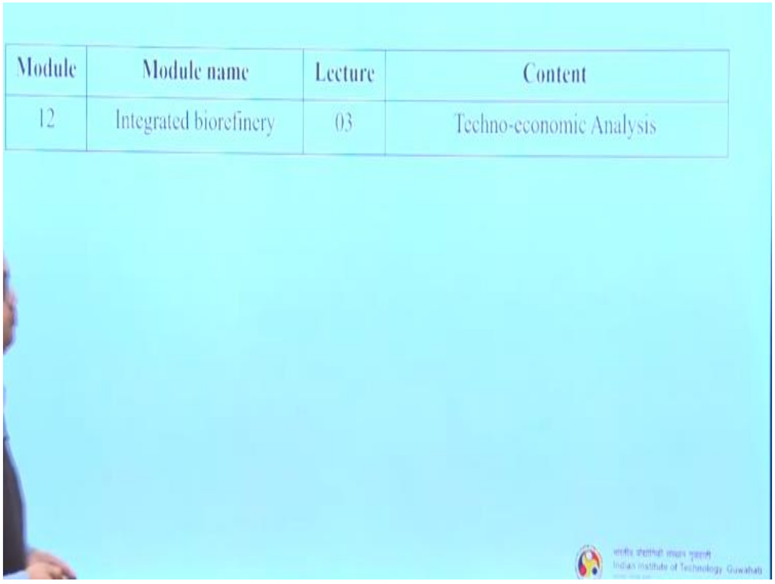
Bomass Conversion and Biorefinery
Prof. Kaustubha Mohanty
Department of Chemical Engineering
Indian Institute of Technology - Guwahati

Lecture – 36
Techno-Economic Evaluation

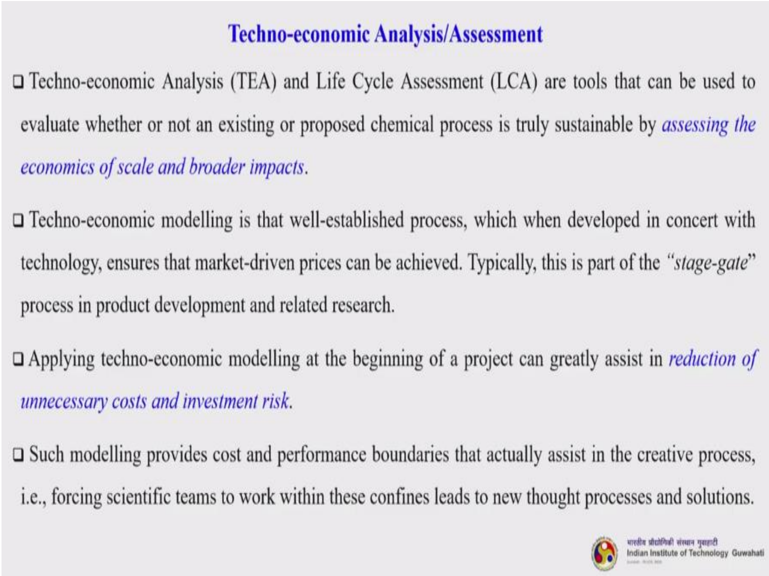
(Refer Slide Time: 00:36)



Good morning students. This is lecture 3 under module 12. And as you know that this is the last module and we are discussing integrated biorefinery and today's lecture and the next lecture, there will be one more lecture, is focused on two very important aspects of the entire biorefinery concept. First one is the techno-economical assessment or analysis or evaluation, so popularly known as TEA; that is what we are going to discuss today.

And in our next subsequent lecture and the last lecture of this course we will be discussing about the life-cycle assessment. So, let us try to understand what is the techno-economical analysis. Why it is required? How it can be done? Then I have taken a case study which is recently published in one of the peer-reviewed international journal. So, that reference is also given. So, you can download the paper and read later on after the class. So, it will make you understand the entire lecture in a better way. So, let us begin.

(Refer Slide Time: 01:31)



Techno-economical analysis and life cycle assessment are tools that can be used to evaluate whether or not an existing or proposed chemical process is truly sustainable. How we will do that? Now by assessing the economics of the scale and there are broader impacts. Now LCA will take care of environmental things and others that is what we are going to discuss in the next class. But today's lecture is completely dedicated to the techno-economic analysis.

Wherein we will be discussing about the economics So, techno-economical modelling is that well established process which when developed in concert with technology ensures that market driven prices can be achieved. So, whatever technology you develop and whether it is a refinery, biorefinery, new industry, may not be necessarily a biorefinery, so you need to go for this TEA and LCA.

So, you start with a feedstock or the base material from which you are trying to develop your product or you are making the product. Then it goes through various processes, conversion processes, purification processes, polishing steps, there are many, then finally you get your purified product and you will end up in getting it in a certain value, the price of it. Now, that price should eventually be related to the already available such products in the market on a commercial scale.

Then only the entire process can become sustainable or economical. Otherwise, it is not going to help the industry. So, typically this part of the stage-gate process in product development and related research. So, applying techno-economic modelling at the beginning of a project can greatly assist in reduction of unnecessary cost and investment risk. So, when somebody wants to start a industry or let us say biorefinery, he or she must be convinced that what are the risks.

One of the risk is basically of course this investment risk where somebody is investing. And another is of course the risks that are associated with the environmental concerns. Now, such modelling provides cost and performance boundaries that actually assist in the creative process that is forcing scientific teams to work within these confines, leads to new thought processes as well as solutions.

(Refer Slide Time: 03:44)

Now, these process models integrating technical, economic and process engineering information are versatile and precise tools that serve as a common language across technical and financial fields, thereby allowing these 8 different types of parameters. The first one is the definition of a project scale and scope for economic value. Second one is evaluation and comparison of the alternative processes. Third is evaluation of alternative technologies for relative value.

Fourth is for more informed project, process, technology decisions throughout the project. Then fifth is providing a framework for test, analysis and a basis for continual processing improvement. Sixth is evaluation of equity investment opportunity, returns and risk. Seventh is sensitivity to changes in prices and efficiencies on project worth. And eight and last one is calculation of the credit requirements, risks and other conditions.

(Refer Slide Time: 04:36)

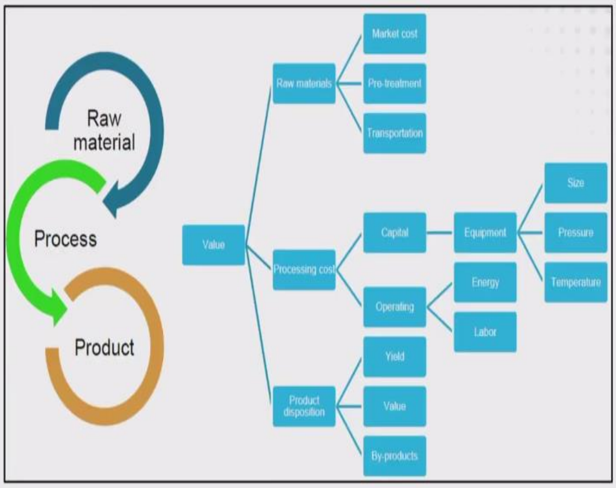


Figure 1. Techno-economic Analysis flowsheet
Courtesy: ARPA-E

So if you closely look at this particular techno-economical analysis, it is a typical flow sheet. So as I was telling you in the beginning of the class, so we start with raw material. Now raw material means what basically? So you look here, the raw materials and what are the things that is actually related to its cost. The first one is the market cost. If the raw material is directly available in the market so that you can procure it, buy it directly, then it has a cost. Even if it is not so you are going to collect it from some sources. Let us talk about our biorefinery, biomasses, then what you are going to do? You need to procure it from forest, agricultural field. So, it is a different model altogether, but there is a cost associated. Second is that pretreatment. We have extensively discussed about pretreatment. What is the need of pretreatment?

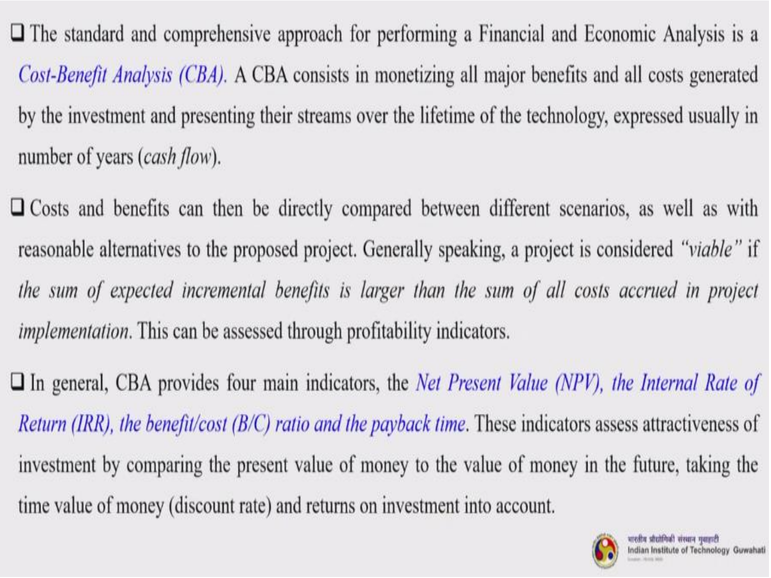
And you know that there is a huge cost associated with the pretreatment. And third is the transportation, another major cost. So, all these costs together will get inside to the raw material cost. Second is the process. Now, what is processing cost? There are 2 different types of processing cost, capital cost and then second is the operating cost. Now, capital cost is basically the equipment cost.

The equipment that is required for converting the biomass into value-added products. Now, that equipment cost will be decided by three factors. First is the size. So what is that type of reactor? 5 liters, 10 liters, 100 liters what is that? Then pressure and temperature. So, all these things will (operating pressure and temperature) subsequently decide about the cost of the equipment. Second is the operating cost.

Now, operating costs have two major things. I am only telling you the major things, there are small ancillary costs also. So, operating cost is first is energy the most important one, second is the labor cost. But third, there are chemicals consumable cost also associated, but when you compare it with energy and labor that is very small, so here it has not been written. Then third is product. Now product disposition.

So, what is the product yield? What is the value of the products and what are the byproducts? Now, this is very important. We have been discussing in our entire course that byproducts or many times people call it waste products are literally not waste. They have certain value addition. So we need to purify it, recover it, and again make it into a marketable product so that it has some value addition.

