Energy Resources, Economics, and Sustainability

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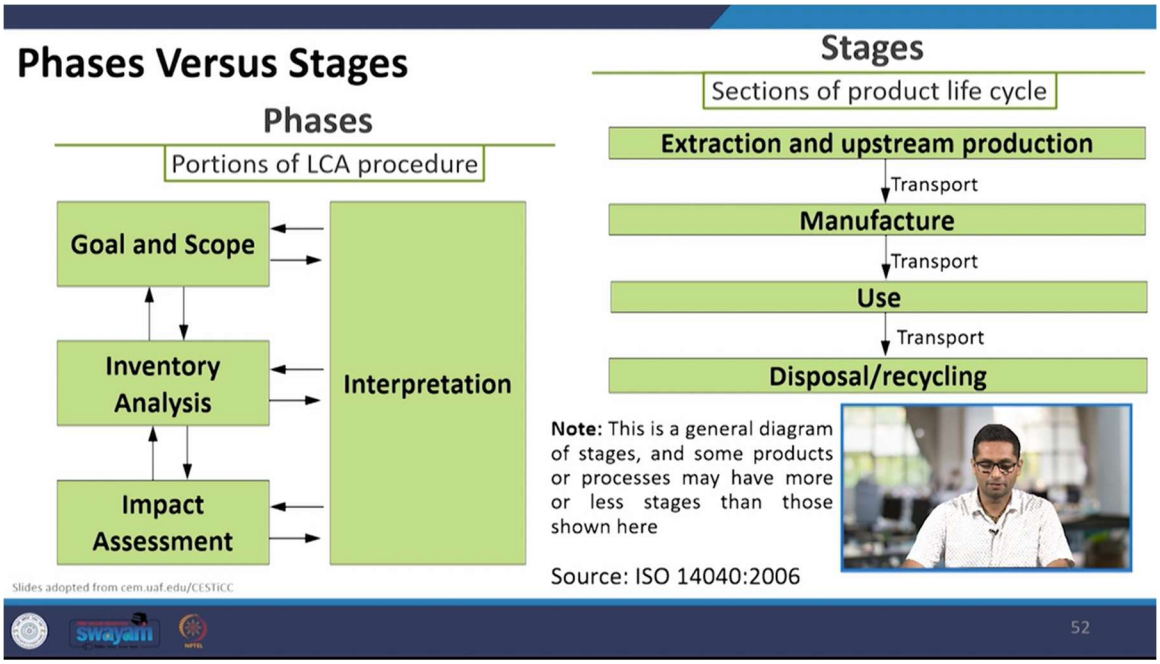
Week – 07

Lecture – 05

Lecture 36 - LCA: Life Cycle Stages

Hello everyone. Welcome to the course Energy Resources, Economics and Sustainability. We are in the process of discussing the integrities of the life cycle assessment process. In the last class, we tried to understand the concept of system, system boundaries and allocation. How these three things can make a lot of difference on the results that we derive from the life cycle assessment process of any particular process or product. We will take this discussion further and in today's class, we will try to understand which are the major life cycle stages that needs to be given due consideration when we are doing an LCA. Let us go through this.



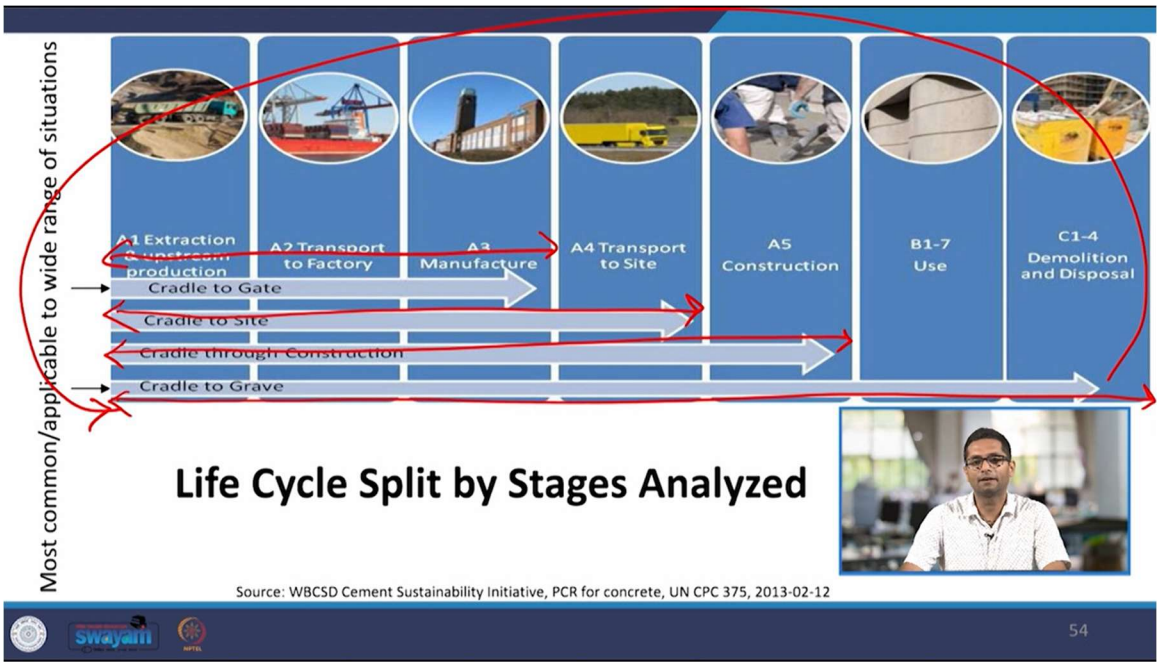
As we have discussed in the initial few classes that the complete LCA process would be divided into different phases and stages. When I talk about the phases, it basically deals with the four main phases which are the goal and scope, inventory analysis, impact

assessment and interpretation. These are the four phases which are needed in any LCA study. If I go over the stages, this could be different for different LCAs. The major stages that one might consider in a typical LCA would include the extraction, the manufacturing process, the use phase as a disposal phase and linking them would be the transportation phase. In this particular lecture, we will be discussing these different stages in much more detail.

Let us take the example of a typical construction company or construction of a building. So if I go with the guidelines that are available for the LCA of construction of building, these are the stages that are of major concern. The first one goes as the extraction of raw material. So you would want to extract the raw material which will be used for constructing. Then this needs to be transported to a factory. The factory would convert many of these raw materials into the elements that would be used for production of buildings or similar civil structures. An example could be the bricks that are manufactured, the wooden material that is manufactured, the different kinds of steel or different kind of billets that might be used in a particular home or a building construction.

