Energy Resources, Economics, and Sustainability

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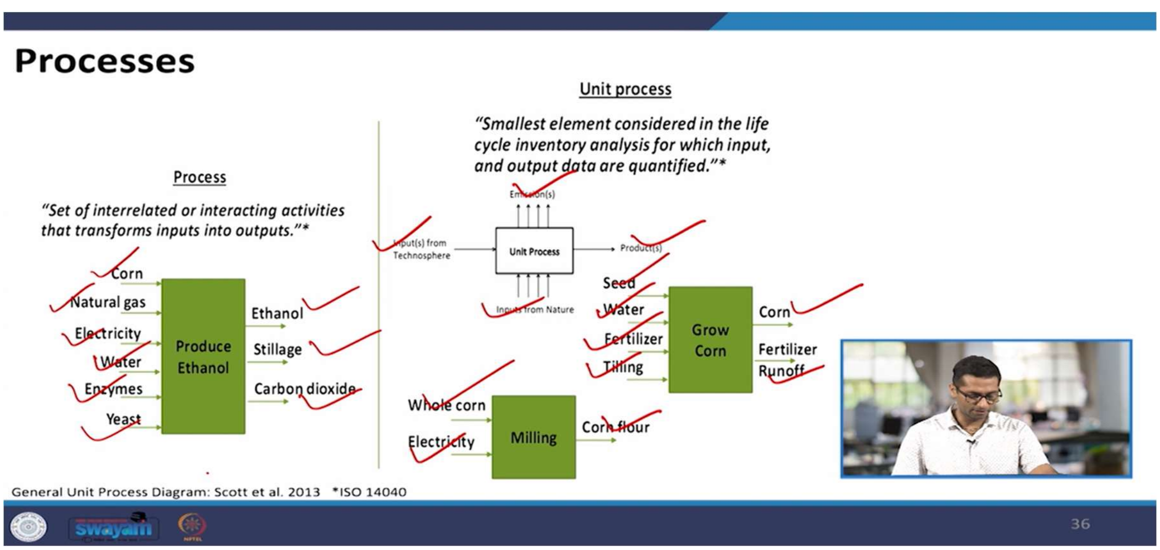
Week – 07

Lecture – 04

Lecture 35 - LCA System, Boundary, and Allocation

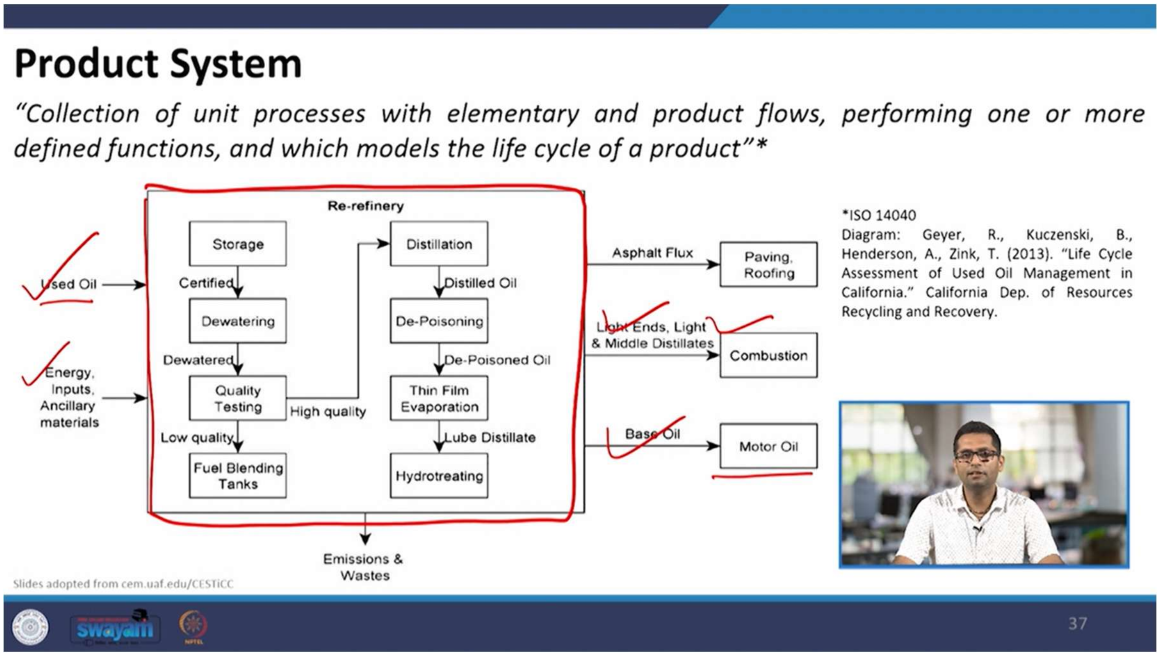
Hello everyone, welcome back to the course, Energy Resources, Economics and Sustainability. In the past few classes, we have been discussing the basic concepts of lifecycle assessment for LCA. We will continue the same process in the coming few classes including today. In the last class, we have tried to understand some of the basics of the functional unit, why that is important, how that is defined and what are the considerations that need to be taken into account while you are using a functional unit. We will move a step further and go towards the system boundary or defining the system and how do we allocate the different products that come out of a system. So, in today's class as well, we will be focusing more on the scope of the LCA study which comes under the first parameter or the first phase of an LCA, defining the goal and scope and under the scope, one of the major things that needs to be designed or discussed is the system boundary as well as allocation procedures and this is what is going to be the topic of today's class.



So, let us first try to understand what do we mean by a simple process. So, if I go with the ISO definitions, a process can be defined as a set of interrelated or interacting activities that transform the inputs into outputs. So, that is basically a process or any energy production process that will be taking many inputs from the nature or from the technosphere and producing useful outputs, useful form of energy as well as a lot of emissions and this is what I mean a process. Again, a process can have inputs that can come directly from the nature or there could be some inputs which have been upgraded from the natural flows and these kinds of flows are called the process flows and these are also referred to the process or the flows that are coming from the technosphere in the technical language. So, what you see in the slide in front of you is a typical process diagram for the production of ethanol that is coming from corn or biomass. So, what you see in front of you is a typical process diagram for a process that is trying to convert corn which is a sort of biomass into ethanol by the normal process of fermentation. So, the different inputs that would be going into a process like this would be corn, some natural gas for heating, electricity for various kinds of operation of equipments, water, different enzymes, yeast and what will be the products? It will be ethanol, the CO_2 emissions that might come up, stilage. So, this is what the process if you take it like a black box. But this process in turn could be broken down into smaller processes and which are called unit process.

