Energy Resources, Economics, and Sustainability

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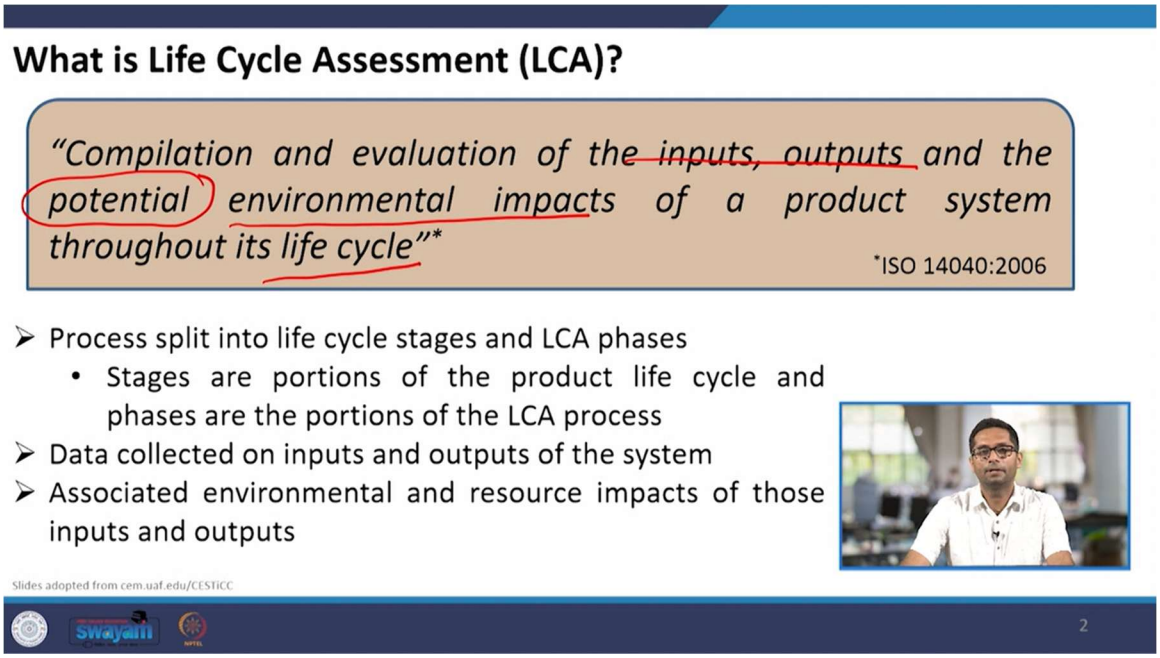
Week – 07

Lecture – 02

Lecture 33 - Introduction to Life Cycle Assessment (LCA)

Hello everyone, welcome back to the course Energy Resources, Economics and Sustainability. In the past few classes we have been discussing the importance of sustainability and the importance of quantifying sustainability. But we also understood that there is no single acceptable method for quantifying the sustainability. Be it environmental emissions, economic well-being or the social wellbeing. There are different matrices that have been proposed in the past. A lot of these matrices comes with their own advantages and disadvantages. In today's class and the classes further, we will try to discuss one such matrix which is called the life cycle assessment method.

We will try to understand the basics of this methodology, how it can be used, its importance for quantifying the sustainability for an energy production process and we will try to understand the application with the help of a few examples. Again I would like to repeat that LCA or life cycle assessment is not the only method for quantifying the sustainability of an energy production pathway, there could be many other methods but it is one of the most widely used method and like any other modelling tool or simulation tool it has its own challenges and weaknesses. So, let us start with the basics of LCA starting with the definition.

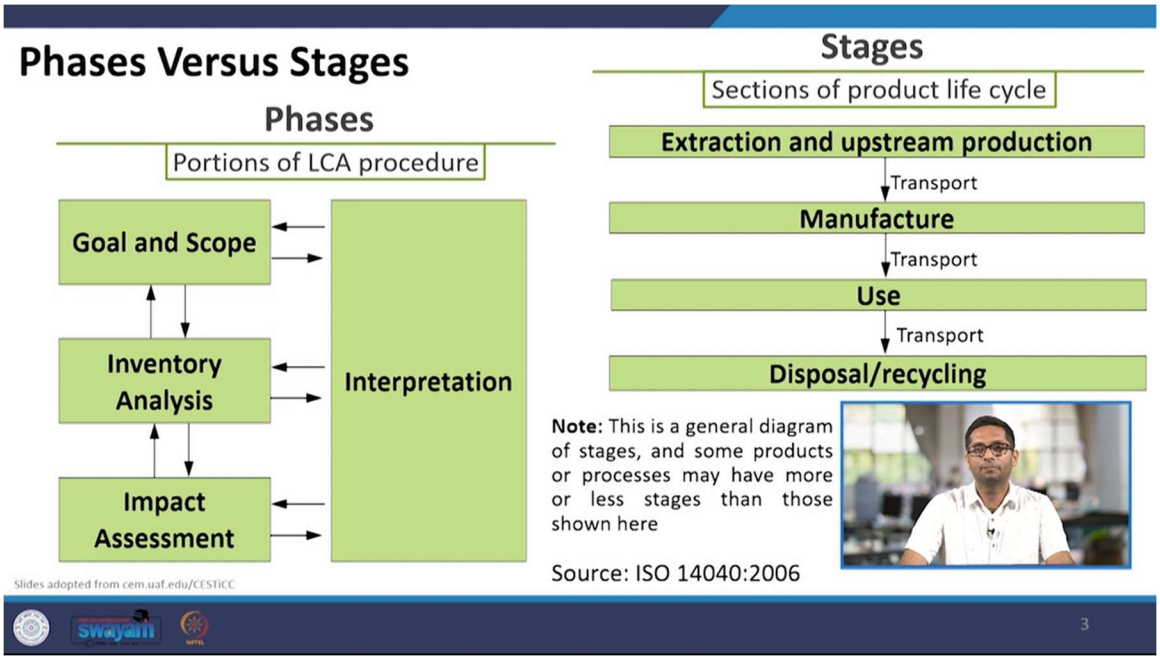


So, if I go with the definition of an LCA which is going by the ISO standards which basically dictate the methodology by which you would carry out life cycle assessment, it goes by the form it is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. So, what is important here? It is a life cycle, we are considering the different inputs, outputs over the life cycle of a particular system which means I start with the extraction of raw materials for any particular system and it ends with the disposal of the end products. Further, what I am trying to quantify is the environmental impacts and it is important note here that the environmental impacts that I say here are potential. There is no way I can say with 100% certainty that this is going to be an environmental impact for so and so intervention and that is why this methodology is giving you potential environmental impacts. This particular methodology is split into stages and phases.