Finally, this essential elements for construction would have to be transported from the manufacturing company to the construction site. Finally, the construction happens. Once the building is constructed, it would be heated and cooled, lit up and used and for plenty of years and when the useful life of a particular building would be over, this would be demolished and disposed of. So this is how the aspects or the different stages that would be involved in the lifespan of a typical building. It starts from the extraction of raw material, conversion to transportation to facility, conversion of these raw materials into key elements that are used for construction, transportation of these key elements to the

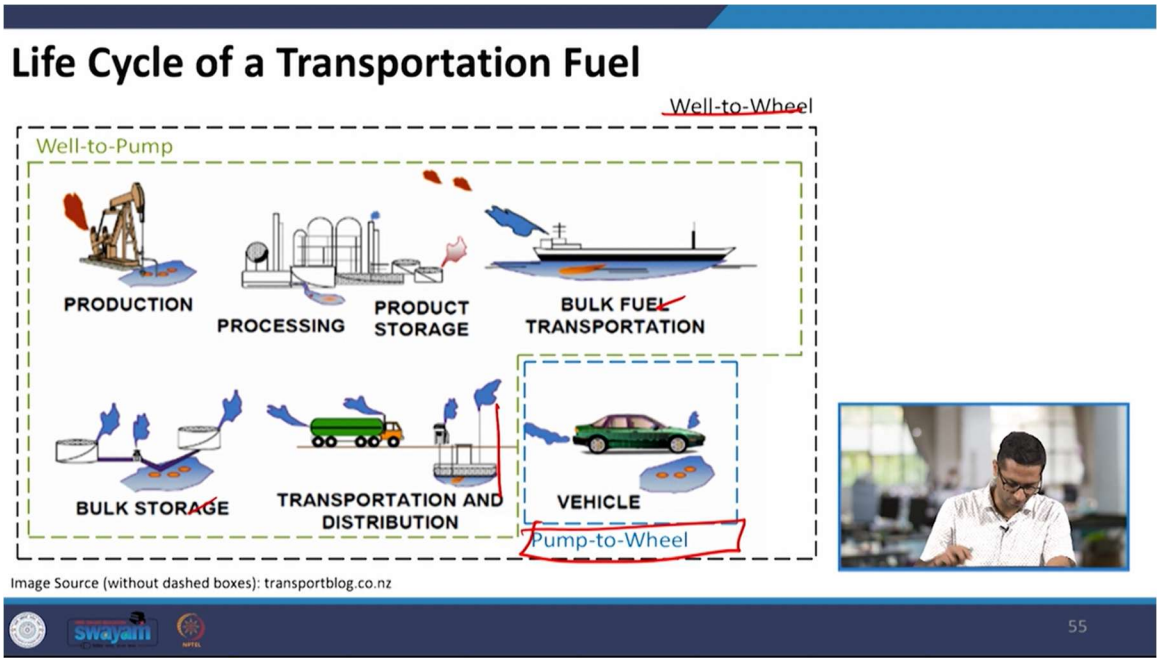
construction site, building, the construction of the building altogether, the use phase of the building and finally the demolition or the disposal of the building.



And if I consider this kind of lifespan, there could be different kinds of system how this could, that could be adopted. And a typical system boundary could be called cradle to gate where I am just concerned about building of the key elements for the building manufacturing process. Suppose I am only concerned about the emission that are associated till we are making the bricks or till we are making the wooden pieces that we are using into the building or till the place we are using it for nuts and bolts, the steel nuts and bolts that might be used for the manufacturing process and that kind of approach is called cradle to gate. So we start with the cradle which is extraction of raw material and end at the factory gate till I have the manufactured process being there. A step further could be the cradle to site where we are also taking into account the transportation of these key elements till the construction site and this is what is called the cradle to site approach.

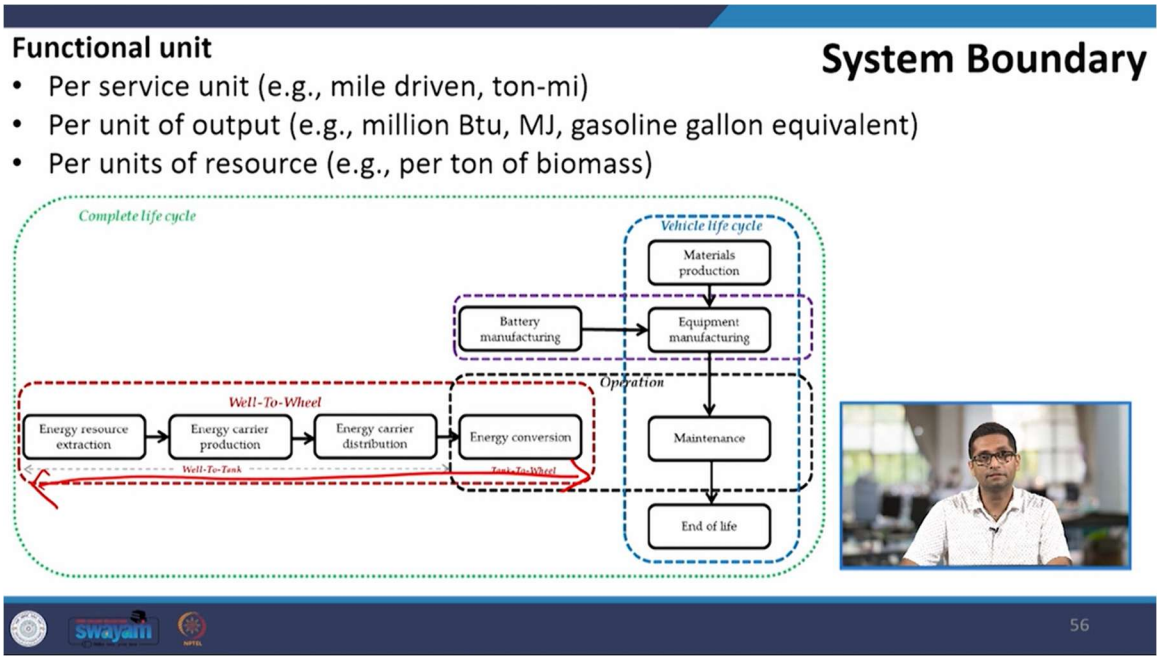
Way further would be like cradle to construction where we are also taking into the construction phase into approach where we are taking into account all the energy that might be going into the lifting of the different raw materials, the construction phase. But we are no longer concerned about the use phase and the demolition phase. A much more comprehensive approach a step further would be where we are also considering the use phase as well as the demolition and the disposal of the building under consideration and that is what will be called the cradle to grave. And these are normally used terminologies that you are going to come across when you are going through an LCA or you are conducting an LCA for any particular product or process it can go by the name cradle to

gate, gate to gate, gate to grave some of like where you are like going from the factory gate till the disposal of a particular product. There are also studies which are now taking into approach which is called cradle to cradle which is basically stemming out from the circular economy approach where the disposal of a product leads to the further production of the raw materials and that approach is called cradle to cradle approach. But if you go about a typical LCA cradle to grave and cradle to gate one are the most used ones but there are many different notations that are attached to it.



