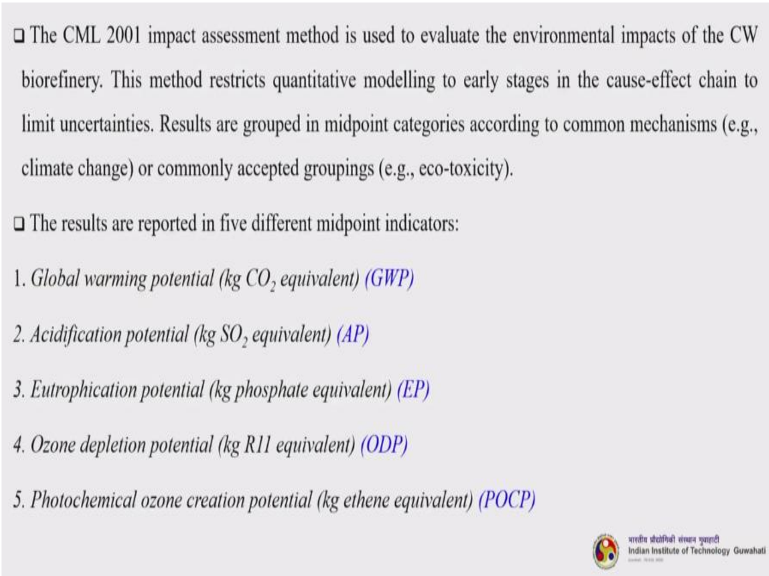

Now the CML 2001 impact assessment method is used to evaluate the environmental impacts of the CW biorefinery. This method restricts quantitative modelling to early stages in the cause-effect chain to limit uncertainties. Results are grouped in midpoint categories according to common mechanism say for example climate change or commonly accepted grouping say for example ecotoxicity The results are reported in five different midpoint indicators:

First, is global warming potential that is measred in kilograms of carbon dioxide equivalent. Second, is acidification potential, it is measured in kilograms per sulphur dioxide equivalent. Third is eutrophication potential, it is measured in kilogram of phosphate equivalent. Fourth is ozone depletion potential, it is measured in kilograms R11 equivalent. And the final one is photochemical ozone creation potential, it is measured in terms of kilograms per ethene equivalent. So, these 5 major parameters are very important.

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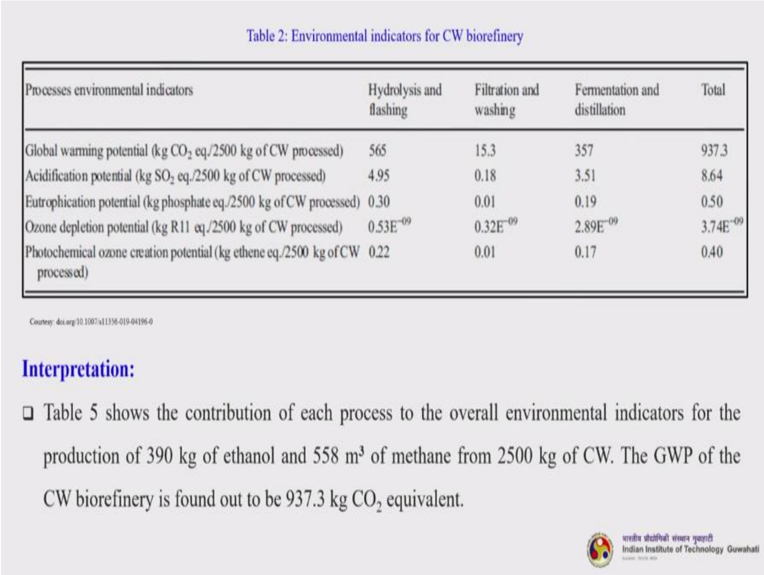

Table 2: Environmental indicators for CW biorefinery

Processes environmental indicators	Hydrolysis and flashing	Filtration and washing	Fermentation and distillation	Total
Global warming potential (kg CO_2 eq./2500 kg of CW processed)	565	15.3	357	937.3
Acidification potential (kg SO_2 eq./2500 kg of CW processed)	4.95	0.18	3.51	8.64
Eutrophication potential (kg phosphate eq./2500 kg of CW processed)	0.30	0.01	0.19	0.50
Ozone depletion potential (kg R11 eq./2500 kg of CW processed)	$0.53E^{-09}$	$0.32E^{-09}$	$2.89E^{-09}$	$3.74E^{-09}$
Photochemical ozone creation potential (kg ethene eq./2500 kg of CW processed)	0.22	0.01	0.17	0.40

Courtesy: doi.org/10.1007/s11356-019-04196-0

Interpretation:

- Table 5 shows the contribution of each process to the overall environmental indicators for the production of 390 kg of ethanol and 558 m³ of methane from 2500 kg of CW. The GWP of the CW biorefinery is found out to be 937.3 kg CO_2 equivalent.