(Refer Slide Time: 07:04)

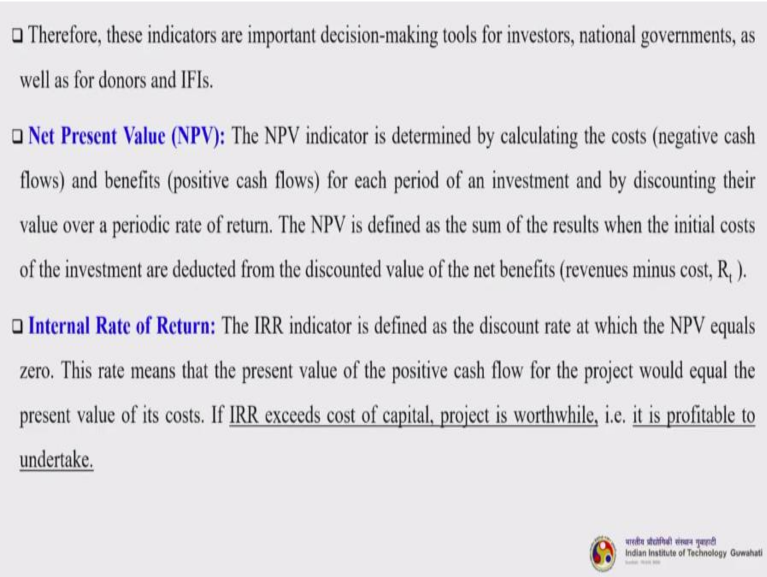


So the standard and comprehensive approach for performing a financial and economic analysis is a cost benefit analysis. It is called as CBA. So a CBA consists in monetizing all major benefits and all costs generated by the investment and presenting their streams over the lifetime of the technology expressed usually in number of years, which is known as cash flow. Now, costs and benefits can then be directly compared between different scenarios as well as with reasonable alternatives to the proposed project.

Generally speaking, a project is considered viable if the sum of expected incremental benefits is larger than the sum of all costs accrued in project implementation. And now this can be assessed through profitability indicators and there are various parameters to do that. Now, in general CBA provides four main indicators. The first is the NPV which is the net present value. The second is the IRR, which is known as the internal rate of return.

Third is B by C ratio, which is benefit by cost ratio. And the fourth is the payback time. Now, these indicators assess attractiveness of investment by comparing the present value of money to the value of money in the future, taking the time value of money, so that is the discount rate basically, and returns on investment into account.

(Refer Slide Time: 08:20)

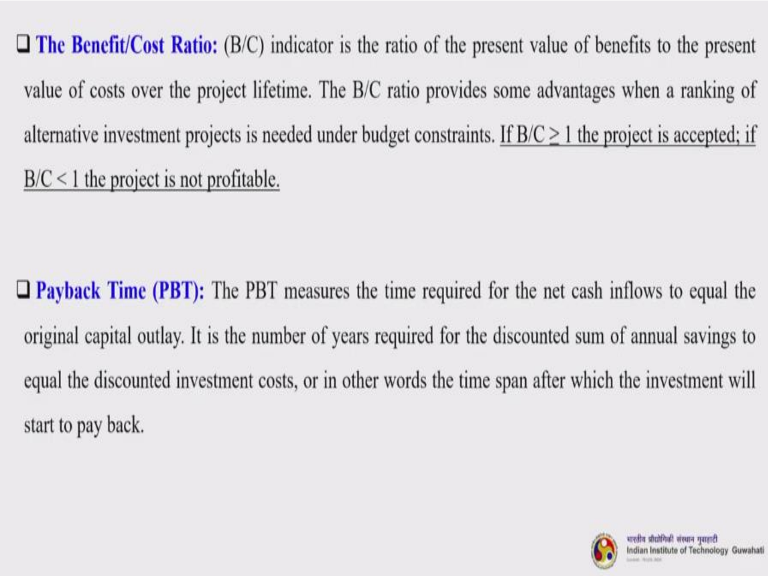


Now, therefore these indicators are important decision making tools for investors, national government as well as for donors and IFIs, the international financial institutes. Now net present value: so NPV indicator is determined by calculating the cost (negative cash flow) and benefits (that is the positive cash flow) for each period of an investment and by discounting their value over a periodic rate of return.

Now, NPV is defined as sum of the results when the initial cost of the investment are deducted from the discounted value of the net benefits. So, basically revenue minus the cost. Then next one is the IRR, internal rate of return. Now IRR indicator is defined as the discount rate at which the NPV equals 0. Now, this rate means that the present value of this positive cash flow for the project would equal the present value of its cost.

So, how it actually accounts into you can understand from this next sentence that, if IRR exceeds cost of capital, project is worthwhile that is it is profitable to undertake, otherwise it is not so.

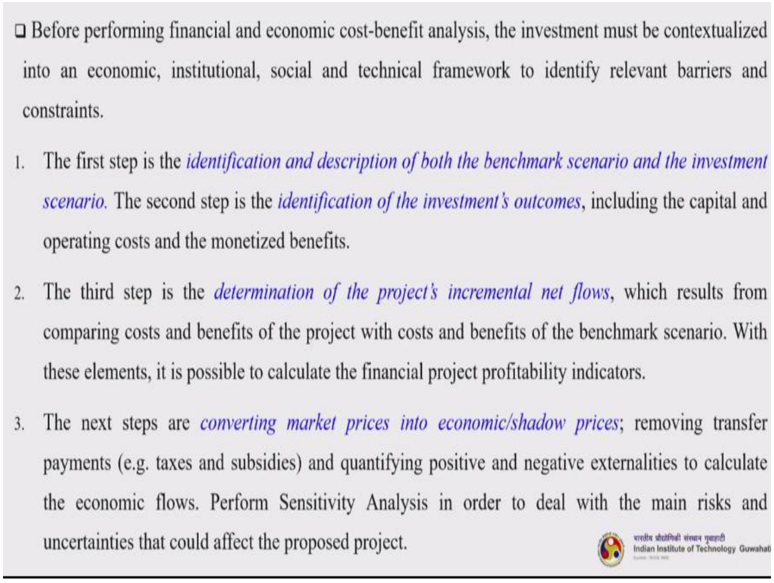
(Refer Slide Time: 09:23)



So then the benefit by cost ratio. So B by C indicator is the ratio of the present value of benefits to the present value of costs over the project lifetime. The B by C ratio provides some advantages when a ranking of alternative investment project is needed under budget constraints. So if B by C is greater than 1, the project is accepted. If it is less it is not profitable, so there is no question of accepting the project.

Then, one of the most important one is the payback time PBT. So the PBT measures the time required for the net cash inflows to equal the original capital outlet. So it is the number of years required for the discounted sum of annual savings to equal the discounted investment costs or in other words the time span after which the investment will start to pay back. So, you generate profit basically.

(Refer Slide Time: 10:11)



So, before performing financial and economic cost-benefit analysis, the investment must be contextualized into an economic, institutional, social and technical framework to identify relevant barriers and constraints. So, the first step is the identification and description of both the benchmark scenario and the investment scenario. Now, the second step is the identification of the investment's outcomes including the capital and operating costs and the monetized benefits.

Then the third step is the determination of the project's incremental net flows, which results from the comparing costs and benefits of the project with costs and benefits of the benchmark scenario. Now, with these elements it is possible to calculate the financial project profitability indicators. So, the next one is converting market prices into economic or shadow prices.

Removing transfer payments that is taxes and subsidies and quantifying positive and negative externalities to calculate the economic flows. Perform sensitivity analysis in order to deal with the main risks and uncertainties that could affect the proposed project. I will talk about sensitivity analysis in the fag end of today's lecture.

(Refer Slide Time: 11:20)

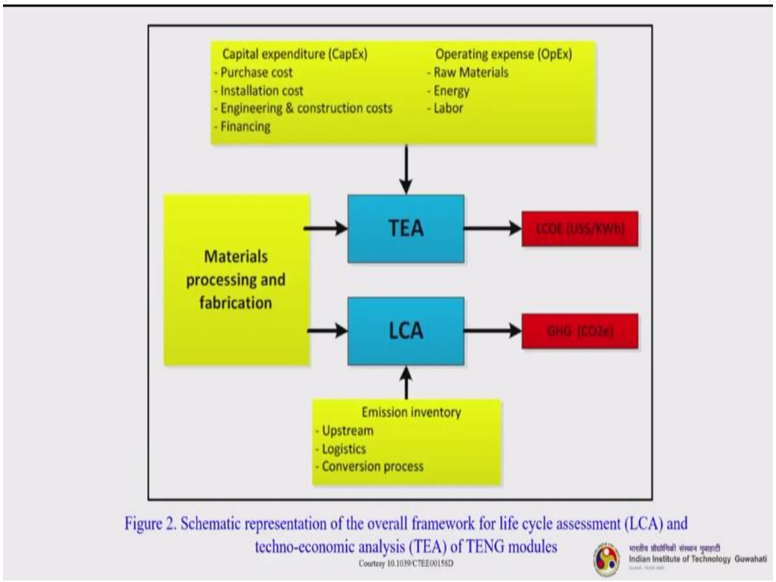


Figure 2. Schematic representation of the overall framework for life cycle assessment (LCA) and techno-economic analysis (TEA) of TENG modules

Courtesy 10.1039/C7EE00158D

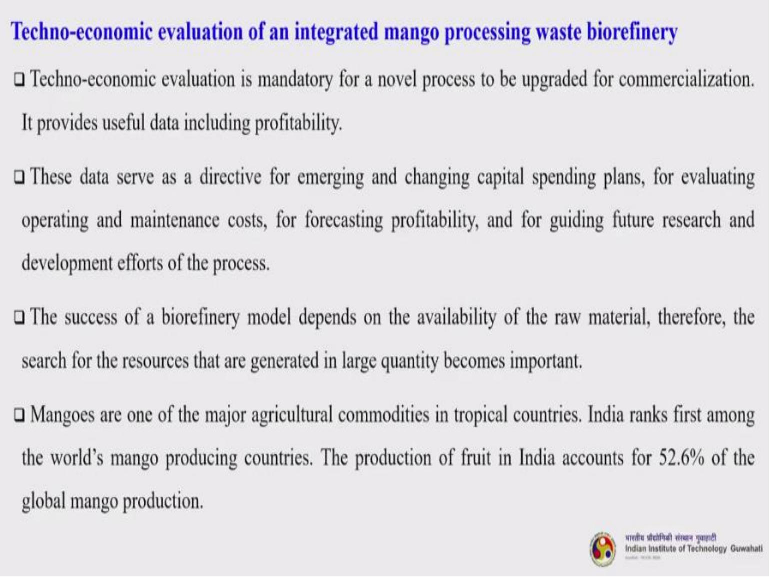
Let us look at this particular schematic representation of the overall framework for LCA and TEA analysis. LCA we are going to discuss in next class in detail. So, you can see that capital expenditure. Purchase cost, installation cost, engineering and construction cost, then there are financing costs, then there are operating costs. It is written as CapEx and OpEx. So, raw materials, energy, labor. This is what we discussed in the figure 1 first.