Further we could have slightly different terminologies for different industries. Take for example the fuel industry in terms of the vehicle fuels that is being produced they use a slightly different terminology in the terms of well to pump where the processes that they would be concentrating on would be coming from production, processing, transportation, bulk and till the dispensing center which could be the oil petrol pump. They are not concerned about how the petrol is getting used in a particular vehicle what they are really concerned about in the filling station of the petrol pump from the production process. This is what is called the well to pump approach. In addition to the well to pump approach would be the pump to wheel approach where we have filled in the different kinds of fuel into the vehicle and we are normally using this fuel and this particular type of emission would be the pump to wheel where we are not concerned about how the fuel was produced or what are the factors that are associated with the production of the fuel. We are just concerned about the emissions that are coming from basically the tailpipe of the vehicle. I combine these two and what I get is the well to wheel approach which is basically analogous to the cradle to grave approach as we have studied in the previous example and this is the kind of terminology that you would normally come across when you are reading an LCA which deals with the production of different kinds of fuels. Also

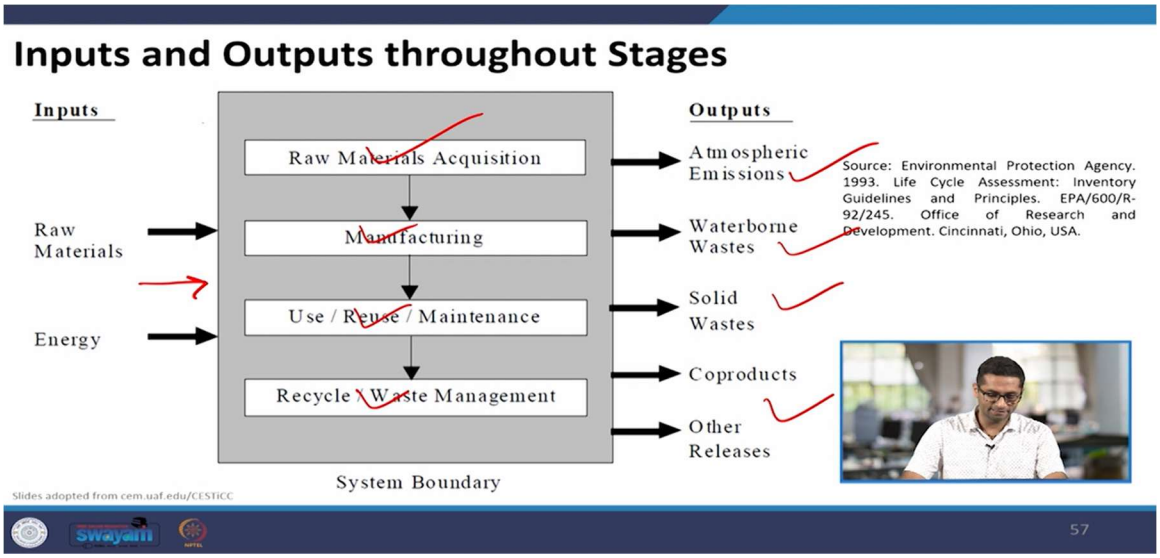
if you remember one of the initial few classes where we were doing the energy supply chain analysis we used a similar terminology where we were discussing the efficiency of different hydrogen based fuels in terms of the well to pump and well to tank and tank to well. So, there we have used the term well to tank and tank to wheel and well to wheel. So, that is again something analogous that we have discussed in the initial few classes.



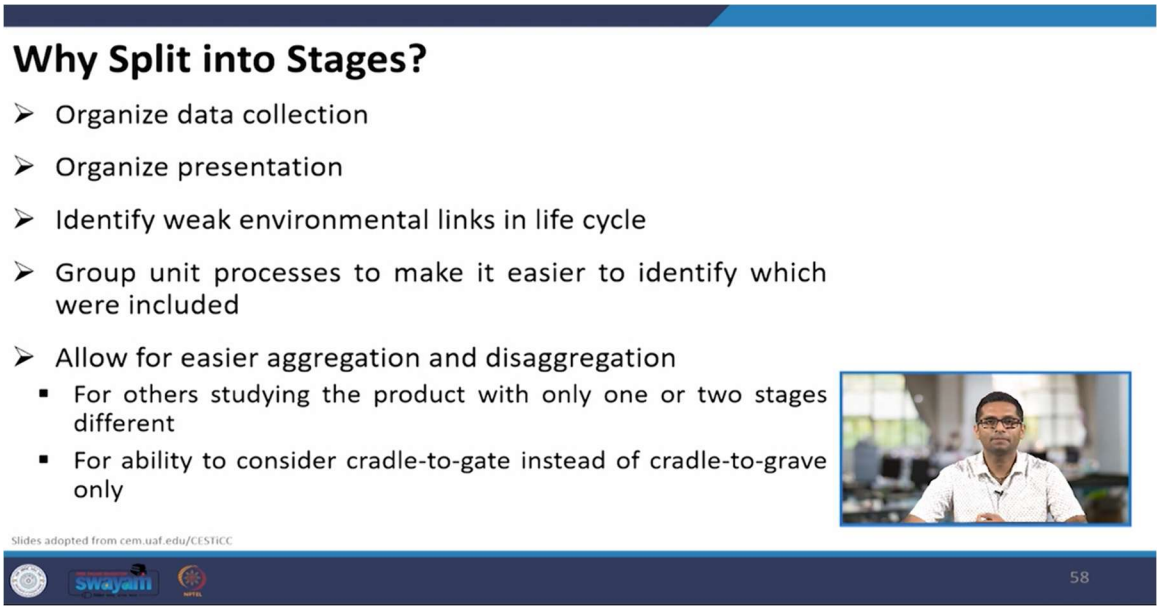
Further when we are dealing with an LCA in the transportation sector there could be different aspects to it. One is could be the life cycle of the fuel that is being consumed by the vehicle. So, if I am taking for the example or typical life span or we are considering LCA for an electric vehicle there could be two ways of looking at it. One could be the energy that goes into the electric vehicle for moving the electric vehicle.

Another aspect could be the vehicle life cycle itself, the manufacturing of the vehicle, the manufacturing of the battery which could have key emissions, the maintenance and the end of the life. Further if you are just talking about the operations it could be the conversion and the maintenance one. So, there could be different interlinkages for the same kind of product that we are focusing on. So, that needs to be taken into account when we are considering the LCA because there might be many life cycle assessments that you might be coming across which are comparing IC engine vehicles with EVs. But it needs to be understood what type of life cycle these studies are actually considering.

Are they just considering the fuel part or are they also considering the vehicle manufacturing part because the results could have very serious implications.