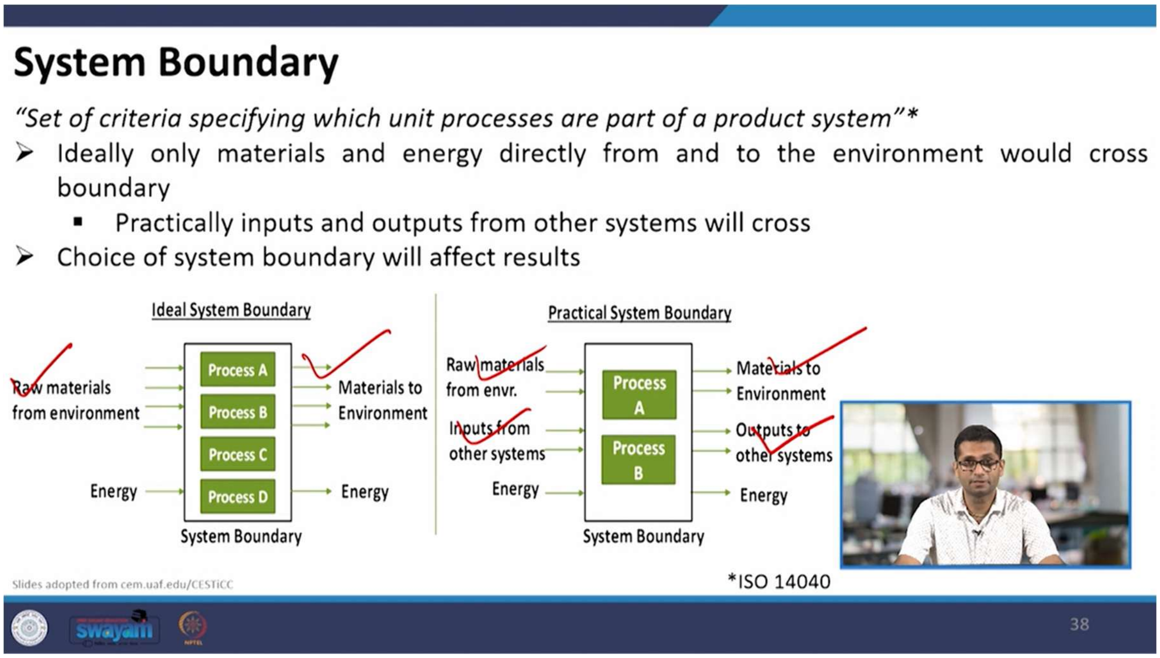
So, if I take the definition of unit process, the smallest element considered in the life cycle inventory analysis for which input output water are quantified, which means I will be breaking down the bigger process into smaller inputs in the form of series of parallel flows which would be a non-destructive element. I cannot break down the element further for the aspect of inputs and outputs. And for this particular process, there would be inputs that are coming from the nature, the inputs that come from the technosphere or the ability inputs. So, just for an example, so in the earlier example, the input of corn or natural gas could be something that are the inputs that are coming from nature, whereas electricity is something that has been produced using some of the natural inputs and that could be considered an input from the technosphere. What we finally get is the product as well as the emissions to the atmosphere or to the different like spheres of the earth.

Further, a typical example of a unit process could be the growing process of the corn. So, what goes in? It is the seeds that go in, the water goes in, the fertilizers go in and the tilling goes in and what you get output as an output is the corn as well as the different kinds of runoffs, like one of could be the extra water which has fertilizer into it and that might eventually enter into water body. A similar unit process could be the milling process, which the input is the whole corn as well as electricity for the milling process and what you get as an output is the corn flour. Let us try to understand this with the help or like in a bigger perspective in the form of system.



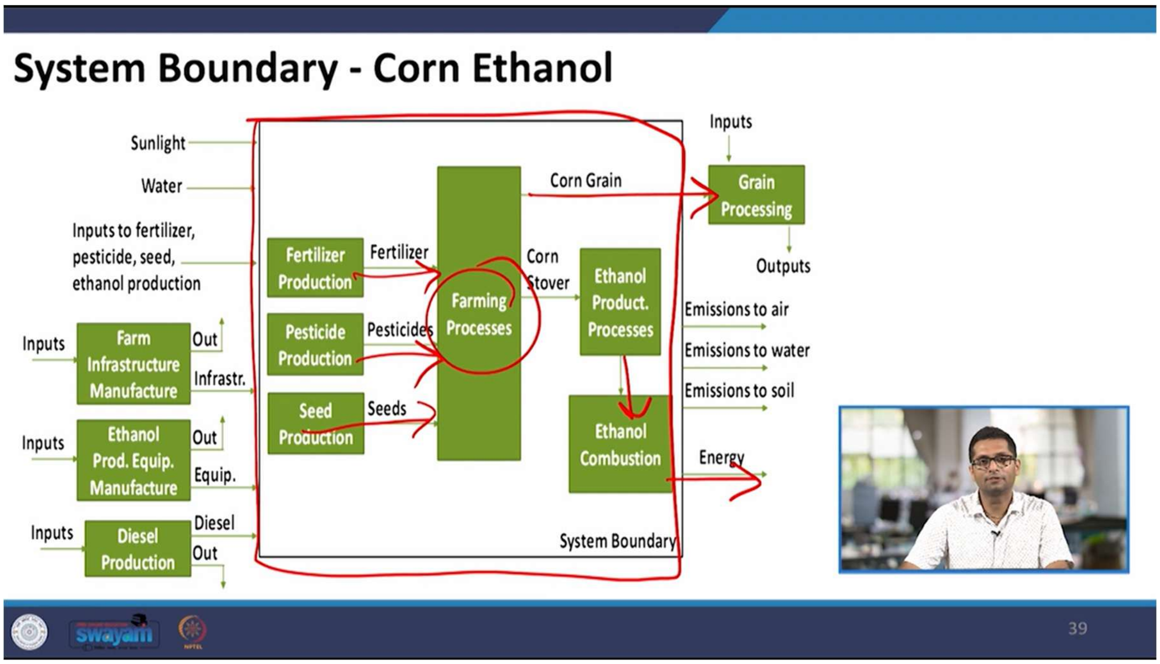
So, when I talk about a product system, I typically have a definition which says it is a collection of the unit processes with elementary and product flows performing one or more defined functions and which models the life cycle of a product. So typically for any life cycle analysis or life cycle assessment, what you would have you would have flows like this and different inputs and then these inputs going through a flow of events or transformations and giving you a series of products. So, this is an example where we have taken in the conversion of used oil or the used oil from the different cooking facilities gets converted into usable form again. So we have the used oil entering in, it might be stored, dewatered, it might be tested and finally it enters into a refinery where it would be distilled, depoisoned and it would be hydrated as well and finally you could have a series of products that come out from this distillation or from this conversion process. It could be the base oil which could be used as in the motor oil, there could be some light distillates which could be used for combustion and there could be some kind of asphalt flux which can be used for other applications like paving or roofing. But ultimately what is happening is you have the raw material in the form of the used oil as well as the other inputs from the nature as well as the technosphere like energy in terms of electricity or other kinds of catalyst that might be entering.

Then it goes through a series of conversion basically dewatering, quality testing, distillation, depoisoning, hydro treating and that ends up in the series of products. So what is important to understand here is the boundary that we have considered here and this is one of the important thing when you do an LCA. This boundary basically defines or is defined as a system boundary which is your area of interest. This is the, these are the processes or this is the complete process for which you will be trying to quantifying all the different inputs and outputs. Whatever is happening out of this box is not much of your concern because there could be linked or unlinked activities happening out of this area of domain but that is not much of your concern. What you are more concerned about what are the different inputs or outputs that are going into this highlighted box and these inputs can be coming from directly from the nature, it could be coming from the technosphere and finally the outputs can also be going to the nature in terms of the different emissions like the CO2 emissions and there could be outputs to the technosphere as well.