So, this table will give you an understanding about the environmental indicators for this particular CW biorefinery. You can see that global warming potential, so kilogram carbon dioxide equivalent per 2500 kilograms of CW that is processed. So, from the hydrolysis and flashing it is 565. Filtration and washing step it is 15.3. Fermentation and distillation is 357. Total is 937.3. That is 937.3 kilograms of carbon dioxide equivalent per 2500 kilograms of CW that is processed.

Now, let us talk about this eutrophication potential. So, it is 0.5, very small, for again 2500 kilograms of CW processed. If you talk about the photochemical ozone creation potential, it is 0.4 kilogram ethene equivalent for 2500 kilogram of the CW that is processed. So, this gives you an understanding about how different types of these processes are generating different types of parameters which we have measured in exclusively 5 different indicators.

The next is interpretation. Now the table 5, I think there is a mistake here it will be table 2. Table 2 shows the contribution of each process to the overall environmental indicators for the production of 390 kg of ethanol and 558 meter cube of methane from 2500 kg of CW. The GWP of the CW biorefinery is found out to be 937.3 kg carbon dioxide equivalent.

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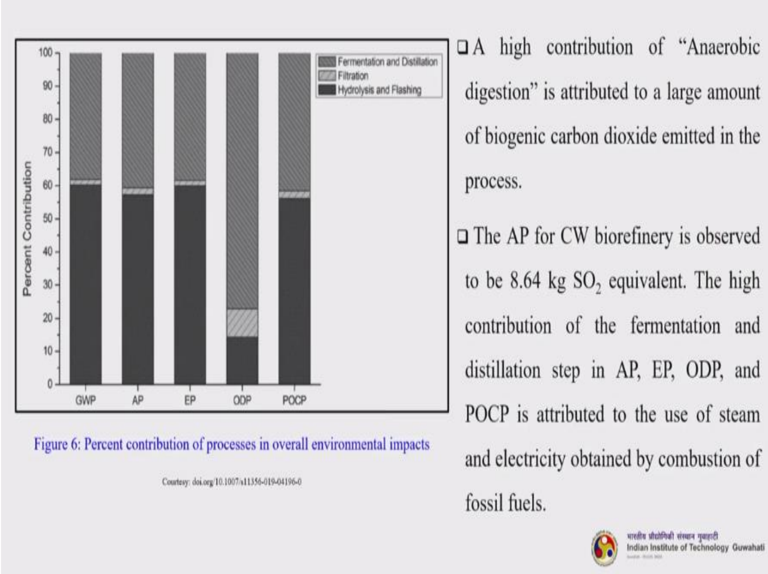

So, if you look into this particular figure 6, it tells us about the percent contribution of processes in overall environmental impacts, again for these 5 different indicators. A high contribution of anaerobic digestion is attributed to a large amount of biogenic carbon dioxide emitted in the process. You can see that during anaerobic digestion it is more.

Then the AP for CW biorefinery is observed to be 8.64 kilogram sulfur dioxide equivalent. The high contribution of the fermentation and distillation steps in AP, EP, ODP and POCP is attributed to the use of steam and electricity obtained by combustion of fossil fuels.

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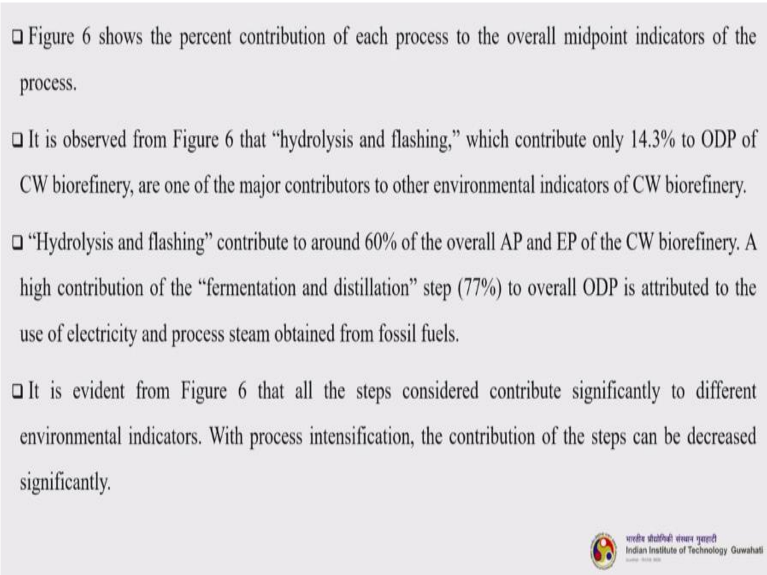

So, figure 6 shows the percent contribution of each process to the overall midpoint indicators of the process. It is observed from this figure that hydrolysis and flashing that contributes only 14.3% of ODP of the entire CW biorefinery is one of the major contributors to other environmental indicators of this particular biorefinery. Hydrolysis and flashing contribute to around 60% of the overall AP and EP of the CW biorefinery.

A high contribution of the fermentation and distillation step, almost 77%, to overall ODP is attributed to the use of electricity and process steam obtained from fossil fuels. It is evident from figure 6 that all the steps considered contribute significantly to different environmental indicators with process intensification, the contribution of the steps can be decreased significantly.