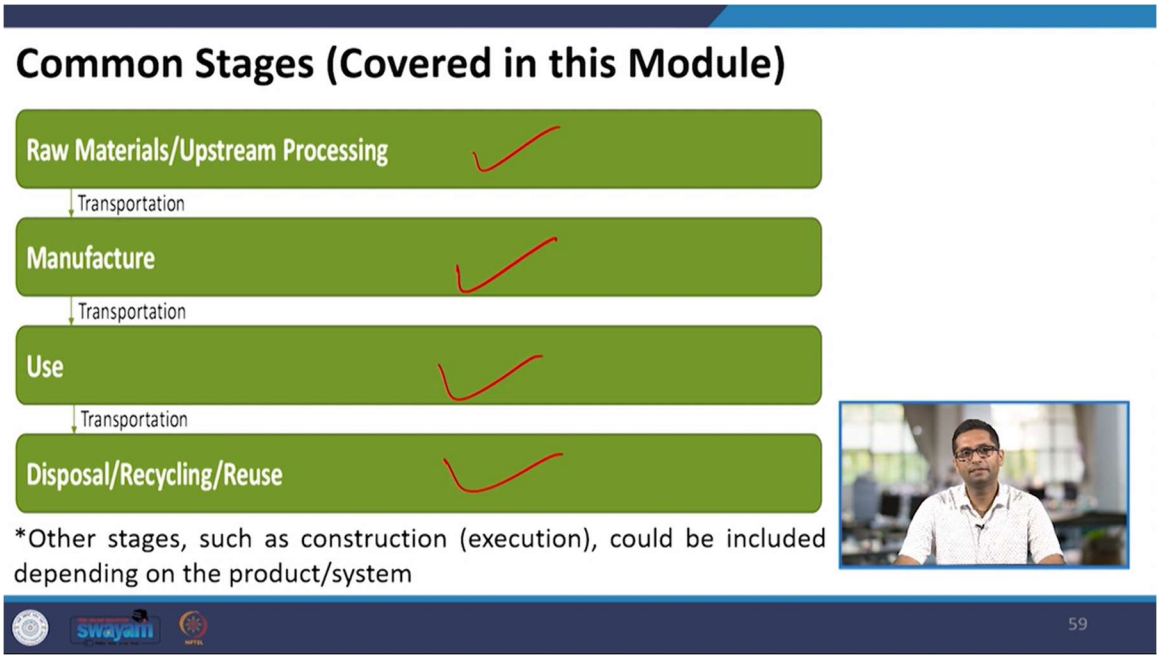


Then I have just included this diagram because this is a part of the like this is a very often used diagram for representing the LCA of a typical process. So, here in what you see is that the different stages coming in a series. So, normally you would have the raw material acquisition, you would be manufacturing finished products, you would be going through a use or a use phase and finally it could be disposal or the recycling. And what comes on into would be the different elements from the nature of the technosphere which are normally the parallel flows. This could be going to different processes and then we also have a lot of parallel flows in terms of the emissions that might be bound to the atmosphere, to the water, it could be solid waste, the co-products. So, what is happening here is we have in series the flow of the raw materials till the final products which are disposed of and in parallel we have the different flows entering in terms of raw materials and energy and different kinds of emissions exiting in the outputs.



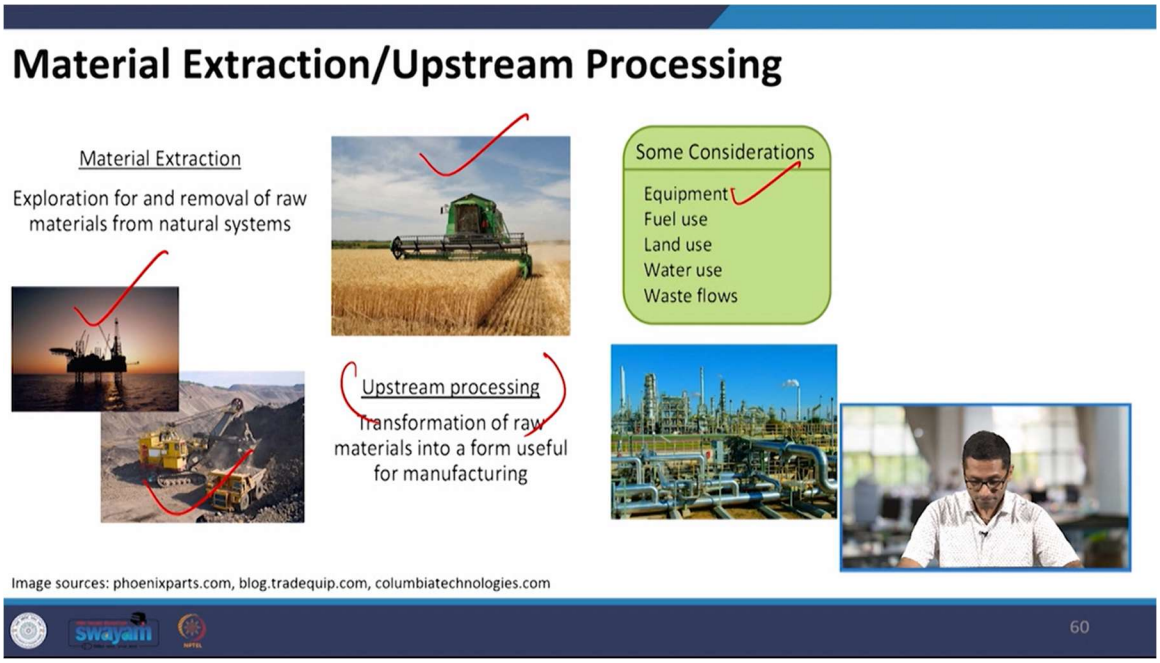
So, one would ask like why do we really need to split the process into stages. One thing is that it helps us organize the data in much orderly manner. We know like what are the kinds of inputs as well the emissions coming from which part of the life cycle of a product.

So, basically if you would want to highlight the hotspots like this is the hotspot that needs to be taken if you want to make a particular process green, we are knowing that. Further it might happen that like there might be other studies which we would want to compare it and there would be studies which are using a different system only maybe cradle to gate or gate to grave. So, if we are giving the process in terms of breaking down the process in terms of different stages, it would be easier for us to see or see your LCA in terms of smaller system boundaries and make it much more comparable to the other LCA that are there. So, it helps us in decreasing the resolution of an LCA and it also helps us other researchers that might be wanting to take a few elements from your LCA. So, it might happen that some other researchers are working on a similar LCA and some of the studies that they are doing have an overlapping system boundary. So, they might want to adopt some of the inventories that you have calculated or you have used and if you have used systems approach where you have broken down the system into small small stages, it might be helpful for their study as well.