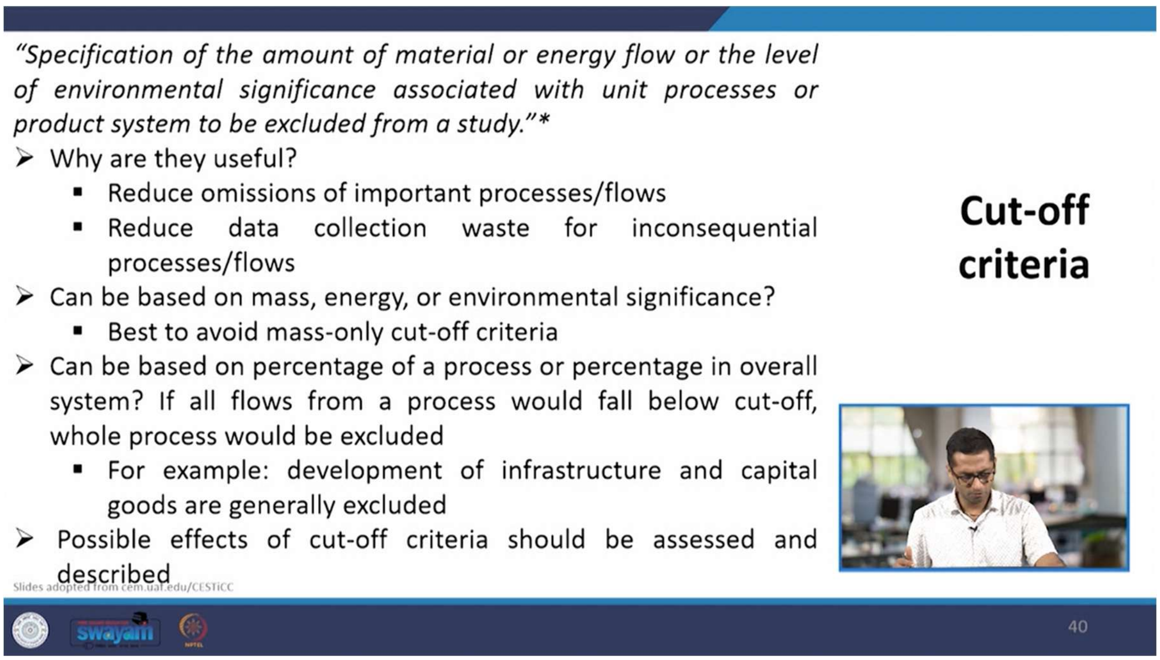


So quantifying again if I go with the definition of system boundary as defined in the ISO criteria it is the set of criteria specifying which unit processes are part of a product system. So we are only dealing with materials and energy flows which are coming from the environment as well as the technosphere with respect to the boundary that we are considering. So if I take about an ideal case in an ideal system boundary I would only have the raw materials that are coming from the environment and finally the emissions are also going to the environment and then there could be energy input and output. But in reality if we consider this is not something we experience for a more practical system boundary we would have the raw materials coming from environment of course but we would have other inputs coming from other systems as well and this could be in the form of electricity and other types of examples and finally we would also have the outputs to the environment and the outputs can be also to the other systems. Similarly if we see we should be considering every single flow in entering and exiting the system boundary but that again is not a reality or that is not doable and that is why we would be taking certain assumption to try to consider as many flows as possible but again like that is not humanly possible and further the choice of system boundary that we select is also going to affect the results. The more entities we include in the system boundary the more extensive the

LCA is going to be and the more factors will be taking into account and this is one of the major reasons why there would be different studies differing in the results. There could be studies who might consider a smaller system boundary while the others could be more have a more extensive system boundary means that they are taking much more bigger system into account and which also means there are bigger flows going into it and there could be much more emissions in those kinds of LCAs.

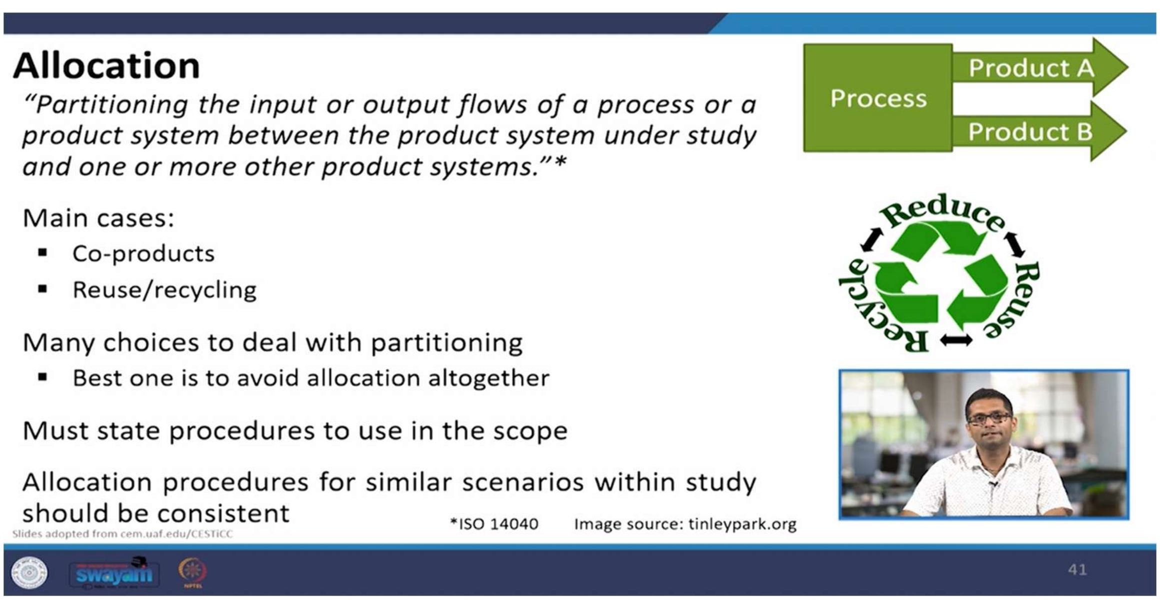


Further let us try to understand this concept more with the help of a typical example. So in this example we are considering the cone which grows in the field is used for the production of ethanol. So we consider the simple process in which we have the cone seeds growing in the seed production and then we have the farming taking place in here. We would have the fertilizers entering in the different kinds of pesticides entering in. Further we would have the production of crn which could be divided into the corn grain which goes to the processing facility and we could have the cone floor being produced and what is left behind is the stover. The stover could be used for ethanol production. The trails of the production we are not going much into detail and finally the ethanol that is produced might be combusted and this gives you energy. Apart from this we also have a lot of processes which might not be a part of the system boundary. Take for the example the infrastructure that goes for the farming purposes like the tractors or the seeders which might be considering because the construction of the tractors or the seeders might entail the use of lot of natural resources as well as energy. Further there could be certain equipment which could be used for the production of ethanol from the corn stover. Again we are neglecting the production of these kinds of equipment. There could also be some kind of emissions associated with the production of diesel through the life cycle of the diesel transportation and again we are not considering that. The system boundary in this case has been highlighted again. We will be considering all the systems or all the processes that come inside this system boundary and all the other things like the infrastructures are normally overseeing. One reason why they are not given much emphasis because the likely impact of these kinds of interventions is expected to be very small. Say for the example the tractor. The tractor taking a typical life of 15 years might be used for tilling a lot of fields. So if you divide all the manufacturing energy and the manufacturing elements that would have gone in the construction of a tractor over the lifespan of the tractor where it is used for farming 2 to 3 crops a season, the final impact would come out to be very small. And so these kinds of assumptions have to be taken in when we define a system boundary.