So, stages are basically the product life cycle which means extraction, the raw materials to the finished products, distribution of products, use of the products and the disposal of the products. When I say about the phases that is something inherent to the methodology of LCA. It is basically the goal and scope, the life cycle inventory, life cycle inventory assessment and interpretation. Any LCA should have these four phases. Often these terms

are used interchangeably but it should be kept in mind that there is an inherent difference between this.

Further, we need to do a lot of data collection for a methodology like life cycle assessments. That means you have to collect a lot of inputs and outputs for a particular system and also we have to quantify the associated environmental impacts which are potential in nature. How does one do an LCA? Most of these things would be guided by the ISO standards which have been laid down.



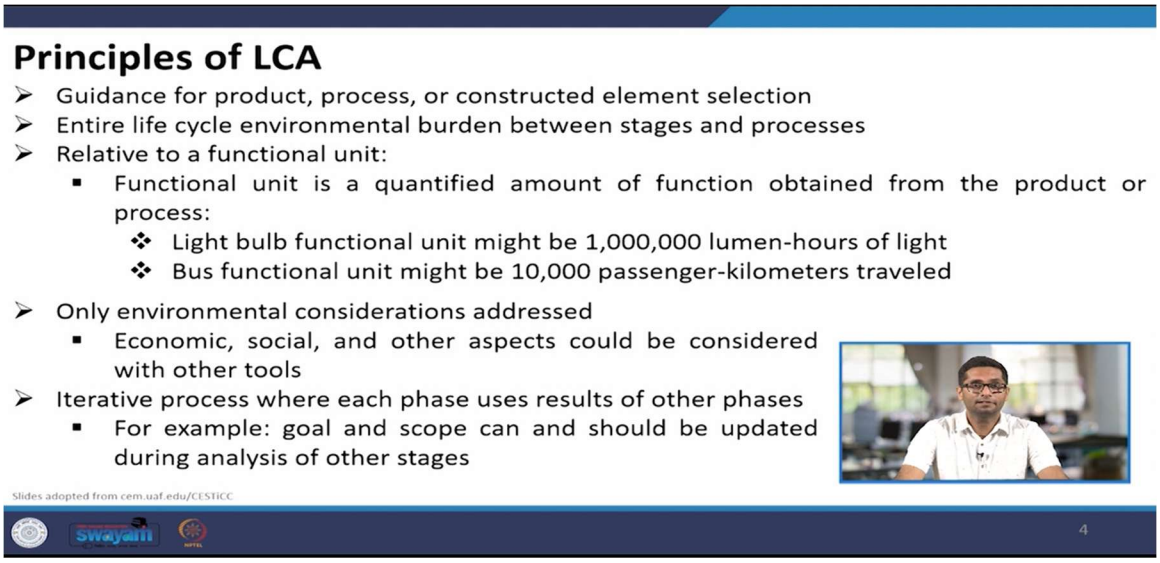
So coming again, let us try to understand the difference between the phases and the stages. Phases is something that is inherent to the methodology of life cycle assessment. The first phase that you would start a life cycle assessment would be defining the goal and the scope. A goal would basically pertain to why would you do a life cycle assessment. Scope basically underlines the different assumptions that you would be picking in for doing a life cycle assessment. This could include the system boundary, the types of the system that you would be including, what are the different types of inputs and outputs that you would want to include. Once you have set up a goal and scope, the next thing would be data collection which goes in the inventory analysis. You would want to collect as much data as can which is pertaining to the spatial and the temporal constraints that you have and put up in the LCA tool that you are using. Once the

inventory has been collected, you would want to see the environmental impact of those inventories which comes in the impact assessment stage. In the impact assessment stage, you would want to see say if I was to set up a coal-based power plant, how much CO2 emission and finally from the CO2 emission, how much global warming or climate change could potentially occur. And finally, we have the interpretation aspect which basically pertains to the previous three aspects, the goal and scope, inventory and impact assessment. As you can see the arrows between the different blocks, they are to and fro arrows.

So there is no one flow events that can be made to occur. The whole process is iterative. The aim is to get the best results possible so that all the four are in synchronization. We can update the goal and scope to synchronize that with the inventory that is available. Further, we have got to update the interpretation based upon the impact assessment and this cycle keeps on going on and on till we have a certain degree of confidence that the results that we are getting are acceptable.

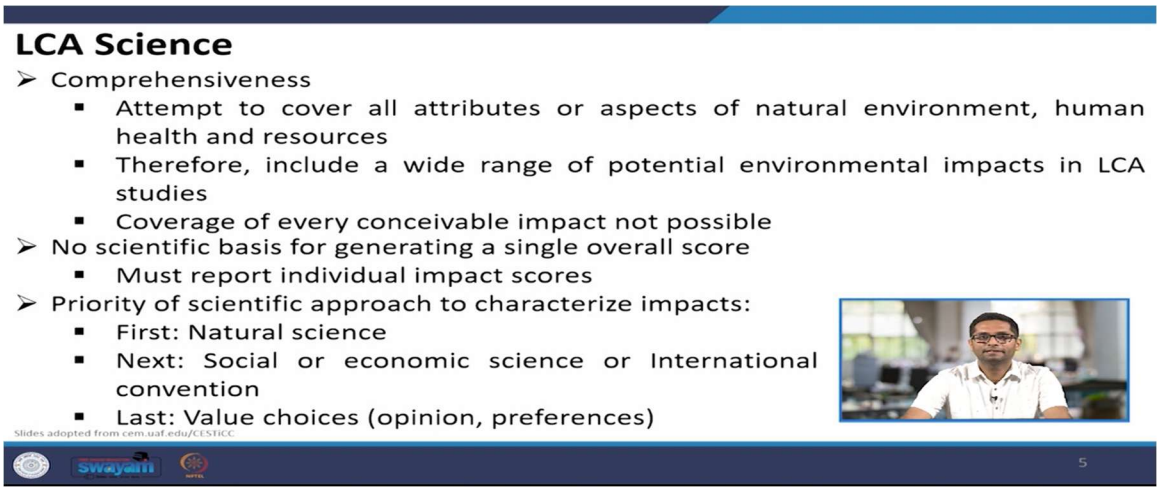
Further, when I go towards the stages of a life cycle assessment process, this is something that would change with the different kinds of process or products or the systems that we are adopting or that for which we would want to do a life cycle assessment. The typical stages for any process or product would be the extraction or upstream production of the raw materials. You would transport these raw materials to the manufacturing stage where you would be using different kinds of interventions for converting the raw materials into the manufactured goods which could be anything. Once the goods or the services are available, you would want to use it. After the use, you would want to dispose of the products and this is how the different stages connect to one another.