So, all these things to be taken into account when you discuss that techno-economical analysis or evaluation. Apart from that, the material processing and fabrication cost, then LCOE and GHG that will come under LCA, the greenhouse gas emission and all that we will discuss next class. Then upstream, logistic, conversion process emission inventory, this also comes under LCA. So, TEA is restricted to different types of costs.

LCA also takes into this type of material processing and fabrication details into its account. So, this is understanding of the overall framework of the LCA and TEA how it can be done together and both are done together actually for any new project that you are going to start. So, I have taken a case study, it is an interesting one, a small work actually. So, there are big works which are reported, big in the terms of number of processes and all.

So, this I have to chosen so that we can discuss it in our class and you can get an understanding that actually how it works. Once you learn the nitty gritties, then you can always go and read more details if you are interested to do so. So, I have taken mango processing waste biorefinery case study which is reported in one of the very good work in the industrial crops and products journal. So, I have given the reference, you can later on see So, let us start.

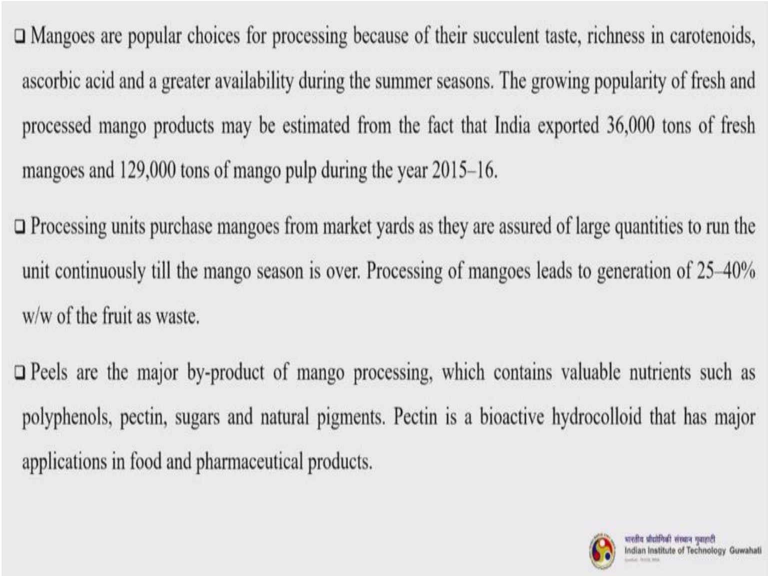
(Refer Slide Time: 13:15)



So techno-economical evaluation of an integrated mango processing waste biorefinery. So techno-economical evaluation is mandatory for a novel process to be upgraded for commercialization. It provides useful data including profitability. Now, these data serve as a directive for emerging and changing capital spending plans, for evaluating operating and maintenance cost, for forecasting profitability, and for guiding future research and development efforts of the process. The success of a biorefinery model depends on the availability of the raw material. Therefore, the search for the resources that are generated in large quantity becomes important. Mangoes are one of the major agricultural commodities mostly in the tropical countries and India ranks among the first in the world's mango producing countries.

The production of fruit in India accounts for 52.6% of the global mango production. So, you can understand that how much of waste we actually generate and why there is a need to talk about the mango processing waste biorefinery.

(Refer Slide Time: 14:16)

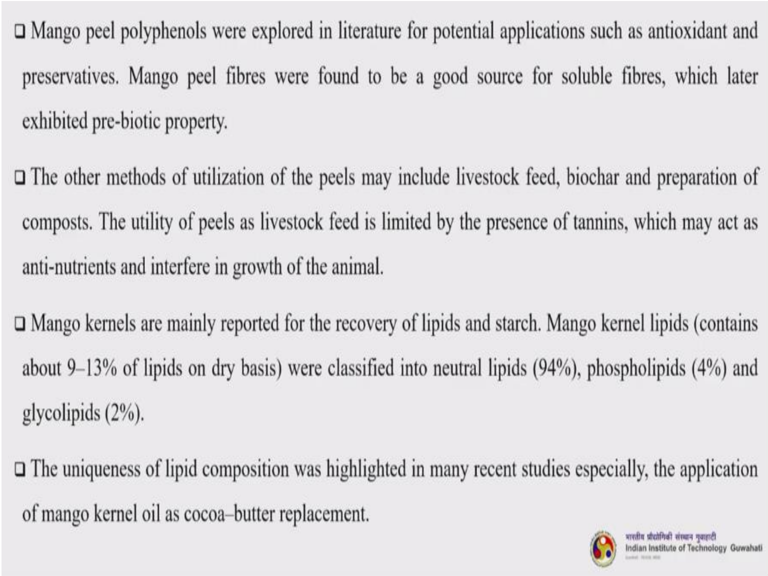


Now mangoes are popular choices for processing because of their succulent taste, richness in carotenoids, ascorbic acid and a greater availability during the summer seasons. The growing popularity of fresh and processed mango products may be estimated from the fact that India exported 36,000 tons of fresh mangoes and 129,000 tons of mango pulp during the year 2015-16. So, this is the statistics which I got from the manuscript.

I am sure this statistics has been increased and we may have added more tons to whatever being written here. So, processing units purchase mangoes from market yeards as they are assured of large quantities to run the unit continuously till the mango season is over that is very important. So, processing of mangoes leads to generation of almost 25 to 40% of the fruit as a waste.

Peels are the major byproduct of mango processing which contains valuable nutrients such as polyphenols, pectin, sugars and natural pigments. Pectin is a bioactive hydrocolloid that has major applications in food and pharmaceutical products.

(Refer Slide Time: 15:20)

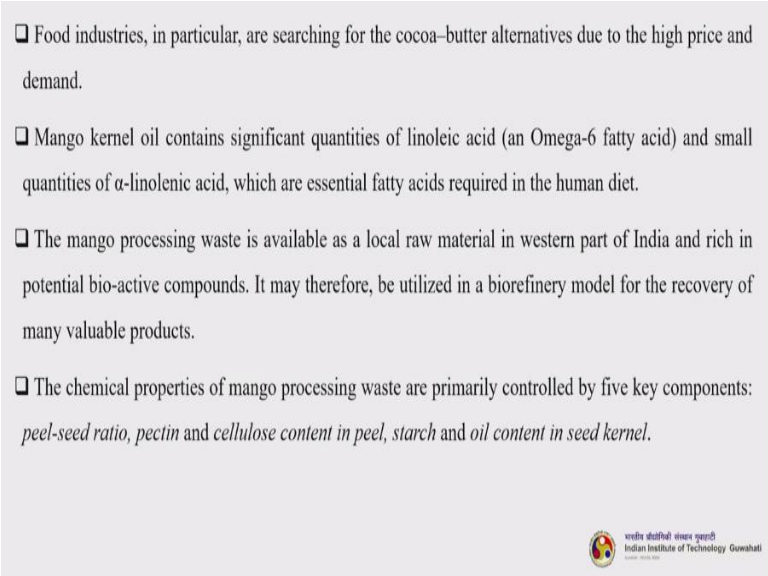


Mango peel polyphenols were explored in literature for potential applications such as antioxidants and preservatives. Mango peel fibres were found to be a good source for soluble fibres, which later exhibited pre-biotic properties also, so that is very interesting actually. So that is why a lot of work has been going on on this conversion. The other methods of utilization of the peels may include livestock feed, biochar and preparation of compost.

That utility peels as livestock feed is limited by the presence of tannins which may act as anti-nutrients and interfere in the growth of the animal, but it depends on how much tannin is present. So mango kernels are mainly reported for the recovery of the lipids and starch. Mango kernel lipids that contains about 9 to 13% of lipids on dry basis were classified into neutral lipids that is almost 94%, then phospholipids 4% and glycolipids 2%.

Now, the uniqueness of lipid composition was highlighted in many recent studies, especially the application of mango kernel oil as a cocoa-butter replacement because cocoa-butter is very costly.

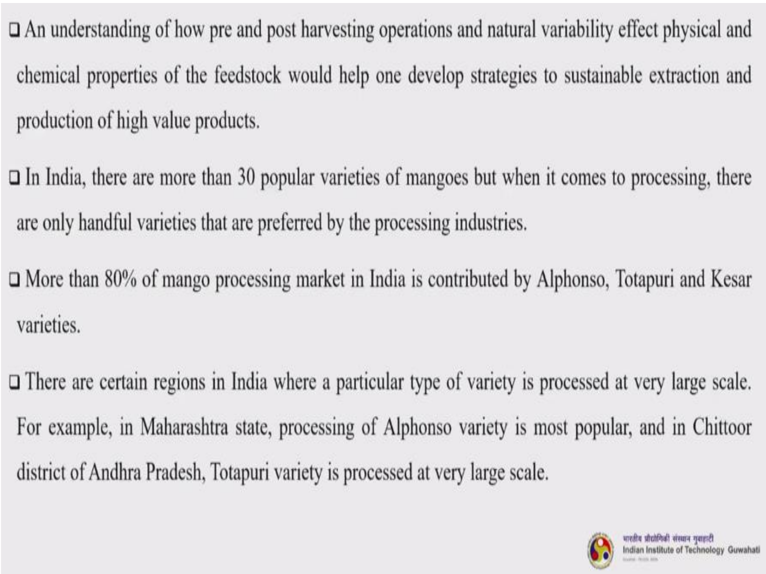
(Refer Slide Time: 16:27)



So, food industries in particular are searching for the cocoa-butter alternatives due to the high price and demand. Mango kernel contains significant quantities of linoleic acid that is an Omega-6 fatty acid, is a good fatty acid, and small quantities of alpha linolenic acid which are essential fatty acids required in the human diet. Now, the mango processing waste is available as a local raw material in western part of India and rich in potential bio-active compounds.