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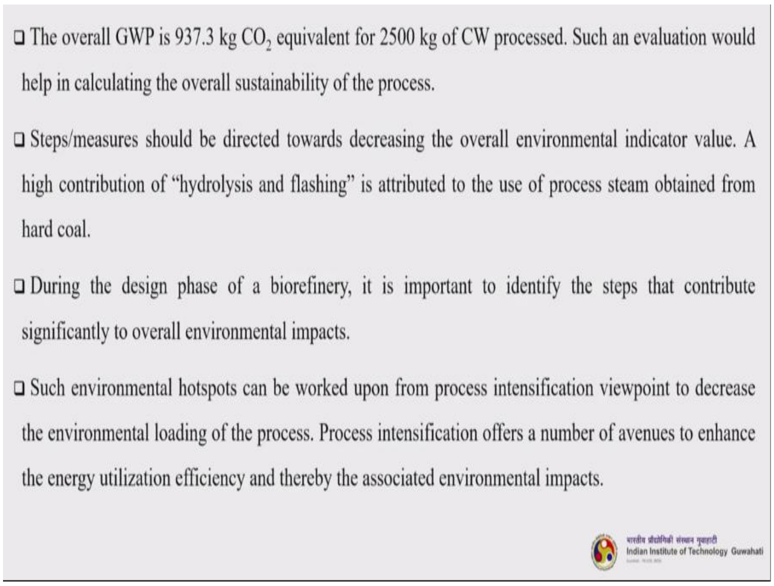

The overall GWP is 937.3 kilograms of carbon dioxide equivalent for 2500 kilogram of CW processed. Such an evaluation would help in calculating the overall sustainability of the process. Steps and measures would be directed towards decreasing the overall environmental indicator value. A high contribution of hydrolysis and flashing is attributed to the use of process steam obtained from the hard coal.

During the design phase of a biorefinery, it is important to identify the steps that contribute significantly to overall environmental impacts. Such environmental hotspots can be worked upon from process intensification viewpoint to decrease the environmental loading of the process. Process intensification offers a number of avenues to enhance the energy utilization efficiency and thereby the associated environmental impacts.

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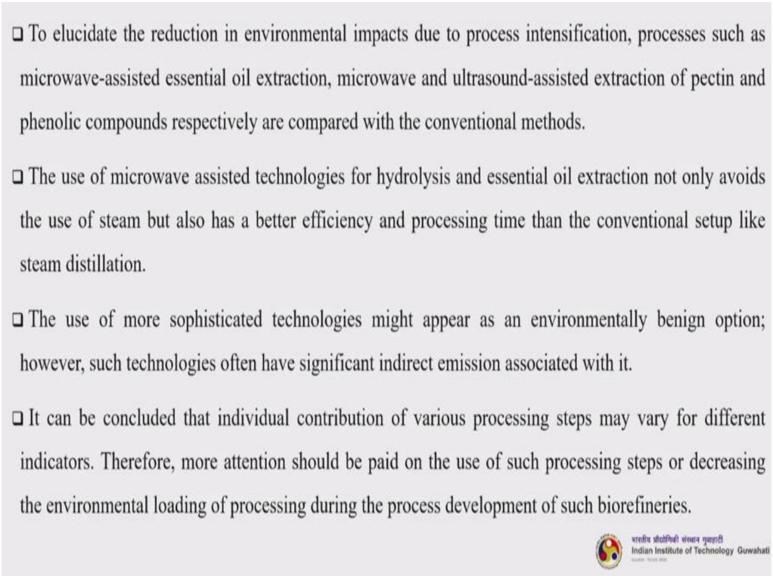

So to elucidate the reduction in environmental impacts due to process intensification, processes such as microwave-assisted essential oil extraction, microwaves and ultrasound-assisted extraction of pectin and phenolic compounds respectively are compared with the conventional methods. The use of microwave-assisted technologies for hydrolysis and essential oil extraction not only avoid the use of steam, but also has a better efficiency and processing time than the conventional setup like steam distillation. The use of more sophisticated technologies might appear as an environmentally benign option, however such technologies often have significant indirect emissions associated with it.

It can be concluded that individual contribution of various processing steps may vary for different indicators. Therefore, more attention should be paid on the use of such processing steps or decreasing the environmental loading of processing during the process development of such biorefineries.

So, I hope that you got an exclusive idea about what is LCA, how LCA can be carried out. So, with this, I conclude today's lecture as well as the entire course. I am hopeful that you have understood the concepts of how biomass can be converted using various techniques. Then what is a biorefinery, what are the different types of biorefineries that exist or are being planned with reference to the sustainable development goals. Then also we have discussed so many different success stories for different conversion technologies. We have also discussed different success studies which are commercially actually running biorefineries.

Then in the fag end of the lecture, we have discussed about the techno-economical assessment and evaluation as well as the life-cycle assessment and evaluation. So, I am hopeful that this course will be very useful for your academic and research purposes or even somebody wishes to set up industries that is basically biomass based industries also, this course will be very helpful for them.

So thank you very much. If you have any query, you can feel free to write to me at kmohanty@iitg.ac.in or register your query in the Swayam portal itself. So, thank you very much.