There could be processes which do not have all these features. There could be products which could have more than these features and one of the things that is often linking these different stages is the transportation. The transportation of raw material to the factories, from the factories till the distribution centers, from the distribution centers to the end use places, from the end use places to the disposal activities. So these are the different stages that one might come across and would want to quantify while doing a typical LCA. Now let us go through some of the guiding principles of LCA.



So if I go with the ISO standards which basically pertain or which are the defining documents for LCA, they define LCA as basically guidance of product, processes and constructed element selection. They would want or one would want to have the entire life cycle environmental burden between the different stages and the processes as we have discussed in the previous slide. Further, one of the distinctive features that sets apart LCA from the other sustainability matrices is the use of functional unit. So any LCA or life cycle assessment that you do would be using a functional unit according to which all the different impacts are quantified. So it is basically a quantified amount of function obtained from a product or process. Why would you need it? Let us try to understand with the help of an example. Now suppose I would want to compare the sustainability of a light bulb. Now this light bulb could be an incandescent bulb, it could be a CFL bulb or it can be an LED bulb. All the three different types of bulbs have different life spans. An incandescent bulb might not last as long as an LED bulb. Further, the illuminance of the different kinds of bulbs could be very different as well. It might happen that 100 watt light incandescent bulb could provide you an equivalent light as given by a 15 watt of LED bulb. So the illuminance is again very different. If you would want to do a good comparison between the different options available, you would have to bring in a functional unit that quantifies these different aspects. So if I have to compare different kinds of light bulbs, one kind of or one suggestion for the functional unit could be 1 million lumen hours of light. Now lumen hours is basically justifying or telling us the

illuminance that is created and 1 million is the amount that is created. Further, if I would want to compare the different kinds of transportation options, one option could be if I can compare the kilometers of distance travelled. But that might not be the correct functional unit because the different vehicles would have different carrying capacities for the passengers or in terms of flight as well. Suppose if I would want to compare a bus with a four-wheeler, just the kilometers travelled would not be a very good functional unit. And that is why a very good functional unit for these kind of comparison could be a passenger kilometers travelled. So if I have to compare different kinds of vehicles, I might go for maybe a functional unit of 10,000 passenger kilometers travelled. That takes into account the distance that is travelled. Further, different vehicles could have different passenger carrying capacity and that is also taken care into this. It also needs to be understood that in an LCA, primarily it is the environmental impacts that are being quantified. Of course, there are variations like economic input out for LCA as well as social LCA that also try to cater to the economic and social aspects. LCA as a methodology as dictated by the ISO guidelines mainly pertains to the environmental impacts. And that is what it has been used a lot in the past as well. Further, there are other optional tools that people have used and are currently being used as well. And again to add, as we have discussed earlier, the whole process is iterative. It is not a frozen process that once you have chosen a goal and scope, you cannot update it later or once you have taken in a few inventories, you cannot update the inventories pertaining to the geographical location or the time span that you are looking at. So the whole aim of the process is to get the best results and to make the updations as and when they are needed.



If I go towards the LCA, the science that go behind a typical LCA, it is pretty comprehensive. It tries to attribute the aspects to the natural environment, the human health as well as resources. We try to understand what would be the typical effect of a particular emission that might lead to the degradation of life for a human being or an animal or a bird species. Further, it also tries to quantify the impact on the resources as well as the natural environment.

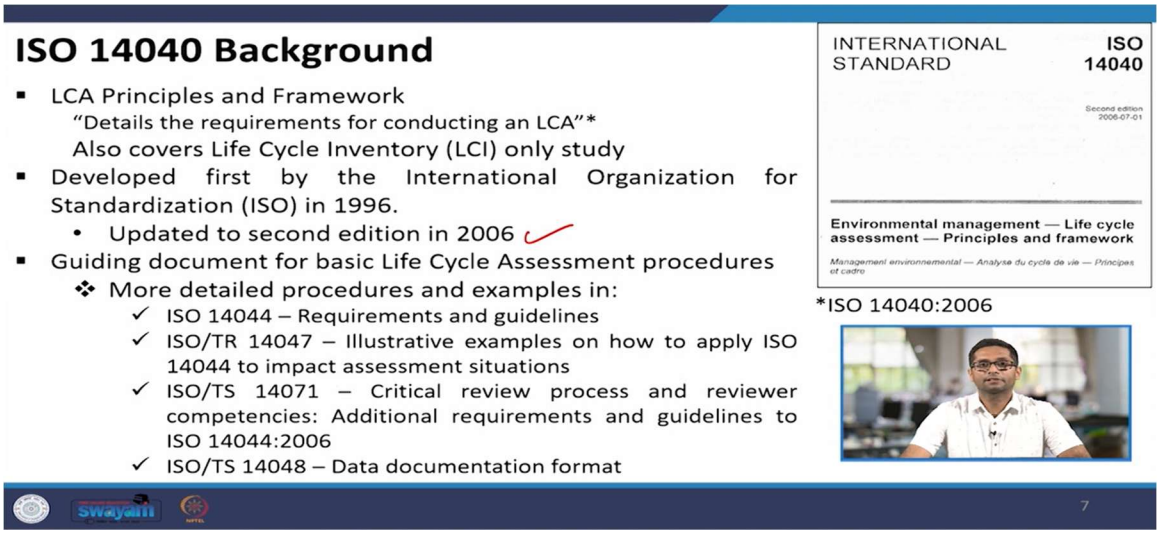
Also, there is no one environmental impact but a series of them. Global warming potential is just one of them. Another typical example could be ozone depletion potential. And further another example could be acidification or eutrophication. Some of this which we have discussed in the past. And it's very difficult to add all of them together. And in many of the LCA methodologies, you would see that these typical values are given and it's for the user to choose from. In many of the cases, it might not be possible to give you one single value where you say, okay, this is the value for this process and this is value for this process, now compare. Because there are different impacts and these impacts have their own implications. And these implications would be depending upon the person who is looking at it.