It may therefore be utilized in a biorefinery model for the recovery of many valuable products. The chemical properties of mango processing waste are primarily controlled by 5 key components. First is peel to seed ratio, then pectin and cellulose content in the peel, starch and oil content in the second kernel.

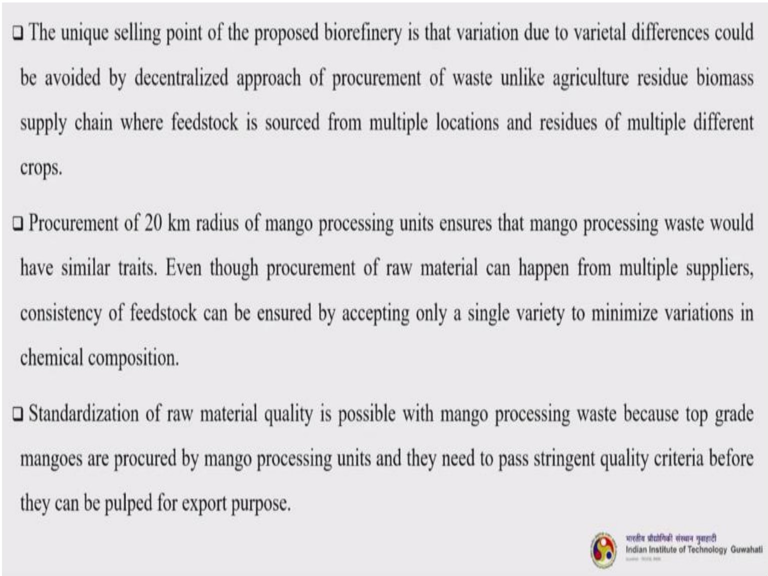
(Refer Slide Time: 17:13)



An understanding of how pre and post harvesting operations and natural variability effect physical and chemical properties of the feedstock would help one develop strategies to sustainable extraction and production of high value products. In India, there are more than 30 popular varieties of mango, but when it comes to processing there are only handful varieties that are preferred by the processing industries.

More than 80% of mango processing market in India is contributed by Alphonso, Totapuri and Kesar varieties. So, we have so many varieties in India of the mango. So, there are certain regions in India where a particular type of varieties processed at a very large scale. For example, in the state of Maharashtra processing Alphonso variety is most popular. Alphonso is mostly being produced only in Maharashtra. And in Chittoor district of Andhra Pradesh, Totapuri variety is processed at a very large scale.

(Refer Slide Time: 18:06)



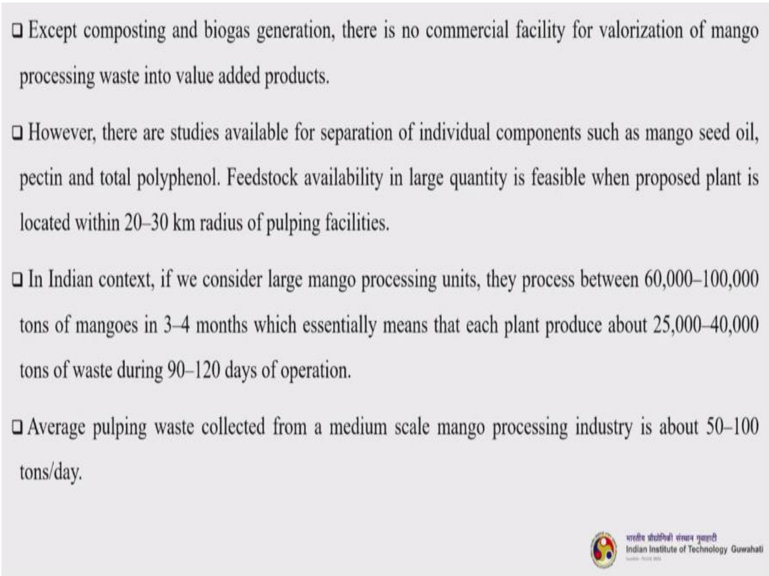
So, the unique selling point of the proposed biorefinery is that variation due to varietal differences could be avoided by decentralized approach of procurement of waste unlike agricultural residue biomass supply chain where feedstock is sourced from multiple locations and residues of multiple different crops. So, I hope you understand this. This we are talking about the supply chain management system.

When you talk about a biomass based refinery, you need to procure it from different parts of the agricultural fields and forest. When we are talking about mango waste refinery, please understand that mangoes are already coming to that mango processing plant and we are getting the waste entirely directly from the processing unit and we can also set up the small scale biorefinery plant itself along with the mango processing unit.

So that is also doable and if that is done then it will save a lot of other cost also, logistical cost. Now procurement of 20 kilometer radius of mango processing unit ensures that mango processing waste would have similar traits. Even though procurement of raw material can happen for multiple suppliers, consistency of feedstock can be ensured by accepting only a single variety to minimize variations in chemical composition.

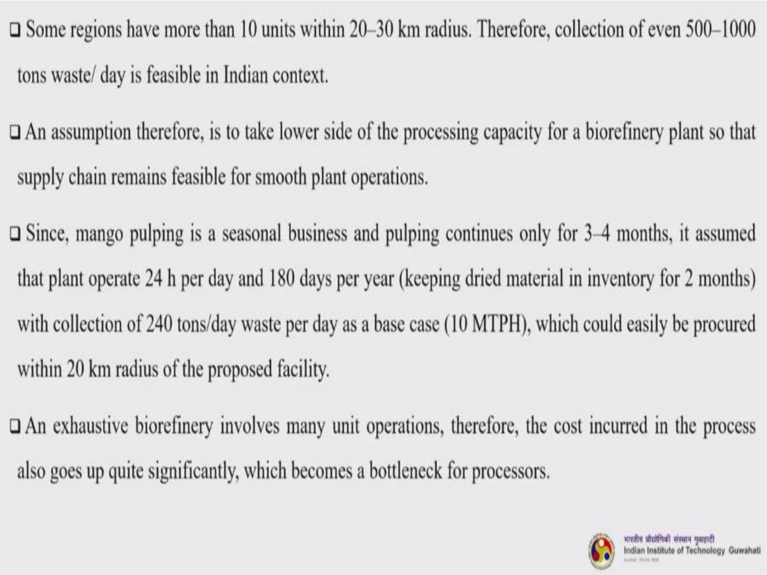
Standardization of raw material quality is possible with mango processing waste because top grade mangoes are procured by mango processing units and they need to pass stringent quality criteria before they can be pulped for export purposes.

(Refer Slide Time: 19:33)



Except composting and biogas generation, there is no commercial facility for valorization of mango processing waste into value-added products. However, there are studies available for separation of individual components such as mango seed oil, pectin and total polyphenol. Feedstock availability in large quantity is feasible when proposed plant is located within 20 to 30 kilometer radius of pulping facilities or else I just told you what will happen - Then your transportation and logistic cost will increase. In Indian context, if we consider large mango processing units, they process between 60,000 to 100,000 tons of mangoes in just 3 to 4 months which essentially means that each plant produce about 25,000 to 40,000 tons of waste during this 90 to 120 days of operation. It is a huge waste. Average pulping waste collected from a medium scale mango processing industry is about 50 to 100 tons per day.

(Refer Slide Time: 20:27)



So, some regions have more than 10 units within 20 to 30 kilometer radius. Therefore, collection of even 500 to 1000 tons of waste per day is feasible in Indian context. So, this is a very interesting observation. This is already reported in literature and we know it is a fact that most of these so called mango processing units are usually located in the state of Maharashtra as well as in Andhra Pradesh and other states also where like West Bengal and few other states.

So, they are located in close proximity or almost 15, 20, 30 kilometer radius. Let it be 50 kilometer also, no issue. So, what is the inherent meaning of this? So, if they are actually located inside this 20 to 30 kilometer radius, then collection of these waste from this particular area is a viable alternative or sustainable alternative in terms of economics. Otherwise, suppose you are collecting from 100 kilometer, 200 kilometer distance.

Then the handling cost, transportation cost will add on so much than whatever a procurement of the waste you are doing that cost of the procurement from the source and getting it to the biorefinery will be so high that even if you process also your final product like pectin and other things are not going to be economical. So, an assumption therefore is to take lower side of the processing capacity for a biorefinery plant so that supply chain remains feasible for smooth plant operation.

Supply chain is the most important aspect of any biorefinery. Since mango pulping is a seasonal business and pulping continues only for 3 to 4 months, it is assumed that plant operates 24 hours per day and 180 days per year. So, keeping dried material in inventory for 2 months that is an assumption with collection of 240 tons per day waste per day as a base case, which could easily be procured within 20 kilometer radius of the proposed facility.

So, your location a biorefinery should be in such a way that all the mango processing units are located within 20 to 30 kilometer radius. So, an exhaustive biorefinery involves many unit operations, therefore the cost incurred in the process also goes up quite significantly which becomes a bottleneck for the process.

(Refer Slide Time: 22:37)

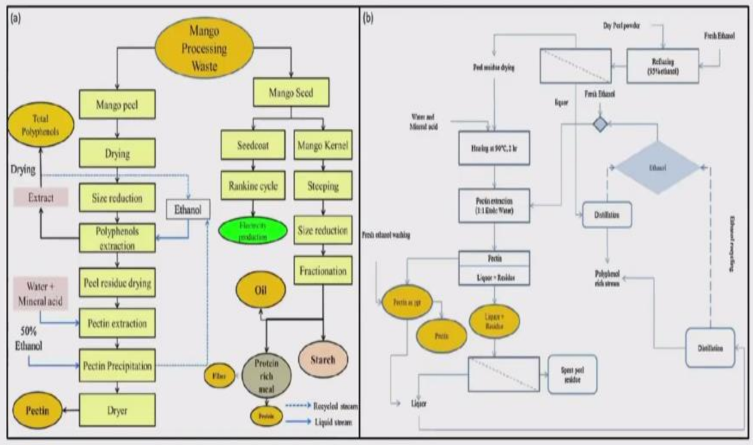


Fig.1: Schematic of (a) Mango processing waste biorefinery (b) pectin production from mango peel waste.