So, let us now try to cover this particular module in much more detail. So, like if what we will try to understand is like try to understand what are the kinds of processes or being considered as raw material phase, the manufacturing phase, the use phase and the disposal phase. There could be apart from that there could be a significant amount of transportation that is being taking place. So, we will be considering the transportation

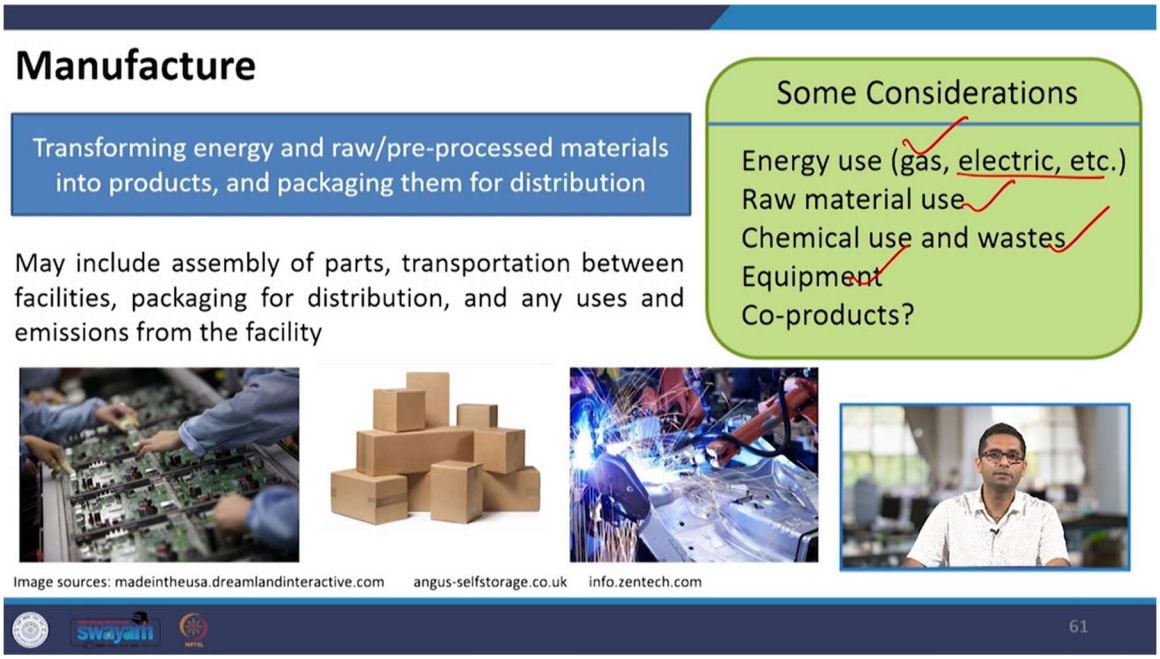
altogether and beyond this there could be some processes which could have phase of say like construction of the machinery that is being used. So, again it might be significant in some cases and might not be significant in others. So, and that could be taken care on the case to case basis.



So, let us start with the material extraction or the upstream processes. So, this would normally be coming in when you are taking any LCA that starts from the cradle. It basically involves the extraction of the raw materials. The typical examples could be extraction of crude from the oil wells, it could be the mining operations for the extraction of coal or other similar metals that might be used in the process or it could even be the harvesting of the different crops that go as in raw material to a lot of as an input from the nature. It might also include some kind of upstream processing. So, for the example the crude that we extract needs to be refined into the different grades of fuel. So, in that case this would be coming into the upstream refining. Further the ores that we are extracting from the mines might need to be converted into different usable metals and these metals would then be converted into different kinds of end products in the manufacturing process.

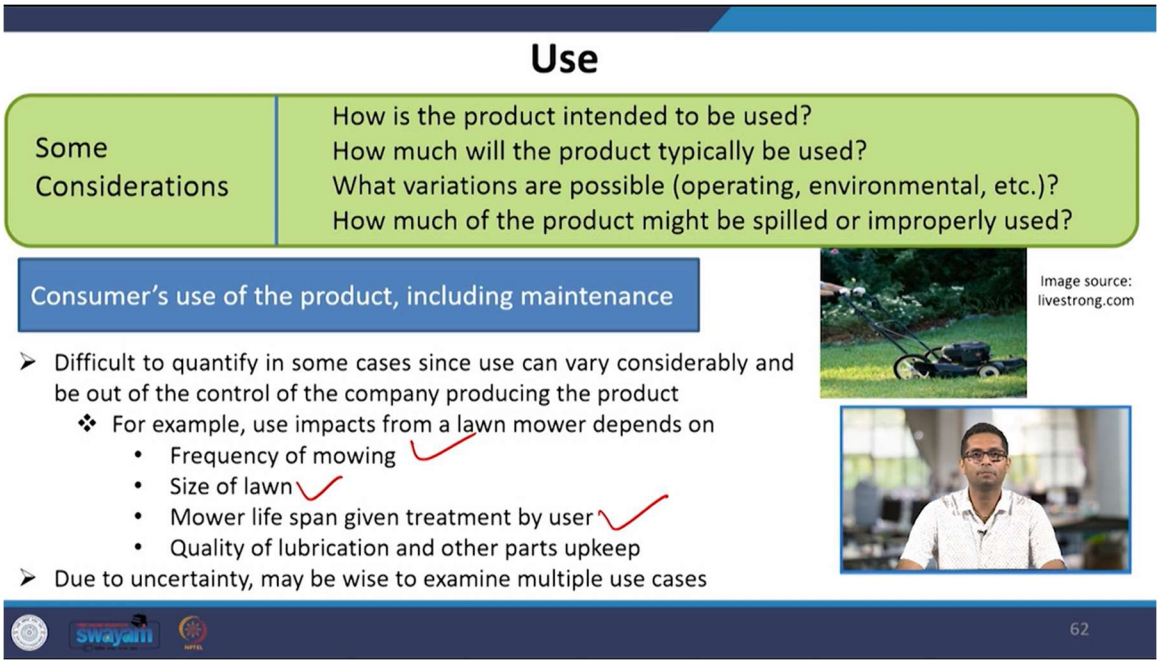
So, you would be considering all this in the upstream processes. So, some important considerations that might be given, that should be given due importance should be the equipment that might be used for these kinds of extraction of raw materials because in some cases that could have significant emissions. There would be a significant amount of fuel that goes or the energy that goes into the production of these kinds of raw materials that needs to be taken into account. Land use could be a significant feature when we are dealing with biomass or any of the feedstock that are coming from the harvesting. This

also entails there could be significant water intake for these kinds of agricultural products. Similarly, water could be also be a significant input if we are considering a process like fracking for the production of oil or gas and we should not neglect the waste flows that goes out of it.