Further, while deciding how to characterize these impacts, the priority that is given is to natural science. First, you would want to go towards the scientific phenomena that basically connects the different types of cause and effect relationships. Like if this is an emission, this could be the possible effect. And pertaining from to this particular effect which now becomes the cause, this could be the final effect. So, it's basically the natural science that plays a major role. But again, it's not always the natural science. Sometimes when the natural science is not available, there are lessons that are learned from the social and the economic sciences as well as the different international conventions that have been set up. It might not always be possible to give an economic value to the type of resource depletion that we have and that is where the economic sciences come into play. The least choice or the last preference is given to the value choice which would depend upon the societies as well as the persons who are building up an LCA. Further to repeat, whenever you are doing an LCA, the preference should always be given to the phenomena linked of the causes and effect to the natural sciences.

Then a question that you might be wondering, like why should you do an LCA? First thing is you would want to identify the opportunities to improve the environmental performance of the product that you are doing. Now, as we are going into the era of sustainability, every product, service or process that we are working in would want to quantify the environmental impact. And this is one such methodology which can help you quantify how sustainable or green or clean you are in terms of the energy requirements or the process as over a whole. Also, you had heard about like with the given importance to hydrogen fuel and other biofuels, now there are government standards like if I have talked about green hydrogen, so there are definitions that are pertaining that green hydrogen is something that would have maybe x kgs of CO_2 emissions per kg of hydrogen produced. And the value of x could be different for India, it could be different from Europe, but how do you determine that value of x? So that is based on possibly a methodology that is like an LCA. Further, you would also want to inform the decision makers that you are indeed going for a green pathway. Now, there are different countries who are aiming for different net zero targets. India, for example, has chosen a net zero target of 2070. But how do you really quantify that you are net zero, the CO_2 emissions are indeed reaching a net zero level. So this is again an application of a process like LCA.

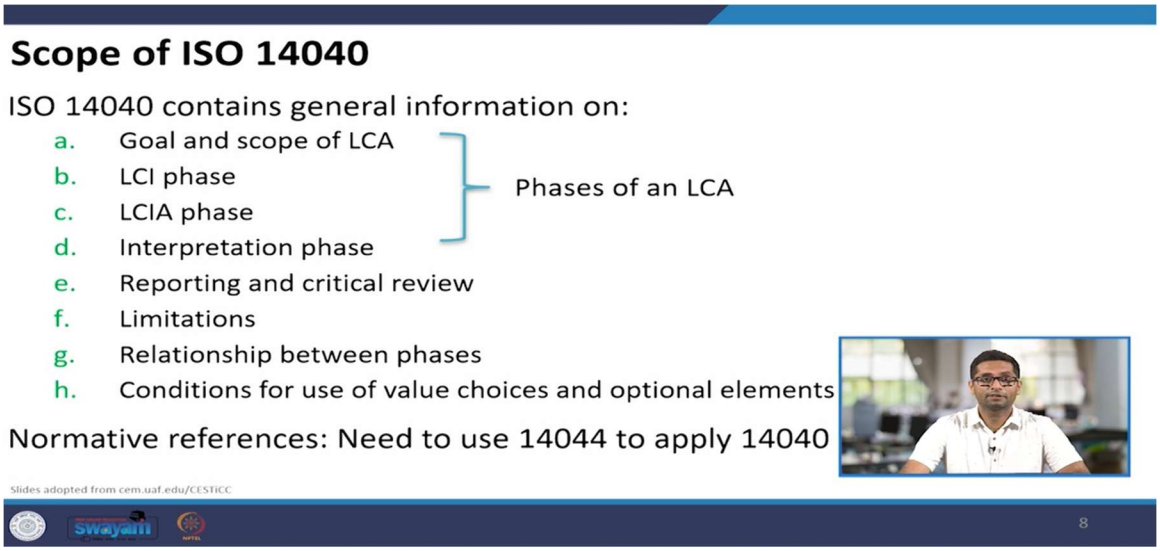
Further, you can also select the relevant indicators for environmental performance. Now, everyone is talking about global warming potentials, CO_2 emissions, that is when net zero is coming in. But does that mean that we stop caring about the water footprint? Does

that mean we stop caring about the ozone depletion? We have to give due emphasis to the other environmental impacts as well. And this is what an LCA helps you out. It gives you the score of different kinds of intervention. How if one intervention is helping in one aspect, it might not happen that it is creating a bigger problem as we have seen in the past. A typical example could be the use of HFCs for helping tackle the ozone depletion potential. But it was later found that these HFCs have even greater greenhouse gas potential. So a methodology like LCA can help you quantify or can help you understand which could be the other drastic effects from a particular solution. So that one solution does not lead to a bigger problem later on. And finally, it can also help in companies coming up with marketing strategies like eco-label where they are putting in the carbon footprint of a product, say if I am using a particular soap, this is the carbon footprint of the soap and something similar.



Now pertaining to the LCA science, how would you know if you are doing the LCA correctly? So LCA as a methodology is dictated by the guidelines which are coming up with the ISO standards. So the first standard came in the year 1996 and further they were updated in the year 2006. So the ISO standard that I am talking on here is 14040 which are being used which gives the basic definitions, what are the elements that are important to an LCA, how would you conduct an LCA. And further there are other ISO standards like 14044 and other 14000 series which basically lay down the guidelines, how would you collect the data, how would you understand the different kinds of allocations, how