Courtesy: Industrial Crops & Products 116 (2018) 24-34

Let us understand how it happens actually. So, the first one, the part one A which is here this side, your left hand side is the mango processing waste biorefinery schematic representation. The B, the second one talks about the pectin production from the mango peel production which is the most important product from this particular waste biorefinery. Let us see this one.

So mango processing waste. So, there are two different things, one is the mango peel, another one the seed. Let us see what is there in the peel. So peel that gets a drying, again huge amount of energy is required. Then you go for some mechanical preprocessing, again energy is required, size reduction basically. So then you extract polyphenols using ethanol. There is a cost involved. Then the peel residue goes for drying, again energy intensive process.

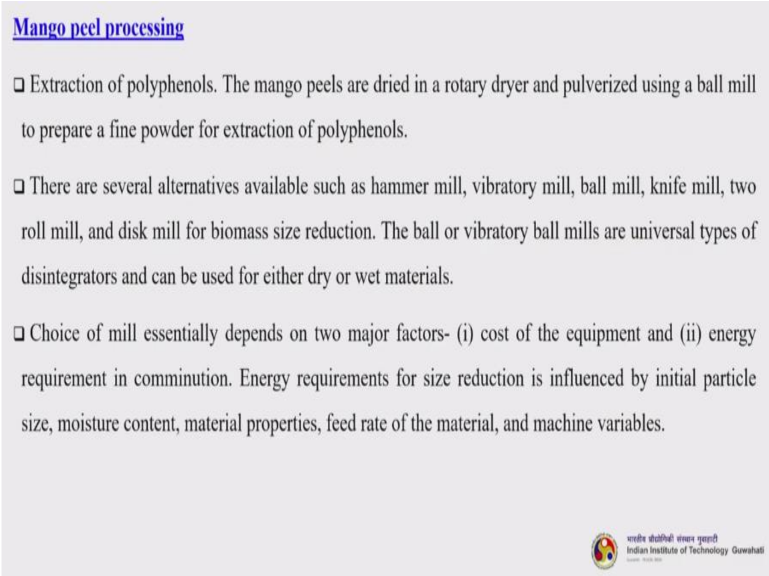
Then you finally remove the pectin or you extract pectin using water plus mineral acids. There are other things. Then you precipitate it using ethanol. Then finally it goes to dryer and you get the dry powder pectin. Now, similarly, the mango seed. Now mango seed has 2 different things. One is the seed coat, another one is the mango kernel which is inside. Now you just send it to electricity production.

Usually it contains some cellulose, hemicellulose very small quantity and mostly lignin and some extractive materials will also be there. Let us talk about mango kernel. So, it goes to steeping, size reduction, fractionation that it contains lots of oil that we have already discussed - different types of oils actually. So, you remove the oil. So, whatever left out is basically starch and there is some amount of protein rich meal - the final cake or the waste material or what you can say the solid part after removing everything it has certain protein content. So that can be used as cattle feed and some other applications. This is all about mango processing waste biorefinery concept. Now let us talk about the pectin production from the mango peel waste. So the dry peel powder. So use ethanol to remove it. Then you have ethanol recovery unit here.

It is an integrated system approach. So, then it goes to, there is a membrane, so you remove that ethanol, then whatever the peel powder that is left out the solid one, you go for drying. Then pectin extraction happens. After the extraction, you have a pectin rich layer. You have a liquor plus residue here. Pectin goes for drying and then you collect it. The liquor plus residue, finally you get a peel residue and a liquor.

Now, that peel residue finally can be utilized for some other purposes like cattle feed and you can also go for some pyrolysis to produce activated carbon or biochar out of this. So, this is an overall understanding of the mango processing waste biorefinery concept as well as how do we produce pectin from the mango peel waste.

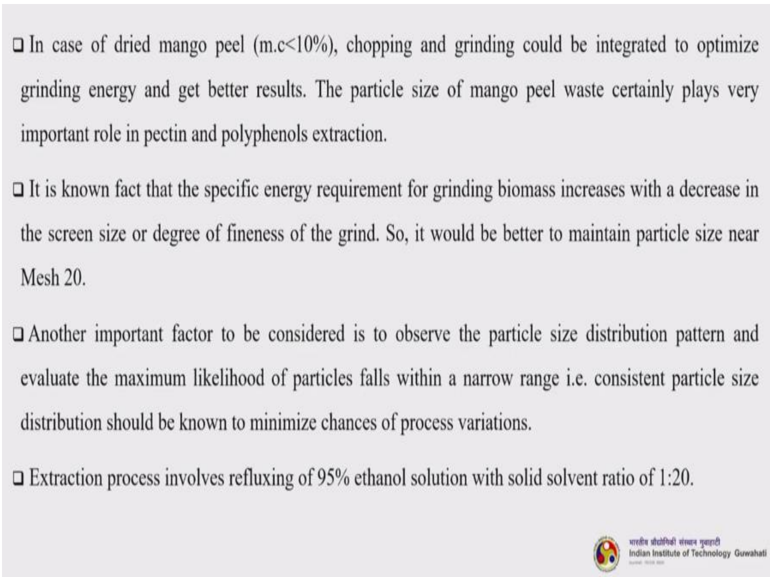
(Refer Slid e Time: 25:42)



So, mango peel processing. Extraction of polyphenols. The mango peels are dried in a rotary dryer and pulverized using a ball mill to prepare a fine powder for extraction of polyphenols. I am just talking about how this processing is happening. We will just briefly discuss. There are several alternatives available such as hammer mill, vibratory mill, ball mill, knife mill, two roll mill and disk mill for biomass size reduction, mechanical processing.

The ball or vibratory ball mills are universal types of disintegrators and can be used for either dry or wet materials. Choice of mill essentially depends on two major factors. First is the cost of the equipment and second is the energy requirement in comminution. Now, energy requirement for size reduction is influenced by initial particle size, moisture content, material properties, feed rate of the material and machine variables.

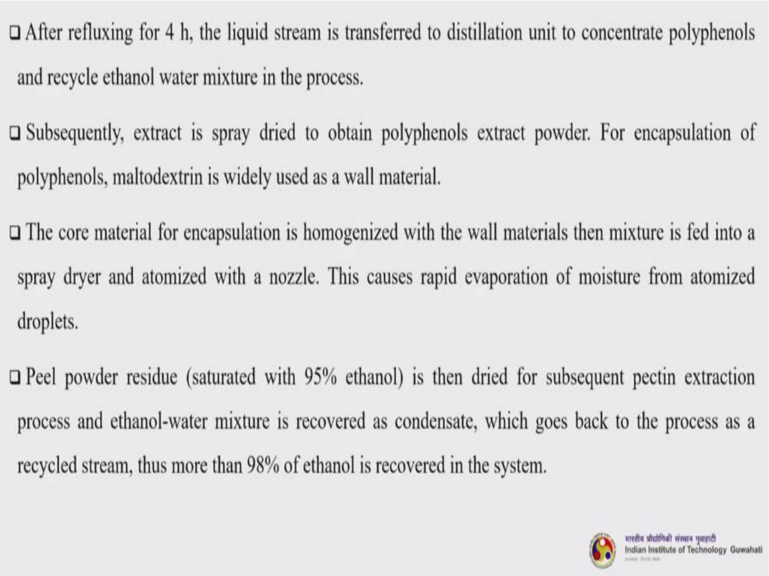
(Refer Slide Time: 26:32)



In case of dried mango peel if the moisture content is less than 10%, chopping and grinding could be integrated to optimize grinding energy and get better results. The particle size of mango peel waste certainly plays very important role in pectin and polyphenols extraction. It is known fact that the specific energy requirement for grinding biomass increases with a decrease in the screen size or degree of fineness of the grind.

So, it would be better to maintain particle size near Mesh 20. So, another important factor to be considered is to observe the particle size distribution pattern and evaluate the maximum likelihood of particles falls within a narrow range that is consistent particle size distribution should be known to minimize chances of process variations. Extraction process involves refluxing up 95% ethanol solution with solid solvent ratio of 1 is to 20.

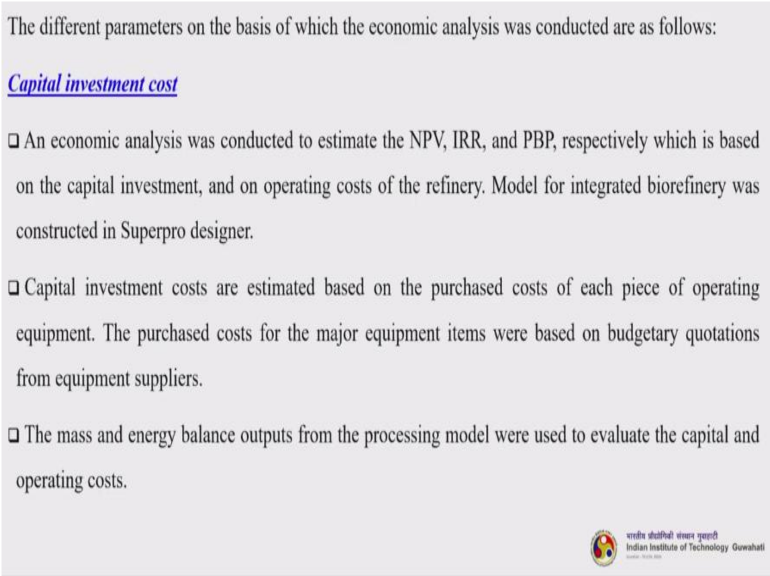
(Refer Slide Time: 27:22)



After refluxing for 4 hours, the liquid stream is transferred to distillation unit to concentrate polyphenols and recycle ethanol water mixture in the process. Subsequently, extract is spray dried to obtain polyphenols extract powder. For encapsulation of polyphenols, maltodextrin is widely used as a wall material. The core material for encapsulation is homogenized with the wall material, then mixture is fed into the spray dryer and atomized with a nozzle.

This causes rapid evaporation of moisture from atomized droplets. Peel powder residue that is saturated with 95% ethanol is then dried for subsequent pectin extraction process and ethanol water mixture is recovered as condensate which goes back to the process as a recycled stream. Thus, more than 98% of ethanol is recovered in the system.