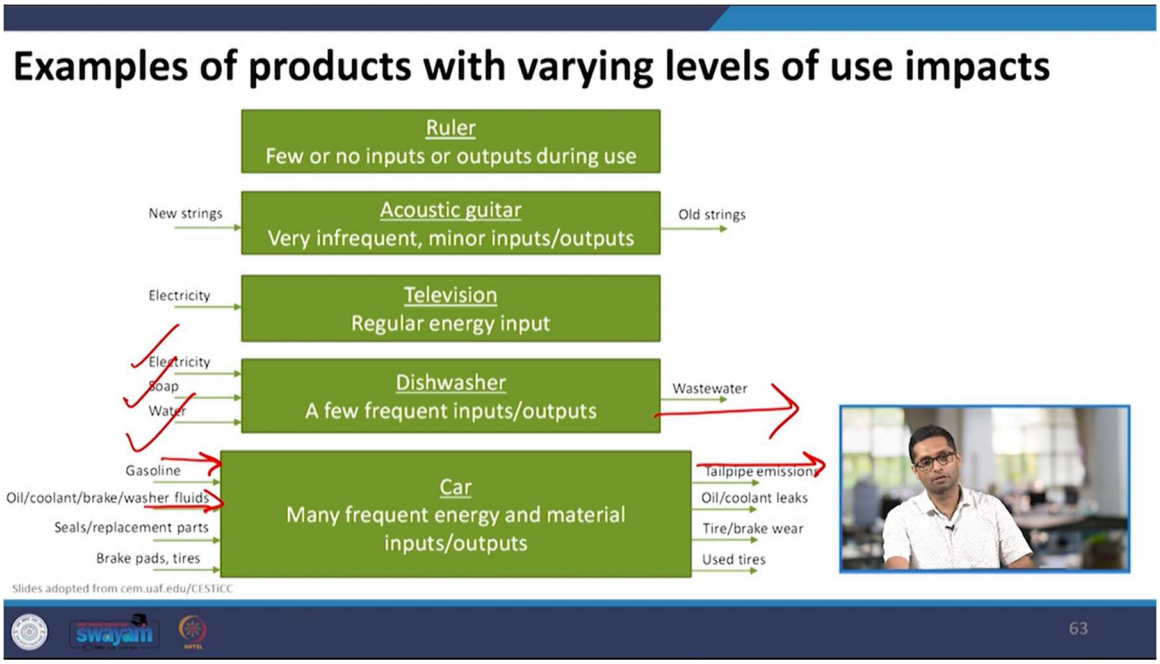
The next step that would normally be coming after the raw material would be the manufacturing phase. So, if I talk about the manufacturing phase it is basically transforming the energy or the raw materials into products and packaging them for distribution. So, this is what is happening in majority of industries. You would have the raw materials coming in and that is being put up into the end products.

A typical example could be coal fired power plant. So, you would have coal going in and what you get is electricity and finally the manufacturing process in that case would be the power plant itself. And further there could be other facilities like the battery manufacturing plant which would have the raw materials in terms of lithium and other kinds of like balance of plant going in and what you get is a finished product in the form of a battery. So, but all this would entail a use of good amount of energy which can come from different sources like it could be electric, if it is heating it might come from gas, the raw material use and there might be certain kind of chemicals or catalyst that going into it. There could be sophisticated equipment that needs to be manufactured and at this point we should also be taking care of the co-products. So, from any manufacturing facility there could be a couple of co-products that can be coming out and it becomes important to allocate the emissions among the different co-products.



Further what comes after the manufacturing phase is the use phase which might not be a part of many LCA because they would just want to consider from the cradle to the gate, the gate of the factory. So, till they manufacture the final product they are no longer concerned how the product is used. A typical reason why people would not take into account the use phase is because of the complexity and the variation that is involved in the use phase. Because a lot of considerations would involve like how the product is used and how much the product will be used in terms of the frequency of the product.

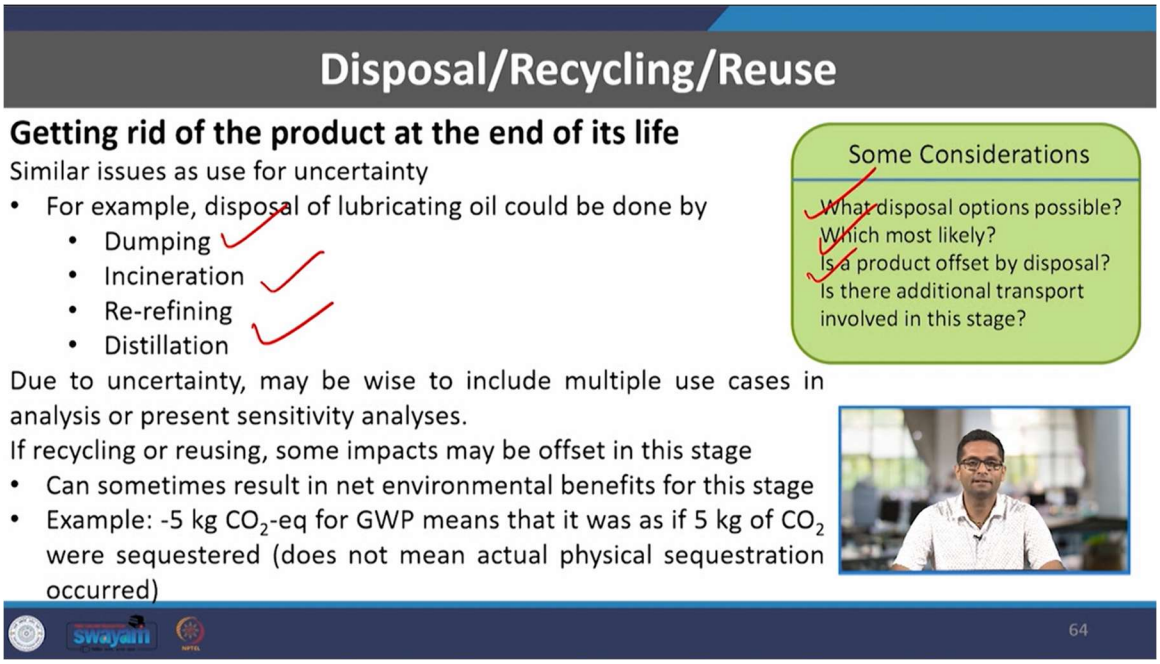
There could be different kinds of variation that can come from the temporal or the spatial aspects and then there could be different kinds of malfunction that might occur based upon how the product is used and that might entail different kinds of emissions happening. Take for example the case of a lawn mover, a typical lawn mover, the life of the lawn mover which is used for cutting grass in a park might depend upon how frequently you are using the lawn mover, what is the size of the mover, what is that or like how is the person handling the lawn mover, is he or she handling the lawn mover with much more care, are the lubrication and the other upkeep provided on time or not. Because this would basically decide how good the lawn mover could be moving throughout its life cycle. And because of this uncertainty that is involved, normally it is prescribed that you have multiple cases in the use phase because based upon the place, the time and the different persons who would be operating a particular equipment or a process, this could be highly variable.



So once you have, also it needs to be understood that like different products could have very different levels of the inputs and outputs that can go in the use phase, this could be very different. So what do they take for the example of a typical ruler or scale which we use for measurement, it would have no input and output that goes into it throughout its life cycle. Compare that with an example of an acoustic guitar. So what would be a typical input and output? It would be the new strings that would be using for changing and when you are changing the strings, you would be normally disposing of the old strings. So that is the only input and output during the use phase of an acoustic guitar. Consider the case of a typical television, the only input that goes is in the electricity, you would not expect an output or a tangible output in terms of material flow to come from a television.