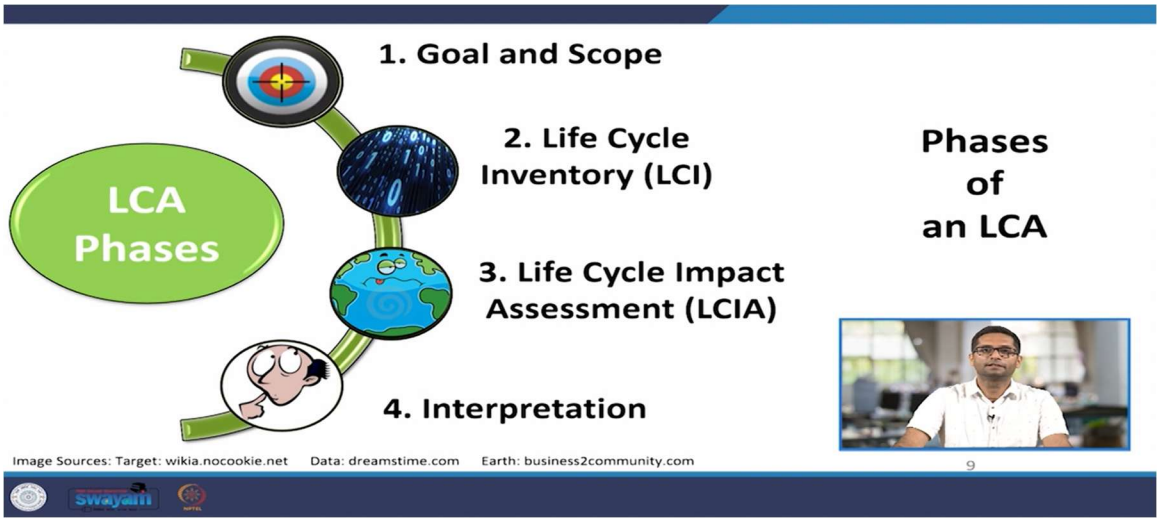
would or also help you understand of conducting such kind of LCA with the help of an example. So there are underlying guidelines which basically guide you how to do an LCA that is worthwhile.



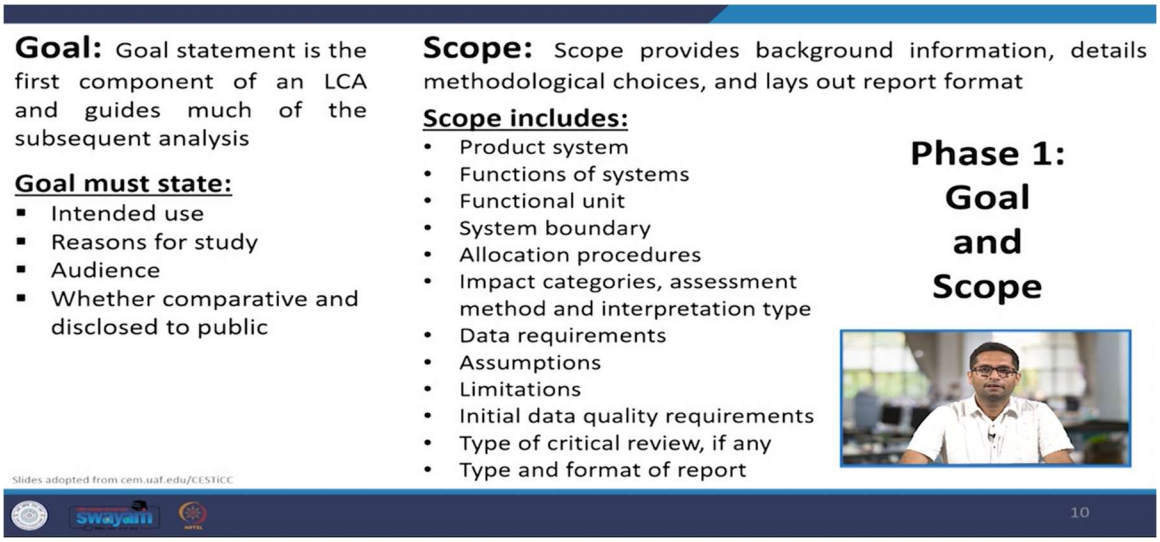
So if I talk about the scope of the ISO 14040 which is the basic document which you would be using for conducting an LCA, it has these features. The first thing is it explains the different phases of an LCA which is the goal and scope of an LCA, the different kinds or the LCA phase, the lifecycle inventory phase, what do we mean by inventory, how do we collect an inventory, then the lifecycle impact assessment and the interpretation phase. So these are the phases which are compulsory to be done if I am doing a lifecycle assessment. Further there are some studies which just focus on the LCIA phase as well.

So in that case we can do it with the LCIA phase but the study will also be known as the lifecycle assessment or lifecycle impact analysis. Further, It also lays down the guideline regarding the reporting and the critical review for the LCA. A critical review always helps you quantify your assumptions and to see that you are not making a mistake that or making assumption that might not be acceptable. It also lists down the limitations of LCA like any other methodology the LCA has its own problems, its own limitations, the relationship between the phases and finally the conditions to for putting in the value choices and the options elements. And also a lot of these things would require a reference to the ISO standard 14044. So many of these terms that we come across in 14040.

0.40 have been explained in the 14044. So for normative references you might want to refer to this guidelines as well.