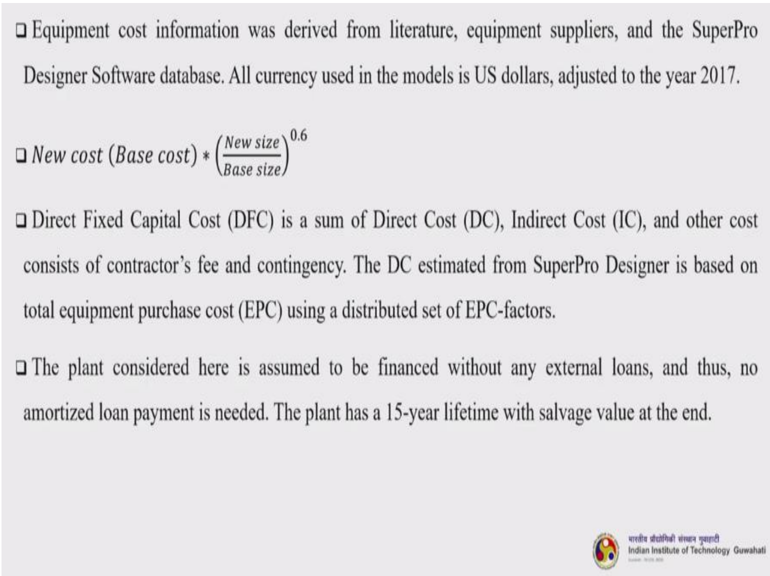
(Refer Slide Time: 28:10)



Now, the different parameters on the basis of which the economic analysis was conducted are as follows. The first one is the capital investment cost. So an economic analysis was conducted to estimate the NPV, IRR and PBP respectively which is based on the capital investment and an operating cost of the refinery. Model for integrated biorefinery was constructed in this Superpro designer, so it is a software, it is a tool to carry out such TEA analysis.

So, capital investment costs are estimated based on the purchase cost of each piece of operating equipment. The purchase cost for the major equipment items were based on budgetary quotations from the equipment suppliers. The mass and energy balance outputs from the processing model were used to evaluate the capital and operating cost.

(Refer Slide Time: 28:55)



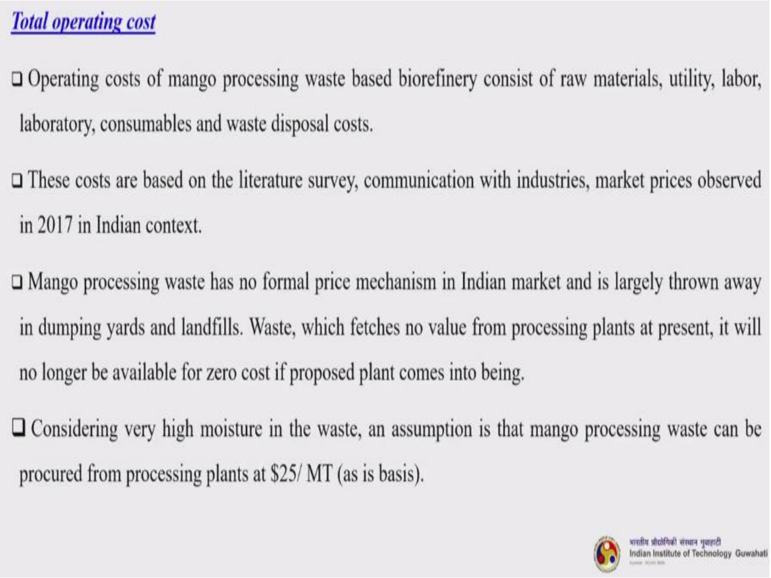
Equipment cost information was derived from literature, equipment suppliers and the Superpro Designer software database. All currency used in the models are in US dollars adjusted to the year 2017. So, the new cost that is the base cost into new size by base size to the power of 0.6.

$$New\ cost\ (Base\ cost) * \left(\frac{New\ size}{Base\ size}\right)^{0.6}$$

So this is being used to calculate the cost. So, direct fixed capital cost is the sum of the direct cost, indirect cost and other costs of contractor's fee and contingency.

Now the DC that is the direct cost estimated from the Superpro Designer is based on the total equipment purchase cost using a distributed set of EPC factors. So, these are some in-built features in this particular software Superpro Designer. So, the plant considered here is assumed to be financed without any external loans and thus no amortized loan repayment is required. Now, the plant has a 15 year lifetime with salvage value at the end.

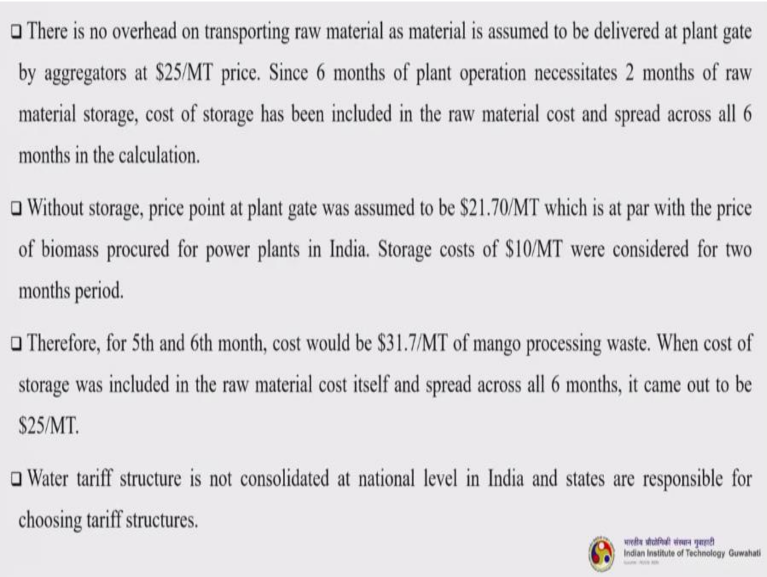
(Refer Slide Time: 29:48)



Then the operating cost: Operating costs of mango processing waste based biorefinery consists of raw material cost, utility cost, labor, laboratory cost, consumables and the waste disposal cost. Now, these costs are based on the literature survey, communication with industries, market prices observed in 2017 in Indian context. Mango processing waste has no formal price mechanism in Indian market and is largely thrown away in dumping yards and landfills.

Waste which fetches no value from processing plants at present, it will no longer be available for zero cost if proposed plant comes into being. Considering very high moisture in the waste and assumption is that mango processing waste can be procured from processing plants at 25 dollar per metric ton as basis that is the basis actually.

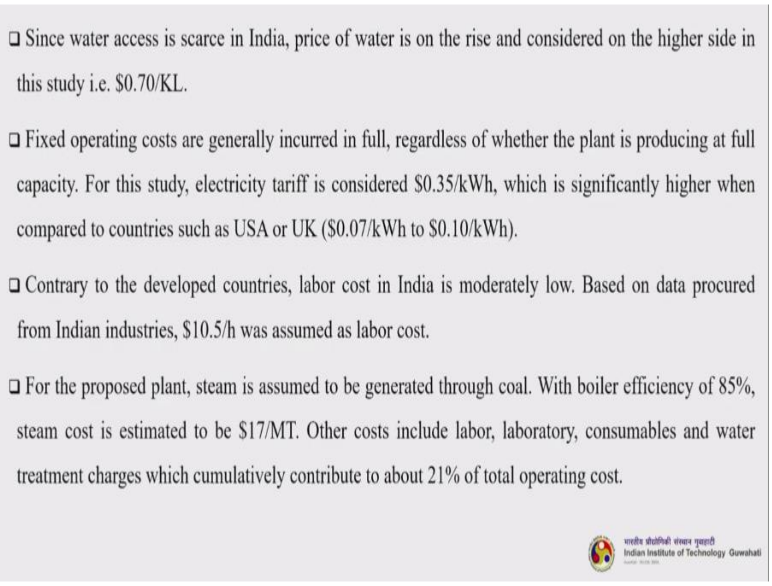
(Refer Slide Time: 30:33)



So, there is no overhead on transporting raw material as material is assumed to be delivered at plant gate by aggregators at 25 dollar per metric ton price. Since 6 months of plant operation necessitates 2 months of raw material storage, cost of storage has been included in the raw material cost and spread across all 6 months in the calculation. So without storage, the price point at plant gate was assumed to be 21.7 dollar per metric ton, which is at par with the price of the biomass procured for power plants in India, at par with that. So, storage cost of 10 dollar per metric ton was considered for 2 months period. Therefore, for fifth and sixth month cost would be 31.7 dollar per metric ton of mango processing waste. When cost of storage was included in the raw material cost itself and spread across all 6 months, it comes out to be 25 dollar per metric ton.

This is how it is actually being calculated. So, water tariff structure is not consolidated at national level in India and states are responsible for choosing tariff structures and it varies. So, it is very difficult to consolidate something on that.

(Refer Slide Time: 31:34)



Since water access is scarce in India, price of water is on the rise and considered on the higher side in this study, we have considered 0.7 dollar per kilolitre. Fixed operating costs are generally incurred in full regardless of whether the plant is producing at full capacity. For this study, electricity tariff is considered to be 0.35 dollar per kilowatt hour which is significantly higher when compared to countries such as United States or United Kingdom, where the energy price is very less.

Now, contrary to the developed countries labor cost in India is moderately low. So, we are offsetting in that labor cost, labor cost is very high in the developed countries. So, based on data procured from Indian industries 10.5 dollar per hour was assumed as the labor cost. It may vary depending upon the area where you are locating it. So, it may be ten 10, it may be 11 something like that.

So for the proposed plant, steam is assumed to be generated through coal. With boiler efficiency of 85%, steam cost is estimated to be 17 dollar per metric ton. Now, other costs include labor, laboratory, consumables and water treatment charges which cumulatively contribute to about 21% of the total operating cost.

(Refer Slide Time: 32:43)

Table 1: Total capital investment cost for PEP, PSEP and WMB processes.