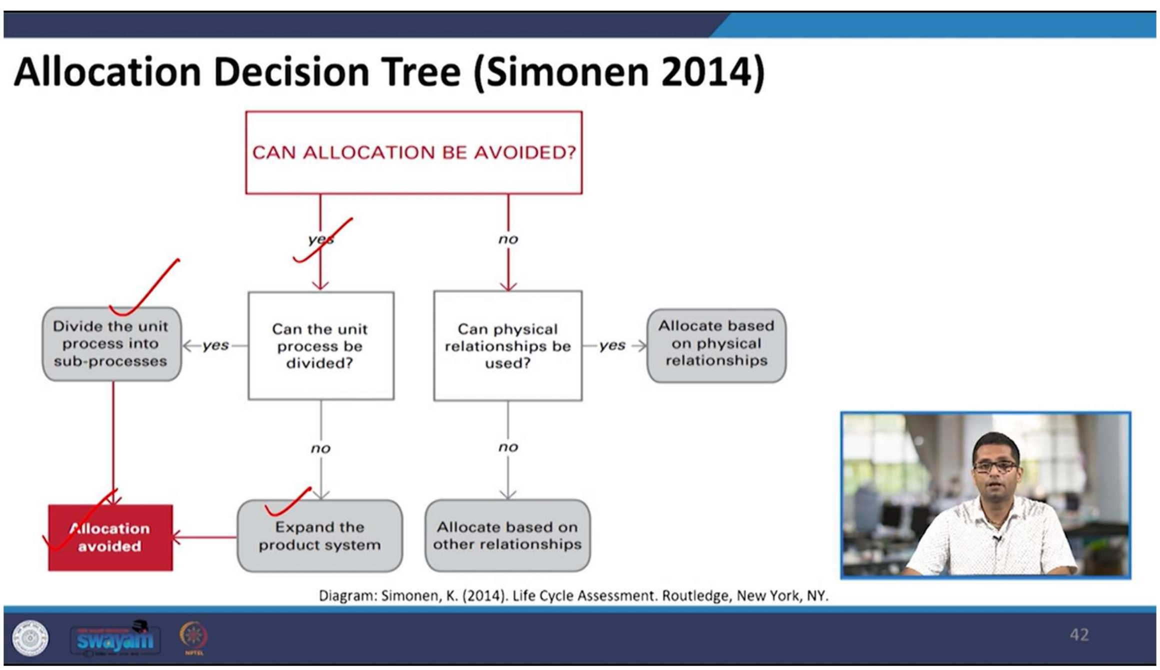
Further what we would normally be using is a cut-off criteria. Cut-off criteria basically means that we are specifying the amount of material or energy flow or the level of environmental significance associated with the unit process or the product in there that would be excluded from the study. So any input that might have the flows in terms of the mass and energy flows that is below a decided level or the environmental significance below a decided level we are going to avoid that from taking into account in the study. The reason for that is it's just not humanly possible to take into account every minute flow into detail. So we set into that if there is a particular flow that has maybe an environmental significance less than a certain percentage, we are going to neglect it because we are not going to see much of the emissions coming from that. And why are they useful? Well it helps us do the LCA coin in the fast way because data comes at an expense and there are human efforts involved, there are certain kinds of expenses involved if you want to buy data from professional bodies and that could be reduced to a great extent. Further this cut-off criteria could be based on either mass or energy or environmental significance. And this is something that needs to be understood.

Normally preference should be given to the environmental significance whenever we are deciding a cut-off criteria. Because if we are going by a mass or energy based cut-off criteria it might happen that a particular emission for a particular element or a compound might be very small but its total effect could be very large. Take for example as we have discussed in the earlier classes that the HFCs that were that came in to replace the CFCs had a very high global warming potential almost of the order of 10,000 times of that of CO2. So if 1 kg of HFC was released into the atmosphere that would be equal to 10,000 kgs of CO2 released. So if we have a chemical which could have a very high potential for a particular impact that might cause a serious harm if we have neglected that. And that is the reason why the emphasis should always be given to the cut-off being decided by the environmental significance of a particular emission. Further this could be based on a certain percentage or like that has been mutually decided that if the total flow is below a certain percentage that might be neglected. And normally it is accepted that the development of infrastructure or the infrastructure expenses that goes at the onset or setting up of any plant can be neglected because that particular process would be used for a lot long time and for a lot of production of output. Take the example of a manufacturing facility that manufactures plastic bottles. So a particular facility would be manufacturing thousands or lakhs of bottles over its lifespan. So if you see the impact of the manufacturing facility being set up on the impact of one plastic bottle that might be negligible and could be easily ignored. The possible effects of cut-off criteria should also be accessed. It might be worthwhile to see if the cut-off criteria would be set up to maybe a slightly higher percentage or a lower percentage how that would have impacted the LCA results on the whole.



Another important point that needs to be understood is the allocation. Allocation comes into picture when we have more than one product being formed by the system. So suppose I have a similar process that leads to the production of product A and B. So how would I divide the emissions that come in from this process between the product A and B? And that is an important question to answer. Again, if I go with the ISO definition of allocation, it says partitioning the input and the output flows of a process or a product system between the product system under study and one or more other product systems. So if there are more than one product, how are you going to divide the emissions between the two? That is an important question to be understood. Further, another application of allocation lies in the reuse or the recycling of the products.

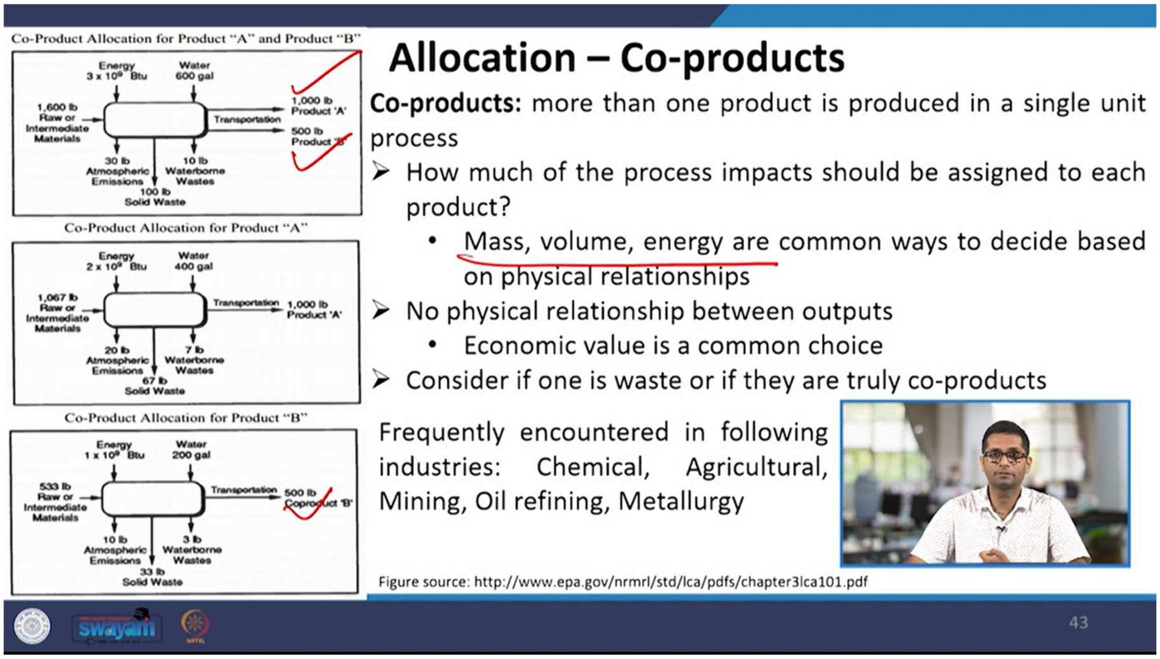
So suppose if you would want to go for recycling of a product, how would you attribute the emissions that are coming from the recycling process as well as the emission reduction that are coming? Do you give it to the original process or to the process for which the recycled product is forming as a feedstock? So that are some of the questions that need to be answered at the onset. And these kinds of choices are normally informed in the scope definition. So that the reader knows these are the methodologies that have been adopted from the onset. And further, it is always advisable to choose consistent allocation procedures for the different part of the process. It should not happen that for one particular aspect of the process, you have chosen one kind of allocation procedure and then going further, another allocation procedure for another process which is the part of the same system. And because this problem is encountered in LCA quite often, there are a lot of strategies that have been proposed for it. And we'll be discussing this as we move further.