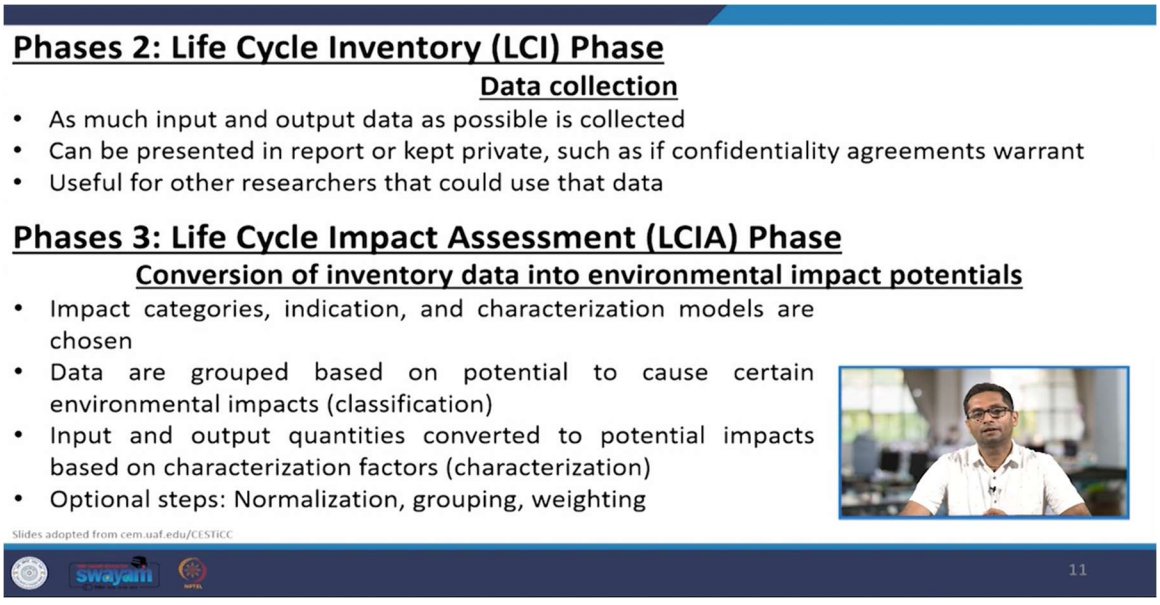


So let us go with the different aspects of an LCA one by one. So as we have discussed earlier the four major phases of an LCA would be goal and scope, the lifecycle inventory, the lifecycle impact assessment and interpretation. So we will go one by one and try to get a better understanding of these phases in detail.



So first let us go by the goal. So a goal statement is basically the first component of an LCA and guides the intended use why would you want to do an LCA. The reasons for the study, who is the expected audience like is it for the corporate or some particular company that you are doing or whether it is for the public at large where it is for the think tanks, it is for the government, who is going to be the audience. Further it also takes into

account whether you can disclose the data or it is going to be something that is going to be concealed and it is just for the upper management of the company to have information about and it is not intended to be disclosed to the public. So these are some of the things that you would normally put down in a goal statement. Coming up the scope, scope basically defines the different kinds of assumptions that you would be undertaking or different kinds of methodological choices that you would be adopting while doing the LCA. The first thing is what are the product systems that you are choosing for. What are the different functions of the product that you are laying for? What could be the function unit along which all the values would be normalized? What would be the system boundaries? What are the basic principles that you are taking in? If there are more than one product, how would you allocate the emissions? What are the different impact categories that you would want to consider? What would be the limitations of the assumption that you have taken in? What type of critical review that you are undertaking and what kind of report you would be providing? Of course, many of these terms would be new to you at this point, but as we go further in the course, in the coming few classes, we will be discussing these terms in much more detail. So the scope for if I put it, it's basically listing down all the different assumptions that you would be undertaking while doing the LCA.

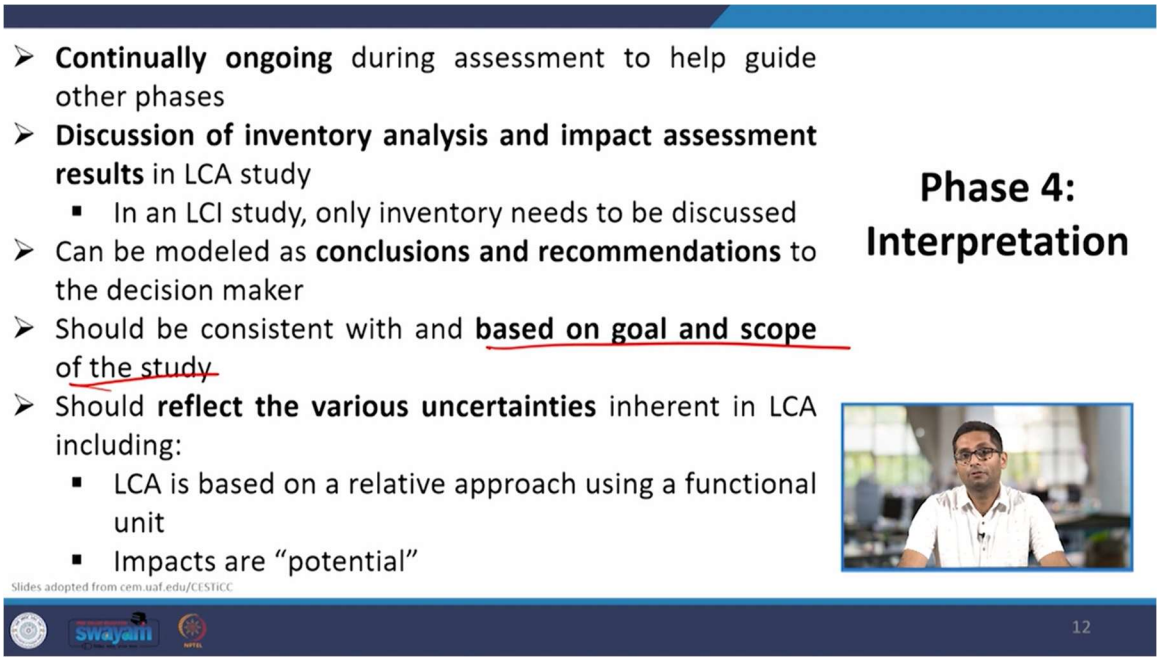


Now in the next phase, which is the lifecycle inventory phase, I would be going for data collection. I would want to collect as much data as possible, which pertains to different inputs and outputs throughout the lifecycle of a product. Say if I am talking about green hydrogen that is linked to solar, the first thing that I would want to link is how the solar panels are created. Then how would an electrolyzer would be created? Is it a PEM-based fuel cell or is it an electrolyzer, sorry, is it a PEM-based electrolyzer or is it an alkaline electrolyzer? Further, I would also want to see how the wiring are created, how the power conditioning is taking place. So these are the things that I would take in. I would want to quantify as many inputs and outputs. Further, if I talk about the emissions, a solar hydrogen plant might not have direct emissions, but it might have emissions during the preparation of the silicon ingots for the solar PV cells.

There would be emissions for the preparation of the catalyst or the membranes for the electrolyzers and this is what I would want to quantify. Once the different types of emissions and the inputs and the outputs have been quantified, I would go to the next stage, which is the lifecycle impact assessment phase. It is in this phase that I would be converting these emissions that are coming from different parts of the lifecycle of a product into emissions. The emissions for a particular process can occur in the raw material phase, in the manufacturing phase, in the use phase, as well as in the disposal phase. So this could be very different for the different kinds of products. Suppose I am talking about biofuels. Biofuels might not have emissions in the use phase because these emissions are considered to be biogenic, but they can have significant emissions during the biomass growth phase, the storage phase or biomass transportation phase. So it can happen that a particular pathway might not have emissions in the use phase, but there could be significant emissions that are coming in in the raw material phase. Further, this is the place where I would also want to quantify the different impact categories that I am considering. It might happen that the process that I am looking for, the geography that I am looking for doesn't have an acid rain problem or doesn't have a eutrophication problem.