Fixed Capital Estimates Summary	Factor of EPC	Cost ($) PEP	PSEP	WMB
A. Total Plant Direct Cost (TPDC)				
1. Equipment Purchase Cost (EPC)	100%	53,16,000	59,33,000	92,68,000
2. Installation	40%	17,07,000	22,24,000	36,67,000
3. Process Piping	30%	15,95,000	17,80,000	27,80,000
4. Instrumentation	20%	10,63,000	11,87,000	18,54,000
5. Insulation	1%	53,000	59,000	93,000
6. Electrical	10%	5,32,000	5,93,000	9,27,000
7. Buildings	40%	21,27,000	23,73,000	37,07,000
8. Yard Improvement	5%	2,66,000	2,97,000	4,63,000
TPDC		1,26,59,000	1,44,46,000	2,27,59,000
B. Total Plant Indirect Cost (TPIC)				
1. Engineering	60%	31,65,000	36,11,000	56,90,000
2. Construction	85%	44,31,000	50,56,000	79,66,000
TPIC		75,95,000	86,68,000	1,36,56,000
C. Total Plant Cost (TPC = TPDC + TPIC)			2,31,13,000	3,64,15,000
D. Contractor's Fee & Contingency (CFC)		2,02,54,000		
1. Contractor's Fee		10,13,000	11,56,000	18,21,000
2. Contingency		20,25,000	23,11,000	36,41,000
CFC		30,38,000	34,67,000	54,62,000
E. Direct Fixed Capital Cost (DFC = TPC + CFC)				
DFC		2,32,92,000	2,65,80,000	4,18,77,000

Courtesy: Industrial Crops & Products 116 (2018) 24–34

So, this talks about the total capital investment cost for the PEP, PSEP and WMB, the 3 different processes in the mango waste processing birefinery concept. So, total plant direct cost, equipment purchase costs, installation cost, process piping, instrumentation, insulation, electrical cost or charges, building cost, building cost is almost 40% you can see. So, yard improvement, then total plant direct cost.

Engineering is 60%, construction 85%. Then total plant cost is TPIC these two + TPDC. So, you get this amount. Then contractor's fee and contingency, the contractor's fee and contingency has been separated here. If you add all these things, you get the direct fixed capital cost equals to TPC + CFC. So, this gives us an understanding about what is the actual values.

(Refer Slide Time: 33:37)

Table 2: Economic evaluation parameters for mango processing waste biorefinery model.

Time parameters	Value	Financing parameters	Value
Analysis year	2017	Equity	100%
Project life	15	Depreciation method	Straight line
Construction period	30	Depreciation period	10 years
Start up period (Months)	4	Income tax	35%
Inflation rate (%)	4	Discount rate (%)	10

Operating parameters	Value	Construction plan	Value
Annual operating time (days)	180	1st year (% DFC)	30
Start up cost (% DFC)	5	2nd year (% DFC)	40
Salvage Value (%DFC)	5	3rd year (% DFC)	30

Courtesy: Industrial Crops & Products 116 (2018) 24–34

So, table 2, this gives us an understanding of the economical evaluation parameters of the mango processing waste biorefinery model. So, these are the time parameters. Analysis year, project life, construction period, then startup period (months 4), inflation rate 4%. Then we have financing parameters like equity, 100% equity here in this case. Depreciation method, a straight line depreciation method was used. Then depreciation period; here it has been taken to be 10 years. Income tax has been assumed as 35%.

It also varies every year, you know that. Discount rate have been fixed at flat 10%. So, then there are annual operating cost, start up cost, salvage value. And construction plan value like first year how much percentage, second year how much percentage, third year how much percentage, the construction also goes on but you start the operation at certain unit. So, it is an ongoing process. So, it has been assumed that within 3 year all sorts of construction will be over.

(Refer Slide Time: 34:37)

Table 3: Annual operating costs and material costs for mango processing waste biorefinery.

Item	Cost ($)	% contribution		
	PEP	PSEP		WMB
Raw Materials#				
1,194,267	1,261,406	1,402,431		
Labor	733,000	958,000		1,739,000
Laboratory/QC/QA	110,000	144,000		261,000
Consumables	161,000	161,000		274,000
Waste Disposal	17,000	6000		39,000
Utilities	4,782,000	5,213,000		6,569,000
#Raw Materials	Unit Cost#	Annual Cost ($)		
Raw materials	**Unit cost**	**Annual cost**		
		PEP	PSEP	WMB
Ethyl Alcohol	$0.75/kg	82,158	82,185	163,718
Hexane	$0.80/kg		15,149	15,149
Mango Peel	$25.0/MT	324,000	324,000	324,000
Mango Seed	$25.0/MT	756,000	756,000	756,000
Mineral Acid	$0.50/kg		216	216
RO Water	$5.00/MT			59,930
Potassium Metabisulfite	$1.50/kg		35,293	35,293
Water	$0.7/MT	32,109	48,563	48,225
		1,194,267	1,261,406	1,402,531

Courtesy: Industrial Crops & Products 116 (2018) 24–34

Capital cost of process plant

- The fixed capital cost (FCC) of the biorefinery plant with the base capacity (10 MTPH) was estimated to be $41.8 million.
- However, for PEP and PSEP processes, FCC was estimated to be $23.2 and $24.9 million, respectively. This is about 55–59% of FCC incurred by mango biorefinery process.
- The purchase and installation of a rotary dryer, extraction unit, storage tank, and centrifuges were the major contributors to the total fixed cost, which was the main contributor to the total capital investment.

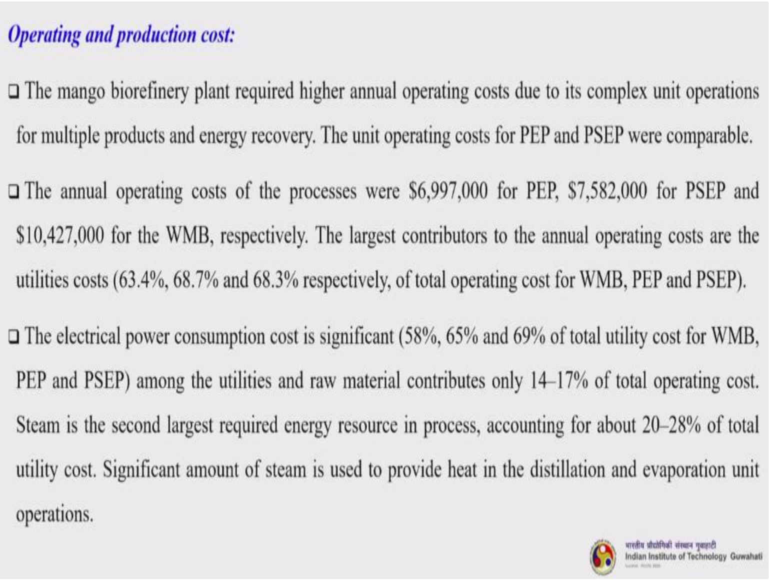
भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
Indian Institute of Technology Guwahati

So, then this table gives us an understanding about the annual operating cost and material cost for mango processing waste biorefinery. So, if you closely look, the costs are basically the raw material cost, labor, laboratory costs, consumables, waste disposal, utilities, all these things. So, if you talk about the raw materials directly as a component, so there is the ethyl alcohol, hexane, mango peel, mango seed, mineral acid, RO water, potassium metabisulfite and water, not much is required.

So, all these costs are tabulated here. So, the fixed capital cost of the biorefinery plant with the base capacity was estimated to be 41.8 million dollars. However for PEP and PSEP processes, FCC was estimated to be 23.2 and 24.9 million dollars respectively. This is about almost 55 to 59% of the FCC incurred by the mango biorefinery process.

Now, the purchase and installation of a rotary dryer, extraction unit, storage tank and centrifuges were the major contributors to the total capital fixed cost which was the main contributor to the total capital investment. So, this is basically the the instruments or equipment.

(Refer Slide Time: 35:48)

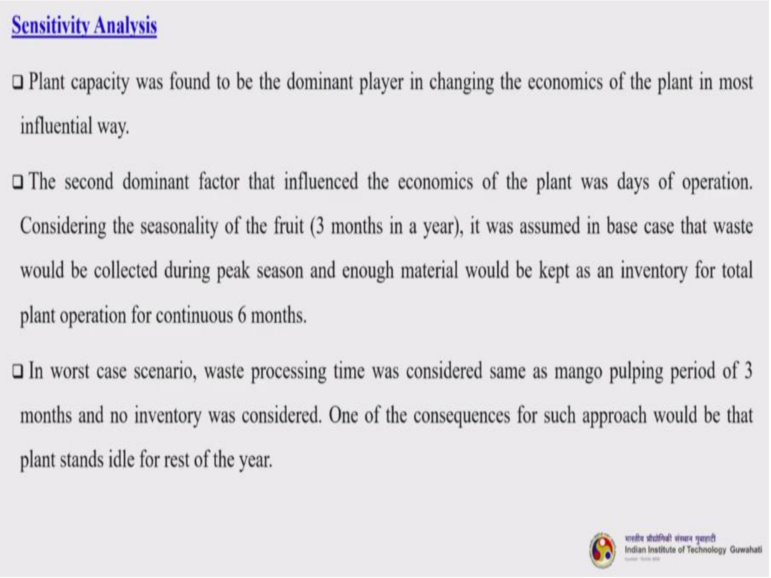


Then operating and production cost. The mango biorefinery plant required higher annual operating costs due to its complex unit operations for multiple products and energy recovery. The unit operating costs per PEP and PSEP are comparable. Now, the annual operating costs for the process were $6,997,000 for PEP; $7,582,000 for PSEP and $10,427,000 for the WMB respectively in dollars.

So, the largest contributor to the annual operating costs are the utilities costs, so that is almost are 63.4%, 68.7%, 68.3%. So, mostly they are comparable and they are of the same scale of the total operating cost. The electrical power consumption cost is very significant almost 58%, 65%, and 69% of the total utility cost for the different processes. Among the utilities and raw material contribute only 14 to 17% of total operating cost.

Steam is the second largest required energy resource in the process accounting for about 20 to 28% of the total utility costs. Significant amount of steam is used to provide heat in the distillation and evaporation unit operations.