Compare that with a dishwasher. So what goes into a dishwasher or a washing machine for that example would be electricity, some amount of soap, water and what goes out is wastewater. And this could be a typically complex for a system or an energy based system say for example in a car, we would have the gasoline going in and the amount of gasoline would depend upon how you are driving the vehicle or your upkeep, what is the mileage the vehicle is able to give you, how good are you at driving and then there could be different quantities of oil, coolants that go into it and there could be further some seals and replacements and then there would be the brakes and the tires that would be going as wear and tear off. So what you have is a tailpipe emissions, so where you get the carbon dioxide, the SOX and the NOx emissions, then you would also have the oil and the coolant that might leak every now and then, there would be tires and brakes which might turn into the particulate metal and then there would be the used tires which would be disposed off. So as we are increasing the resolution you would have the amounts of

inputs and outputs during the use phase increasing at a very fast rate. This is typical for any energy related process or product that we would have multiple inputs and outputs and they need to be quantified quite extensively.

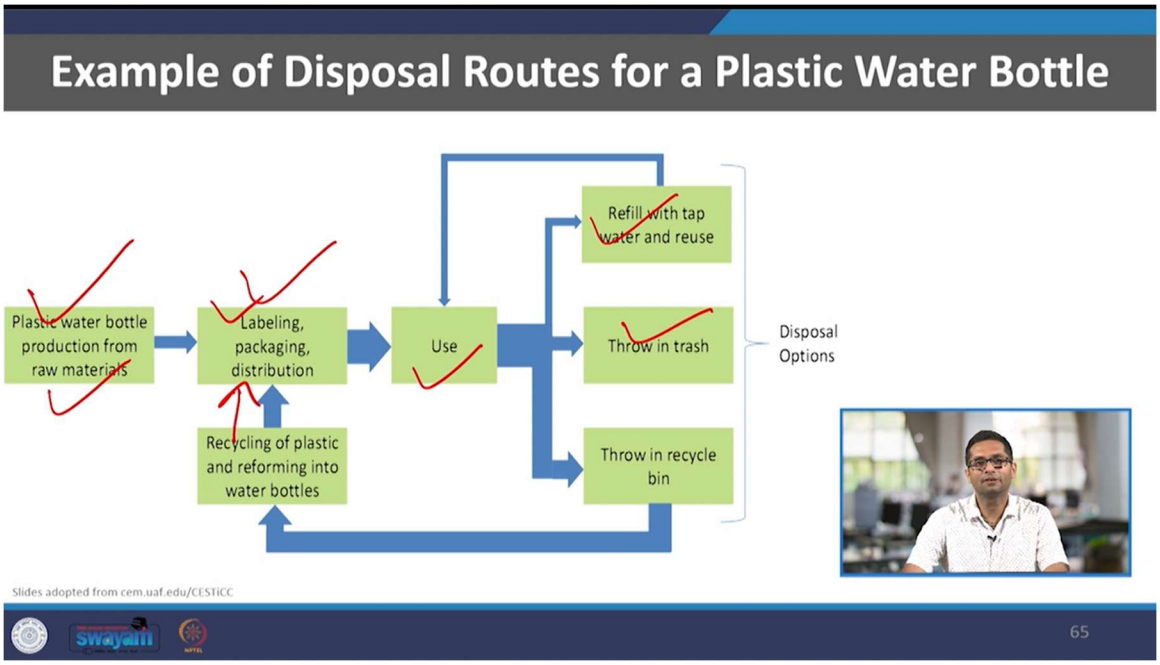


Further another aspect that becomes important is the disposal, recycling or the reuse. So what happens when you have used a particular product or the process ends? So normally you would want to dump that and not many people would get emphasis from the emissions that might come in or that might jump in from the dumping process. So suppose take the example of the lubricating oil that you would be using in your 2-wheelers or the 4-wheelers. So after you are changing the lubricating oil after every year or maybe 2 years, what do you normally do? There could be difference in like who is using it.

A lot of people would want to dump it. Then those who might be much more environmentally friendly and much more informed would want to dispose it as per the guidelines where this oil might be going to an incinerator and being used for energy production. It might also happen that there are re-refining facilities available where this oil could be re-refined into further usable products in terms of the recycle and distilled back. And again because of the uncertainty because every entity who would be using would have a very different aspect and this would change with the different countries, the different states and these kind of strategies will also change with time. So suppose there is a policy that comes in after 2 years or 3 years that you would have to dispose of the lube oil mandatorily by a certain procedure. This might change the results. And what normally happens when you recycle or reuse the products, you would offset the emissions that would have normally come in from the business as usual case. So you might be

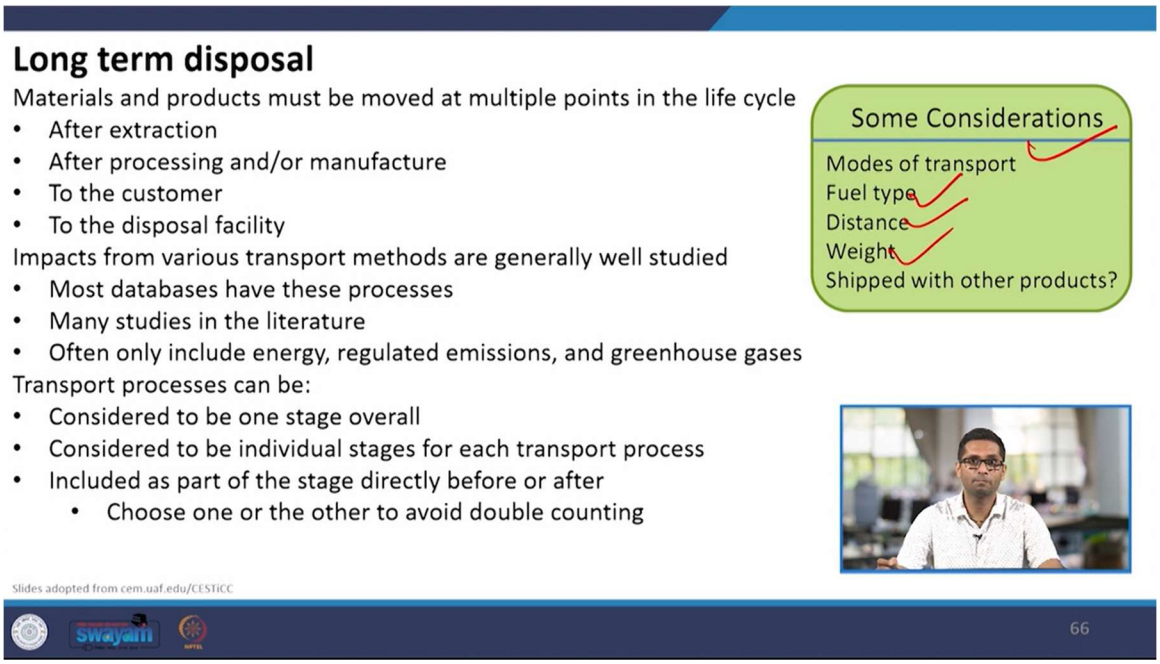
decreasing the production of a lube oil that is coming from crude. So in that case the emission that result might be negative in nature. Take for an example like suppose I am recycling this lubricating oil and it so happens from this particular process aspect my emissions would be minus 5 kgs of CO2 equivalent. So that does not mean that I have taken in 5 kgs of CO2 from the atmosphere and sequestrated in into the oil or any other thing.