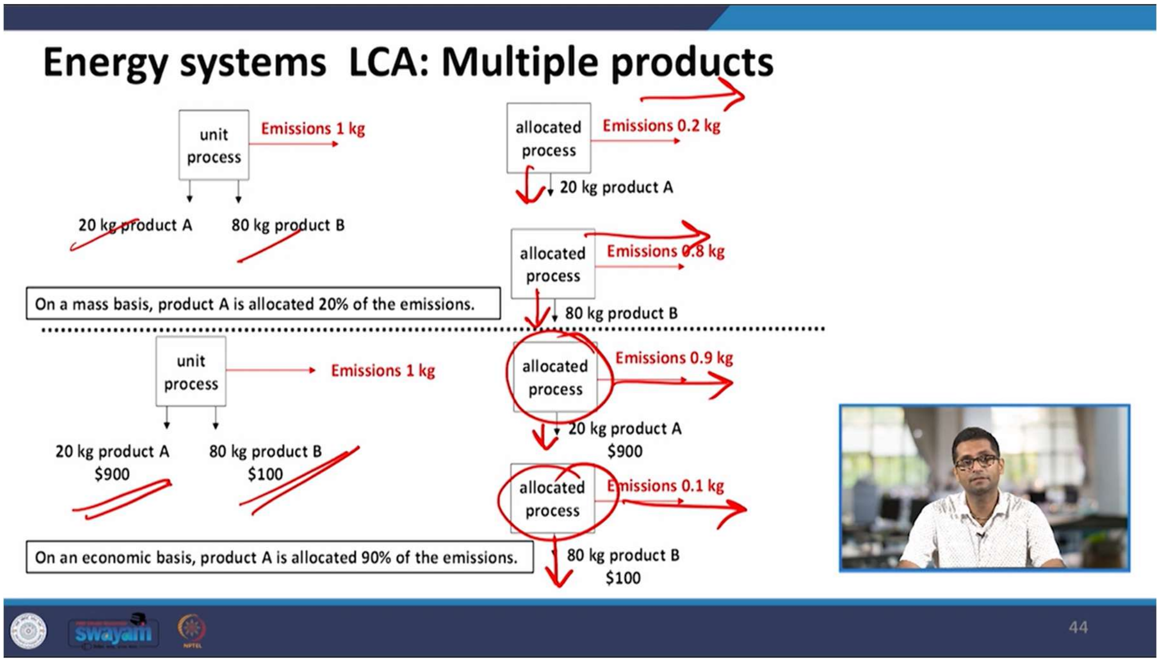
So if we start like one of the basic understanding or one of the basic procedure in LCA states that like we should try to avoid allocation altogether if that's possible. So for this, let us follow a simple diagram which says like first we should evaluate if the allocation could be divided altogether. If the answer is yes, and it means that the unit process could be divided, we should try to do that. So it might happen although we are considering a unit process, but a further study might indicate that even this unit process that we have decided as our knowledge might be still breakable into smaller unit processes. If that is a possibility, the different products might be attributed to different processes and there might not be a need for the allocation altogether.

So if the process could be further divided, I would then divide the process into smaller processes. And in that case, I have avoided allocation altogether. If the answer is no, the process cannot be divided into smaller processes, I would want to expand the system. How do I expand the system will be understanding in the next slide. If the problem arises that I cannot avoid allocation and allocation is something that I have to go with, the first thing that I would take into account is I would try to allocate the emissions based upon physical relationships, which could be mass-based relationships, energy-based relationships, or in some cases volume-based relationships. So I would try to divide the emissions based upon the mass of the different products that are being produced or the energy content of the products that are being produced. Further, in some cases, it might happen that even this kind of allocation is not possible, say for the example of a power plant. So a power plant would typically produce electricity and it might also produce a good amount of ash that might be used in the construction industry.

So in that case, how would I allocate the emissions between the ash that is produced and the electricity that is produced? Because electricity doesn't have any mass, whereas ash would not hardly have any energy. In that case, you might go for an allocation that is based on the economic value of the product and divide the emissions based upon the economic value that you derive from the electricity as well as the ash. And the ISO standards entail that if you are doing an allocation based upon some relationships which are not based on physical relationships, you should go for a sensitivity analysis to understand the effect of this allocation on the final LCA results.