(Refer Slide Time: 35:56)



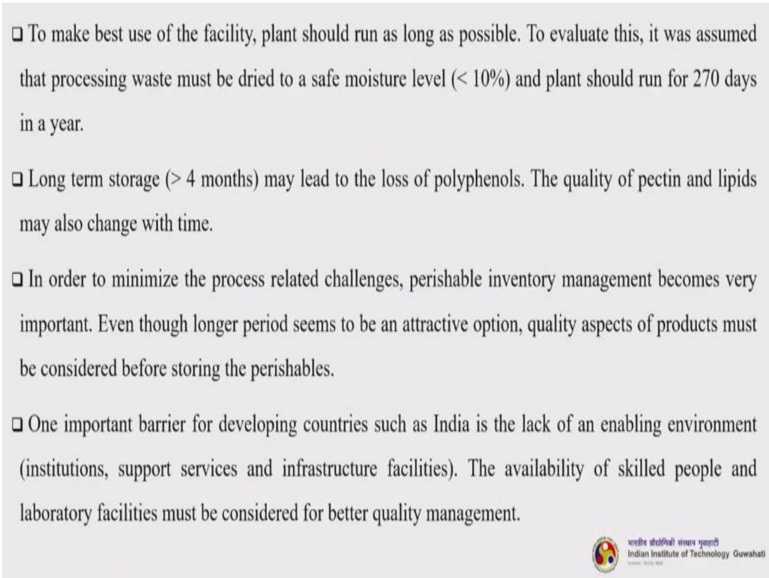
So the last one what I am going to talk about is the sensitivity analysis. Now plant capacity was found to be a dominant player in changing the economics of the plant in most influential way. The second dominant factor that influenced the economics of the plant was days of operation. Considering the seasonality of the fruit that is 3 months in a year (for the mango we are talking about), it was assumed in base case that waste would be collected during peak season and enough material would be kept as an inventory for total plant operation for at least continuous 6 months. In worst case scenario, waste processing time was considered same as mango pulping period of 3 months and no inventory was considered at all. One of the consequences for such approach would be that plant stands idle for the rest of the year, which is not good.

So, in this I wish to say something. So, we have discussed about biorefinery in detail. So many different types of biorefinery, different models, we have all discussed. Now, I hope you can understand that, why this particular plant will keep idle for 6 months; that is not sustainable. What will happen to the human resources that are engaged in this particular mango waste biorefinery?

So, there is a need to look for such other waste which can also be processed in the same type of equipment whatever we have already installed for the mango waste biorefinery processes. It is a very holistic thinking that you can run the plant for the entire one year. There is no question of any shutdown and sit for idle for 6 months. So that is anyway not going to become sustainable because once you shutdown the plant, starting it up is also a costly affair and it is a time consuming process.

So, refinery whether it is small scale, large scale must continue its operation throughout the year, 24 x 7; even if it is not 24 x 7 also. Then only it will become sustainable. So, the only approach is to look for other waste which can be processed in the similar unit operations, which are already installed for the mango waste biorefinery.

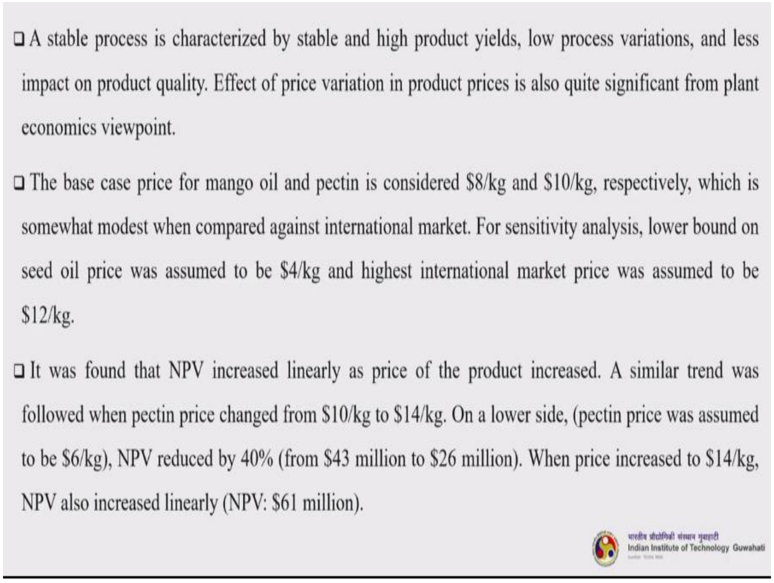
(Refer Slide Time: 39:02)



So to make the best use of the facility plant should run as long as possible. To evaluate this, it was assumed that processing waste must be dried to a safe moisture level, less than 10%, for the storage purpose and plant should run for 270 days in a year. Long term storage greater than 4 months may lead to the loss of polyphenols. The quality of pectin and lipids may also change with time. In order to minimize the processing related challenges, perishable inventory management becomes very important.

Even though longer period seems to be an attractive option, quality aspects of products must be considered before storing the perishables. One important barrier for developing countries such as India is the lack of an enabling environment, that is institution, support services and infrastructural facilities. The availability of skilled people and laboratory facilities must be considered for better quality management.

(Refer Slide Time: 39:52)

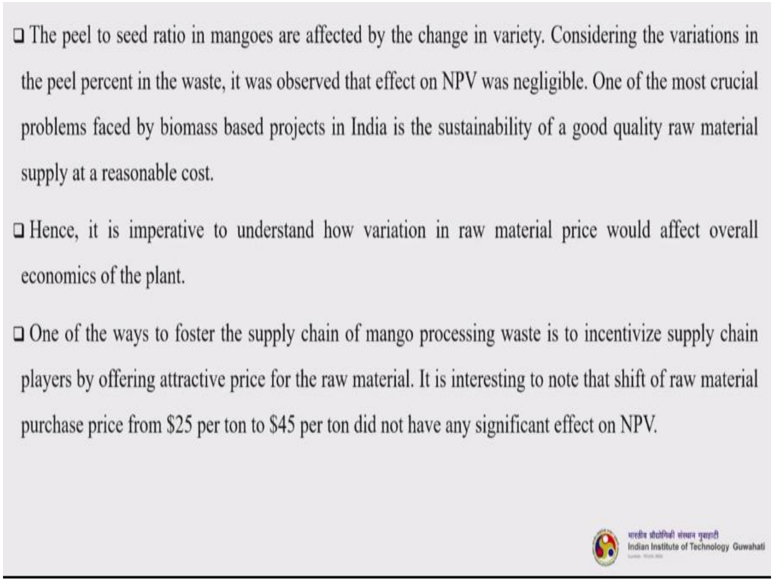


A stable process is characterized by stable and high products yield, low process variations and less impact on product quality. Effect of price variation in product prices is also quite significant from plant economics viewpoint. The base case price for mango oil and pectin is considered as 8 dollar per kg and 10 dollar per kg respectively, which is somewhat modest when compared against international market.

Now, it has to come down further, to make it more commercially successful products. Now, for sensitivity analysis lower bound on seed oil price was assumed to be 4 dollar per kg and the highest international market price was assumed to be 12 dollar per kg; that is quite offset, so that you can look for a very good profit. So, it was found that NPV increased linearly as price of the product increased.

A similar trend was followed when pectin price changed from 10 dollar to 14 dollar per kg. On the lower side, pectin price was assumed to be 6 dollar per kg, NPV reduced by 40%. When price increased to 14 dollar per kg, NPV also increased linearly, $61 millions. So, this is just an understanding about how it will happen when we talk about the sensitivity analysis.

(Refer Slide Time: 41:05)

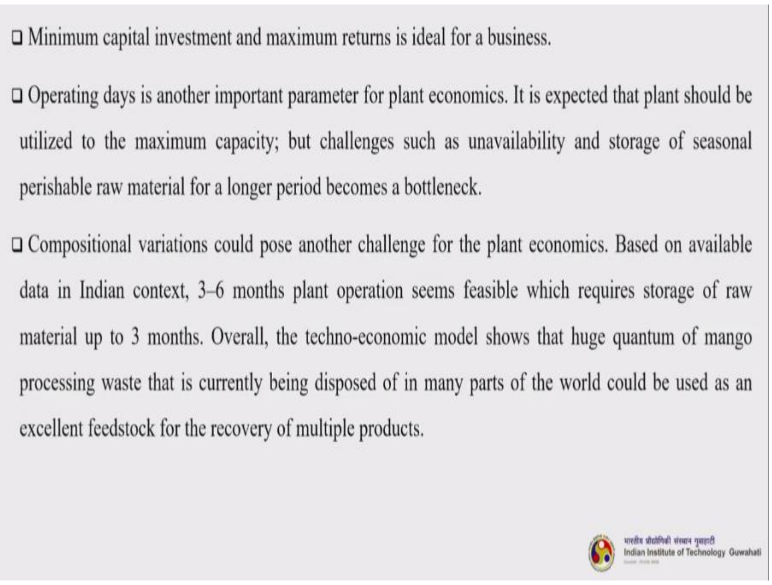


So, the peel to seed ratio in mangoes are affected by the change in variety. Considering the variations in the peel percent in the waste, it was observed that effect on NPV was negligible. One of the most crucial problems faced by biomass based projects in India is the sustainability of a good quality raw material supply at a reasonable cost throughout the year.

I have been telling this, that the supply chain management issue is the most important factor that should be tackled or looked into before anybody starts any biomass based biorefinery anywhere in India. So hence, it is imperative to understand how variation in raw material price would affect overall economics of the plant. One of the ways to foster the supply chain of mango processing waste is to incentivize supply chain players by offering attractive price for the raw material.

It is interesting to note that shift of raw material purchase price from 25 dollars per ton to 45 dollars per tonne did not have any significant effect on the NPV. I hope you get a message and understanding that how this economical evaluation is basically being carried out, what are the typical cost, capital cost, operating cost? So, I deliberately chose a short case study so that we can quickly understand. There are very excellent works reported in literature. If you are interested, you can just download and read more into that.

(Refer Slide Time: 42:29)



So minimum capital investment and maximum returns is ideal for a business. Operating days is another important parameter for plant economics. It is expected that plant should be utilized to the maximum capacity, but challenges such as unavailability and storage of seasonal perishable raw material for longer period becomes a bottleneck. So, this is a bottleneck for any biomass based industries.

Compositional variations could pose another challenge for the plant economics. Based on available data in Indian context, 3 to 6 months plant operation seems feasible which requires storage of raw material up to 3 months. Overall, the techno-economical model shows that huge quantum of mango processing waste that is currently been disposed of in many parts of the world could be used as an excellent feedstock for the recovery of multiple products.

So, as I told you many times unless and until in a single biorefinery you look for multiple products, then your biorefinery is not going to become sustainable and economical.

(Refer Slide Time: 43:27)

(Overview of next lecture)

Module	Module Name	Lecture	Title of Lecture
12	Integrated Biorefinery	04	Life-cycle assessment

Thank you

For queries, feel free to contact at: kmohanty@iitg.ac.in

So, I hope you get an understanding about what is the techno-economical evaluation analysis is all about. In our next class. I will talk about the life-cycle assessment and then we will close the course. And thank you very much. And if you have any query, you can always drop a mail to me at kmohanty@iitg.ac.in or please register your query in the Swayam portal, we will answer it. Thank you.