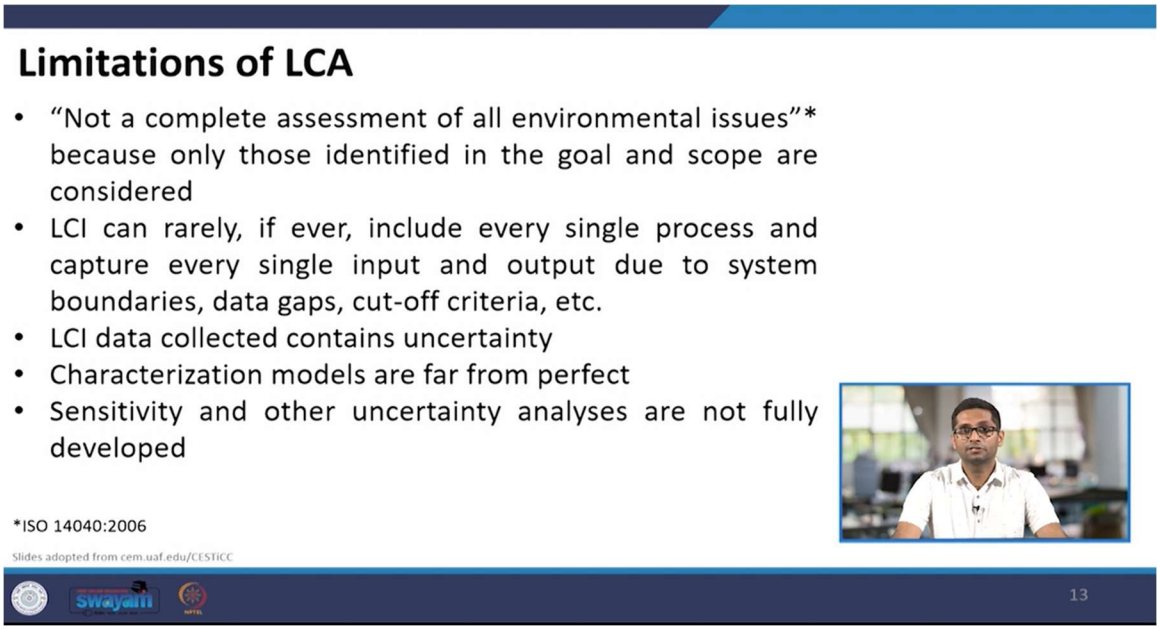
So these are some of the things that I can neglect. Further, there are also optional steps available in terms of normalization, grouping and weighing, where I can club different

types of emissions to come up with a consolidated number. And these are optional elements which one can take in.



Now finally, once you have brought in all the data, you have quantified the different emissions, the effect of the emissions, there would be an interpretation phase. And this is a continuously ongoing process. You can have interpretation coming from the goal and scope, the inventory analysis, the inventory, the impact assessment stage. We would want to come up with certain conclusions and recommendations. So if you're writing a report, interpretation is something aligned with the conclusion, the recommendation that you're trying to make. And these would be coming once you have synchronized all the four phases of the LCA. Again, this interpretation should be in line or consistent with the goal and scope that you have initially put in for the LCA and that is very important. This is basically justifying that you are reaching a point from where you started with. And finally, we should also try to reflect the different kinds of uncertainties that are inherent in the LCA. The data that we are using is not always perfect. The models or the characterization models that are used to convert the emissions into the possible impacts are again not 100% perfect. And as we have discussed in the onset of this lecture, the impacts are all this potential. We can always say that a particular coal plant, because it's emitting so and so amount of CO_2, could have potentially this much impact for the global

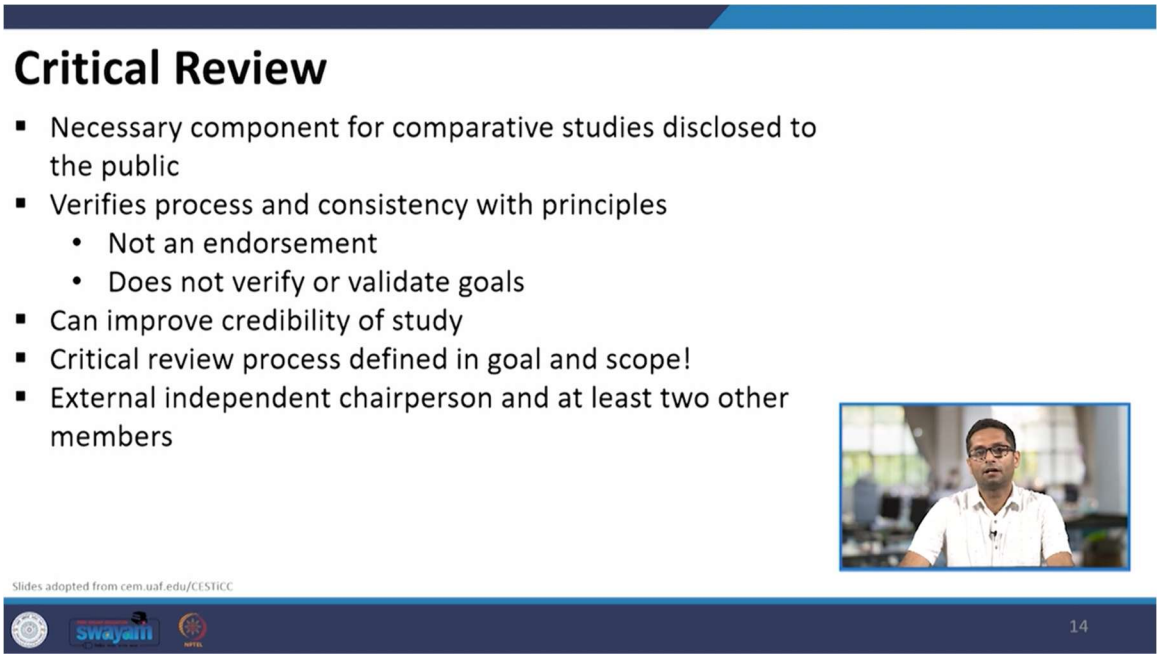
temperature rise or for the potential sea level rise. It cannot be 100% certain that one molecule of CO2 could lead to this much meters of or millimeters of sea level rise. So the impacts are all this potential.