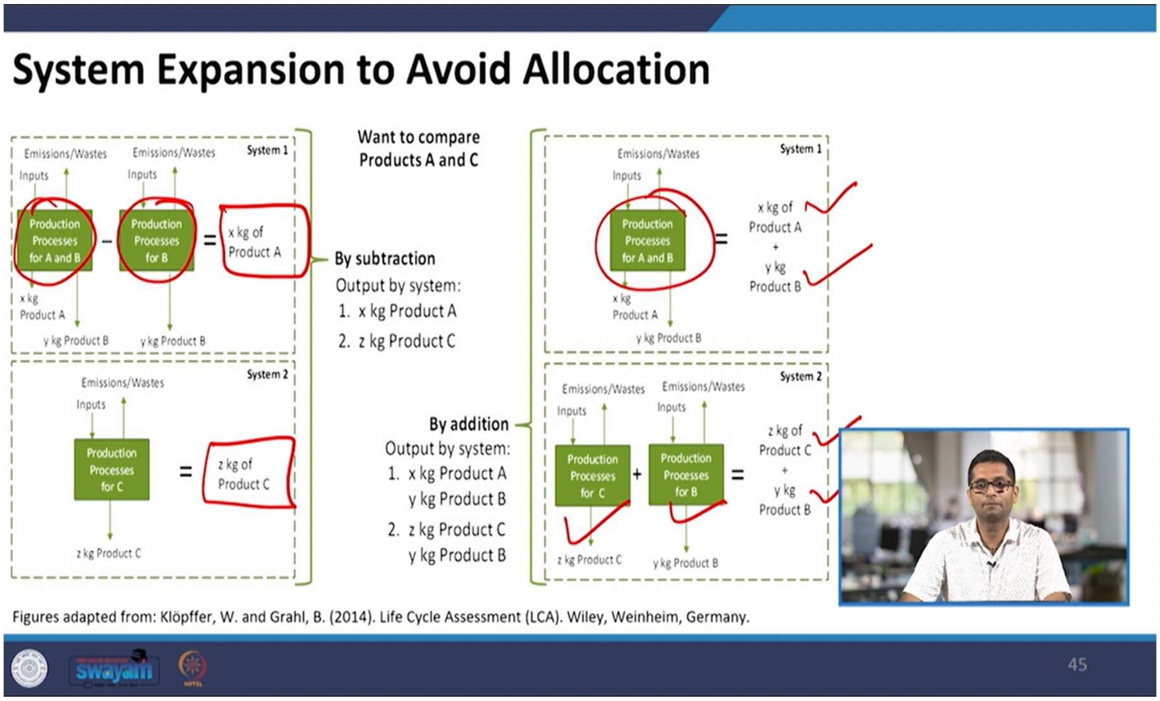


So let us try to understand the allocation of the co products. So suppose I have a system, something similar to what I have shown in the figure on the top left-hand side. So there is a process which takes in 1600 pounds of raw material, a certain extent of energy and water. And what it eventually produces is 1000 pounds of product A and 500 pounds of product B. And if I would have to divide the emissions between the two products, so the first way could be I divide on the basis of mass. So I know of the total quantity of the product that I will produce, two-thirds is product A and one-third is product B. And this is something I do with all the inputs and outputs. Two-thirds of all the inputs attribute to product A and one-third of all the inputs and outputs attribute to product B. So in this case, I can say what is the quantity of emissions that are attributed to product A and what are the quantities of emissions that are attributed to product B. And of course, as we have discussed in the earlier slide that the preference should always be given to mass, energy and volume based relationships. If that is not a possibility and only in the extreme cases, we should go for an allocation which is based on economic analysis or some other relationships like this. And it also entails that we should be going for a sensitivity analysis. Further, these kinds of issues are very commonly encountered in industries that are related to chemicals, agricultural, oil refining, metallurgy because these types of industries entail that a lot of products would be formed. And further, like in the typical case in the energy field would be a biorefinery which has many kinds of typical kinds of outputs. Another could be the green hydrogen that is coming in because that could be a byproduct from many of the processes. So in that case, how do you put the emissions for a process which is a byproduct from other processes. Further, let us also try to understand like how does things change if we take in a different allocation procedure.



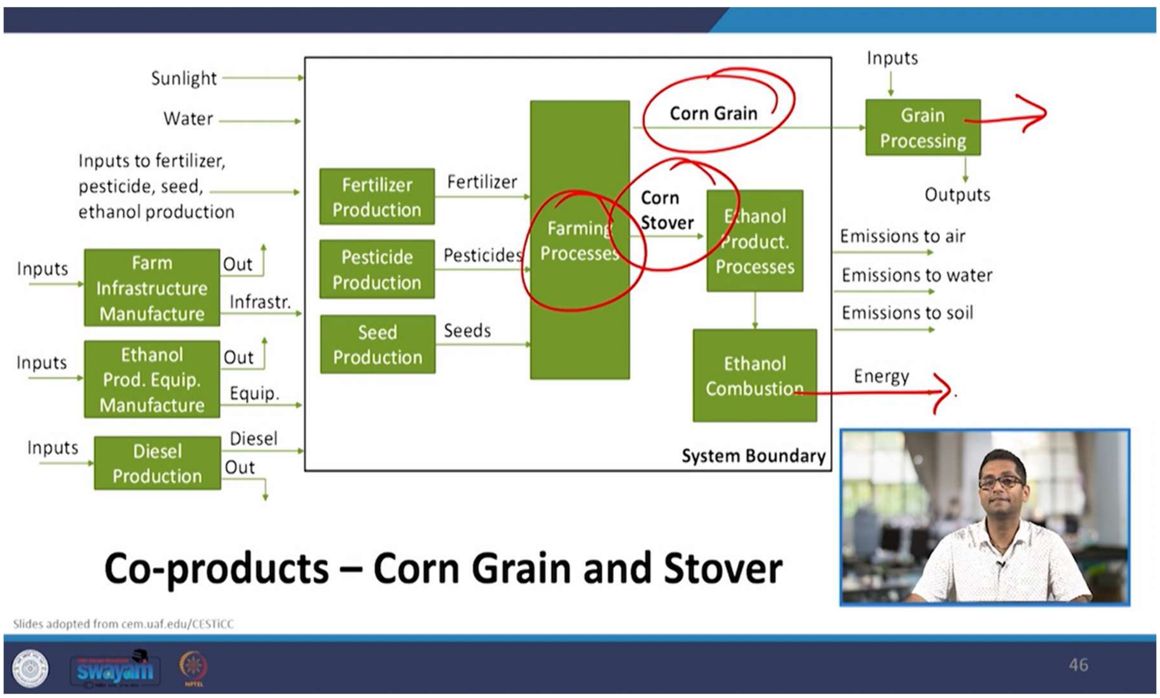
So take the example on the top. So we have a unit process which is producing 20 kgs of product A and 80 kgs of product B. And its total emission is say 1 kg of CO2 maybe. And if I go with a mass-based allocation, naturally I will be allocating 20% of the emissions to product A because that is formed at the 20% rate and 80% of the emissions go to product B. And so essentially I will be dividing this process into two smaller process in which we would have the production of 20 kgs of product A and 0.2 kgs of emissions. And at a similar level, there is another process that produces 80 kgs of product B and the emissions associated at 0.8 kgs of emissions. If somehow it happens that a physical relationship is not possible or there is a vast difference between the economic value of the two products. So suppose 20 kgs of the product A that I am producing has a market value of $900 whereas the 80 kgs of product B that I am producing has a market value of $100. And if I go with an allocation that is based upon economic analysis, the emissions would become almost opposite.

In that case, what happens is 90% of the emissions are associated with the production of product A and just 10% of emissions are associated with the production of product B. So what can be seen is in the figure on the bottom right hand side, we would have the process being only two processes. So one process produces 20 kgs of product A and the emissions are 0.9 kgs whereas the product B produces 80 kgs of product B but the market value is quite less and the emissions associated are very small as well. So we should always be keeping in mind how the allocation can make a vast amount of difference in which emissions are attributed among the different products.