It is basically a way of representing that if I would have not gone for this recycling practice, this 5 kgs of CO2 would have ended up in the atmosphere either by the degradation of this product or by the production of new product that is being formed from a fossil abuse source. So some of the considerations that needs to be given or that needs to be discussed is like what are the different disposal options possible because there could be many of them which are the most likely ones. Is there a product offset? Are we able to replace some of the conventional practices and in turn able to reduce some of the emissions? And will there be any additional transportation involved in this or any additional energy involved in this? Because if there is an additional energy that should be lesser than the energy that is involved in the production of original product itself.



So again the disposal routes could be very varied. Take for example in this case where we have seen the different disposal routes for a product a typical plastic waste bottle. So if we consider the life for a plastic bottle it can come from the production of raw materials which are again coming from crude sources. Then there would be labeling, packaging and the distribution for the water bottle. You would drink water and this is the use phase. So once you have used it there could be 3 options available to you. One is you can throw that in the trash and that eventually ends up in the landfill or in the ocean bodies.

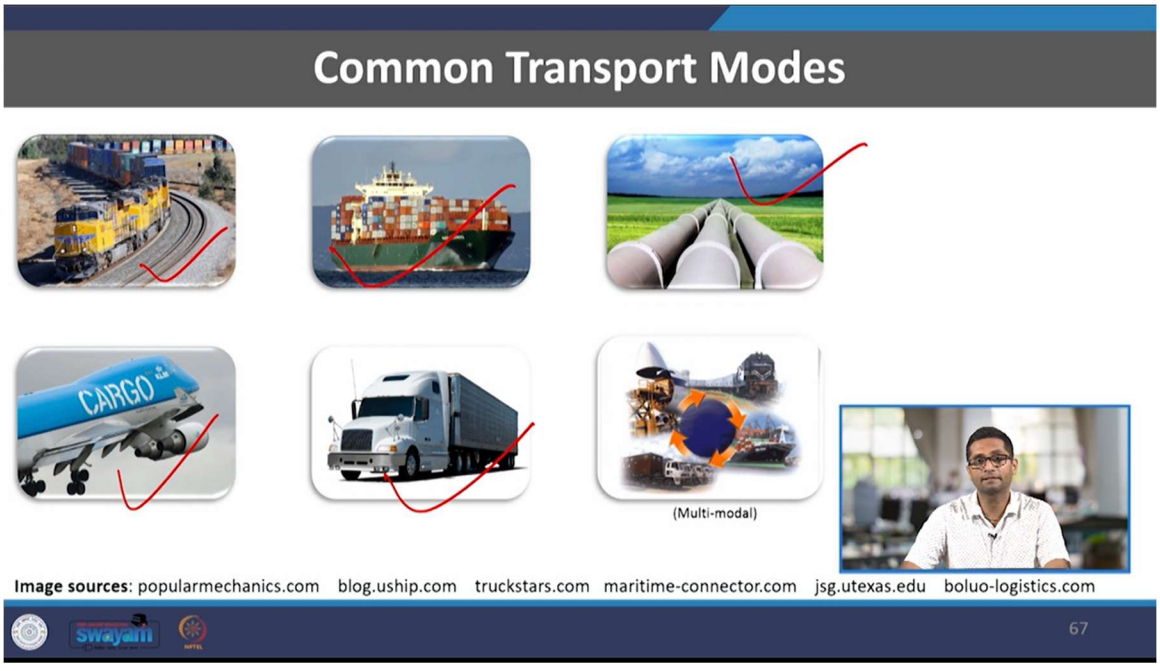
Then the other option could be you take it in your home and use it for drinking purposes every now and then. So you would refill the tap water into it and then reuse it. And then there could be a recycling facility that is available and where you would want to send this bottle and which it will be recycling the plastic bottle and taking back to the packaging in the distribution center. So what we see or we understand here is the different recycling options could be replacing different unit processes in a life cycle. So whereas if we are just reusing the bottle we are avoiding 2 different steps which is the production phase as well as the packaging, labeling and distribution phase. If I am going by the recycling phase I am just able to avoid one process. So different pathways could have different emission profiles in the terms like there could be different types of processes that could be avoided. And further the most common one or the methodology that might not be very appreciable would be like throwing the plastic bottle into the trash cans. And further we have tried to like this figure also shows with the typical flows like it is in the form of a Sankey diagram where you see the width of the flow also indicating the amount of material. So normally in LCA you can do a certain amount of distribution to come up with a much more realistic outlook that you can make an assumption that a certain percentage of the plastic waste would be recycled back, a certain percentage could be reused and then a certain percentage could end up in the waste bins.



Then it also needs to be understood with respect to the long term disposal. So well it might happen that the materials and the products needs to be transported a lot before throughout life cycle and this transportation can happen in different ways. It could happen at the extraction phase between the processing facilities when the finished products are going to the customers and also to the disposal facility. And what normally

happens is like because we are using transportation it entails that we are using a lot of fuels it could be coming from varied sources and whenever we are using fuels there would be associated emissions and this is something we need to take into account. Many people would want to associate the transportation along with some of the major features like they would associate the transportation with the raw material as well as transportation with the manufacturing facility so that they need not consider transportation as a separate entity.

But again this needs to be kept into mind that the assumptions to be consistent whenever we are taking transportation if it is clubbed with a prior or the following process that needs to be consistent throughout. And it also needs to be understood like what are the different modes of transportation that we would want to consider, what could be the different kinds of fuels that would be used because the transportation market is changing at a very fast pace, what would be the typical distance that is travelled by the transportation. It might happen that the trucks or the containers that might be used for transportation might be coming empty in that case the transportation has to be used two way. What would be the typical weight that we would be using and what if like the materials are transported with some other entities where the emissions could be allocated between the two like if there are other products being transported and how would the emissions be allocated.



So some of the typical ways in which transportation needs to be accounted is the transportation using the trains. Then there could be transportation using the marine transportation, the cargos, there could be transportation using the pipelines, there could be the cargo ships, there could be trucks, lorries and then there could be certain

transportation will take into account a combination of all these things. So these are some things that should not be neglected while doing an LCA because again this could add in significant emissions. Take for an example like when you are transporting natural gas through pipelines the typical like emissions from this kind of transportation could vary between 5 to 20% of the content of the natural gas and natural gas being a potent GHG gas it could have significant emissions in the transportation aspect itself. And further like these emissions are normally coming from the databases which we will be discussing in the next class there are certain amount of databases which would keep track of the different emissions that come from different transportation options in different countries and you might want to adopt some of these databases when trying to quantify the emissions that come from the transportation phase. So with this in this particular lecture we have tried to understand the different stages that are involved in the life cycle of a typical product and process and these are the processes which will be typical for any energy production process as well.

We will try to understand what is of importance and what needs to be taken into account so that we can form a much more informed system boundary. So with this we end today's class. Thank you.