Now, if I talk about the limitations of a typical LCA, well, it's not a complete assessment of all the environmental impacts. There is no way any particular methodology can quantify all the possible environmental impacts. It does try to quantify many of the environmental impacts. So one of the most well-known characterization models has almost 18 midpoint indicators or 18 environmental categories. But there could be always some kind of environmental impacts that are outside these characterization models. So that is always a possibility. Again, as a model, it has limitations.

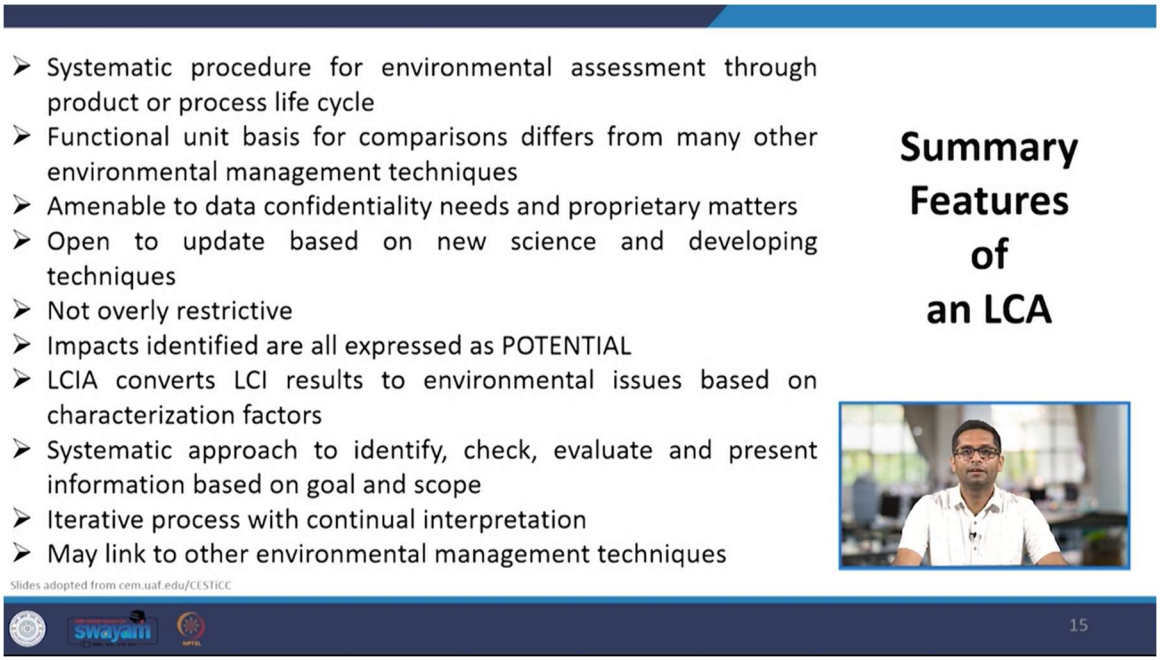
It cannot always quantify every single input and output of the process. There could be many minute mass flows and energy flows that goes into any process. And any particular LCA cannot be 100% sure that they have taken all the impacts or all the flows into consideration. Further, the data we have collected will always be uncertain. We are living in a very dynamic world in which the technology is changing at a very rapid pace. And the footprint of a typical grid electricity that we are using is very uncertain. It keeps on changing with the influx of the renewable energy plus the place at which this electricity is being used also have the electricity supply changes. And it's very difficult to say with

certainty that the data is always correct. Further, the characterization models that are used to convert the emissions into impacts are not the only one. There are different kinds of characterization available for the same kinds of emissions. Each one might give you slightly different results. So, no model is perfect in that sense. And further, scientific community is continuously striving to understand the sensitivity and the uncertainty analysis with respect to an LCA study. Of course, there are many methodologies being suggested. But again, there is an ongoing process to get more and more understanding for these kinds of uncertainty analysis and get to know what could be the best way of representing these analyses. Further, one of the last things that you would want to do after an LCA would be a critical review.



You would want to understand that if the assumption that I have undertaken are widely acceptable or there is some trivial mistake that I'm doing. And a normal process that is undertaken is a review. If you are putting in a study in a peer-reviewed journal, where there would be the different reviewers trying to analyze your assumptions, your inventories, and your interpretation. Further, even if you are doing this as a consultancy assignment or you are doing this as for some corporate, it's always good to have a critical review done by some other LCA professional who can help you understand or help improve the credibility of the study. It's not always defined in the goal and scope, but it's

always good that you go through because of the sheer amount of data that is involved in an LCA process. It's always recommended that the LCA is reviewed by other professionals that can help you make the LCA study better and also make it much more acceptable.



So if I put in the summary points of the points that have been discussed till now with respect to an LCA, well, it's a systematic procedure for environmental assessment through the product or the process lifecycle. One of the basic features that distinguish the LCA from any other methodology that has been advocated in the past is the use of function unit, which helps in making much more recent comparison. Again, this is amenable to data confidentiality as well as the proprietary matters. It's not that if you are taking in data from a corporate which has great secrets, would have to put all the data in the open domain. You can just put in the final results and that would be acceptable. Again, it's not a frozen process. You are able to update this process with the new developing characterization models. You can always update it as the science and technology is progressing and more and more information is available. The impacts that you are coming up or that you are predicting are always potential. You are always going to predict that this could be the potential impact of so-and-so pathway. Further, it's a systematic approach which has its own methodology for identifying, checking,

evaluation, and presenting information. Its iterative nature makes it much more easier for interpretation and it's very easy to be linked with other environmental or economic management techniques. There are many studies who would want to club a typical LCA with other economic assessment techniques or social assessment techniques. So, it's very widely used in conjugation with other kinds of methodologies as well. So, in this lecture, we have discussed some of the basic elements of a lifecycle assessment process.

And in the future classes, we'll be discussing all these different phases in much more detail. With this, we end today's lecture. Thank you.