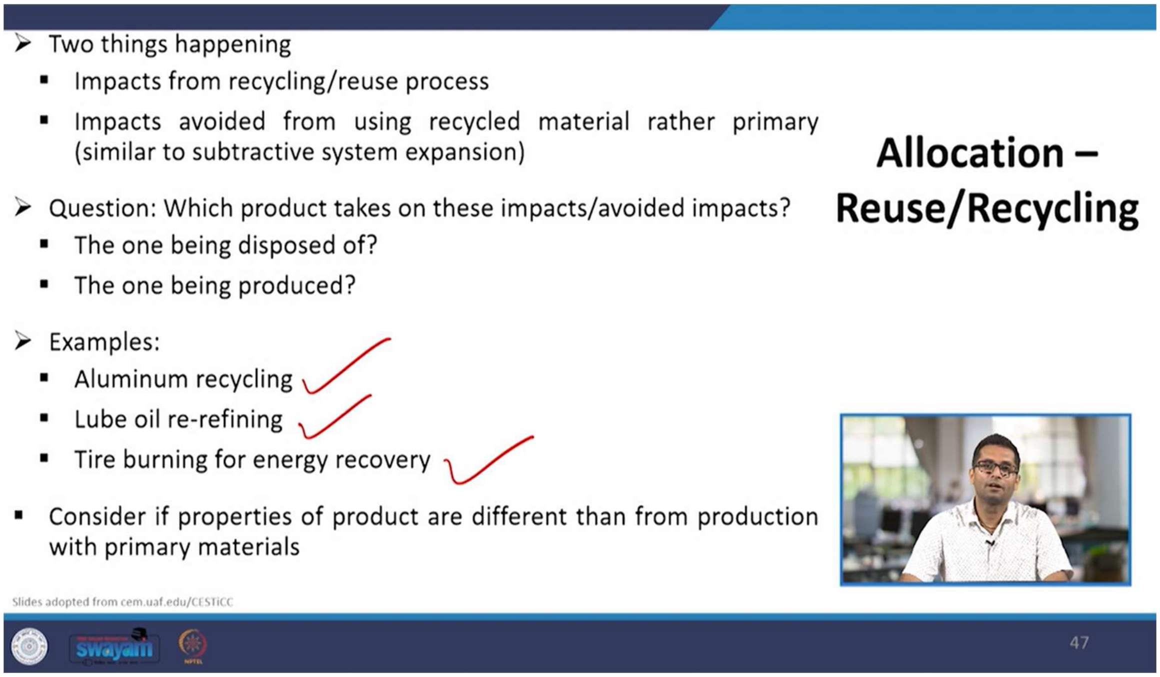
Further, we can also use a system expansion to avoid allocation altogether. So if we would want to compare two different processes, so one is a process which is shown on the top for which we have the products A and B being produced together and then we would want to compare this process with another process that produces only C. So we would try to understand how the system expansion works in the form of addition and subtraction. So we would have here in two, we want to compare two processes. So one system is one that produces a product A but it is also producing B in conjugation with A and then we would want to compare this production of product A with the production of product C. So what we can do is in the first case we can compare the two products by system expansion by subtraction. So what happens in this case is I will be having the system that has the production of product A and product B. Suppose we are producing X kg of product A and Y kg of product B and what I will be doing is I will be finding another process for the production of process B which is one of the most conventional processes for production of process B. And subtracting the emission that come from that or the inputs and outputs that are related to their production process B from the earlier process. So the final output is production of product A and this is something that I can compare easily with product C. So this is the system expansion by subtraction. Going by the opposite it can also happen that I add this production of process B to the production process C. So in that case both my processes will have X kg of product A and Y kg of B being produced. So in this case what is happening is I am taking the first process as such it produces X kg of product A and Y kg of product B. Whereas the system with which I am comparing is the process C which is producing product C and I am adding the product

B again that is again coming from a conventional process. So what I am essentially comparing is the Z kg of product B and Y kg of product B so as to make the comparison consistent. Now these kinds of assumptions can also lead to different kinds of problems. One is that like it might happen that there are a lot of processes for possible for the production of say a product B. So in that case how will you select the one and this different processes could have a very different emissions. So that becomes a problem that if you are selecting a process with a much larger or much lesser emission. Further it might also happen that it's very difficult to produce it's not possible to produce B alone. It's always a co-product of product A. Say take for the example of the corn to ethanol process that we have considered in the earlier example. So the corn stover that was being produced from the corn will always be produced with corn. So it's not that the corn stover could be produced alone and if we have to divide that with the production of corn flour and the corn stover separately that's just not possible.



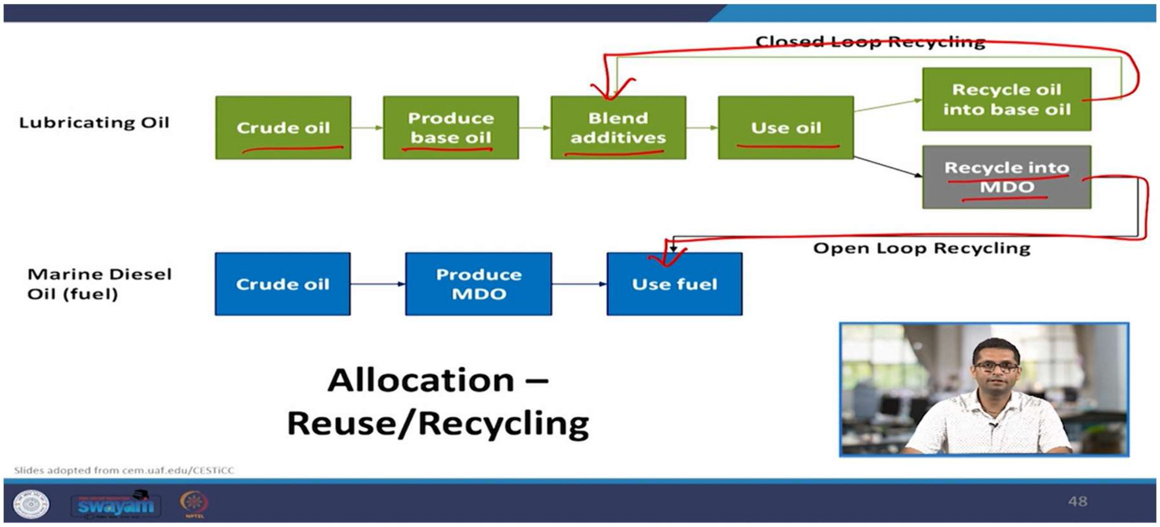
So again we are taking this same example here which brings in the limitations of system expansion. So of course as we have discussed in the earlier slide that the farming process would always produce corn grain and the corn stover.

So if corn grain is the product A and the corn stover is the product B there is no way possibility that I could have a process where the only product is the corn stover production. So in that case system expansion becomes a difficulty and we would have to go with some case of allocation between the two products which is the grain processing leading to some kind of corn flour and the energy which divides the emissions between the two major products.

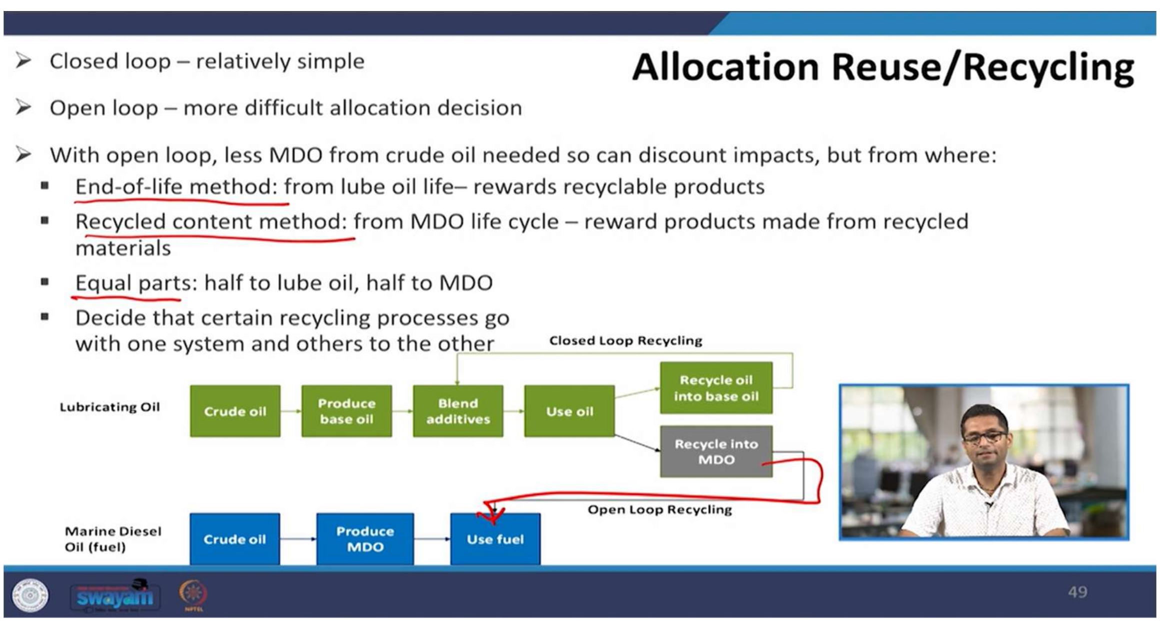


Again the allocation is something that is also becomes important when we are recycling or reusing some of the outputs from the process. Why that is so because the output that we are producing and that might be used as a source or as a feedstock of further production might lead to lesser emissions than the production of the product which is being recycled which is being replaced altogether. But the major question that arises is where do you put in this avoided impacts or the benefits of the impact that I mean avoided. So are these benefits awarded to the process of or the product which is being disposed of or are they being attributed to the product that is being produced.

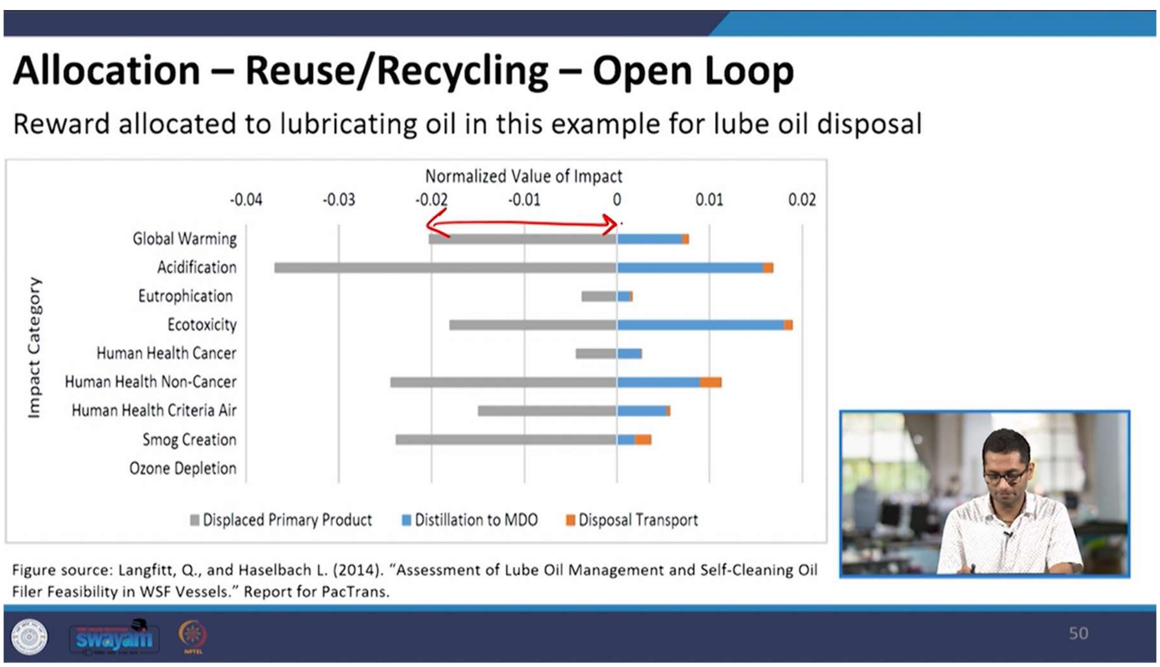
So that is an important question that needs to be answered in the scope definition at the onset of the process so that there is no confusion and the reader of the LCA knows that what kind of allocation has been adopted. And these kinds of like allocations are quite common when we are doing aluminum recycling, lube oil refining or tire burning because the output from this processes could be very well recycled and could lead to replace products that have very low emissions and the impacts could be a beneficial impact which could be good for the environment. Let us try to understand this with the help of an example again.



Suppose let me take the example of a lubricating oil which is produced from crude oil. From crude oil you are producing the base oil and adding some additives from which it comes the lubricating oil that you use in your vehicles and after the use of the oil there could be two things. Either you can recycle this oil back into the same supply chain where the oil is recycled back as an additive and gets used back again in the same flow. Then another option could be this used oil could be converted into some kind of marine oil which can be used in marine transportation. So here I am using the recycled oil for the marine transportation and what it does essentially is it is going to replace some of the marine oil that is going to be produced using crude oil. So these two types of recycling are called closed loop recycling and open loop recycling. In a closed loop recycling you will be recycling back into the same process whereas in an open loop recycling you will be recycling the product to another process. While a closed loop recycling is quite easy to understand and the effect of recycling is not felt by the final emissions. It's basically the open loop recycling that makes the process much more complicated.



So what happens in the case of an open loop we need to allocate the emissions which doesn't arise in a closed loop recycling because the process is in common. So we would have the emissions coming in and it's directly allocated to the oil that is finally produced. Whereas in open loop you can allocate the emissions or you can allocate the benefits that are coming from the recycling either to the original diesel oil that was for the lubricating oil that was being used. Or it could be allocated to the process where you are using this for recycling say in this case the marine diesel oil. So the process that gets the emission benefits turns out like will get the benefit and can show that it's much more of a green process. Further there have been discussions that if the emissions reductions could be equally partitioned between the two processes which is called the equal parts method. And again there is no scientific basis for this but it's just a sort of division that equally imparts the emission to the two processes. In the earlier cases if you are attributing the benefits to the original process it's called the end of life method. Whereas if you're attributing the emissions just to the process where the recycled product acts as a feedstock it's called the recycle content method. And further there could be more discussions among the parties who are conducting or who are the stakeholders who are doing the sales here like what kind of methodology needs to be adopted. Because these kinds of assumptions could widely vary the results in terms of how the emissions are allocated among the different processes. So just for the sake of an example from this particular study for the replacement or upgradation of lubricating oil into useful form.



So we see that because of the replacement we would have a negative emission this is what has been avoided and these are the emissions that go into the recycling process. So it's always going to be somewhat of a it's like in many of the cases it's going to be a beneficial process if we are can able to recycle. And this benefits where do we attribute this benefits becomes important as we are conducting an LCA. So with this in this in this particular class we have tried to understand the concepts of the system the system boundary and the importance of allocation. And in the future classes we'll be taking this discussion further to understand like what are the different aspects of the system that are normally taken into consideration. With that we end today's class. Thank you.