Energy Resources, Economics, and Sustainability

Prof. Pratham Arora

Hydro and Renewable Energy Department

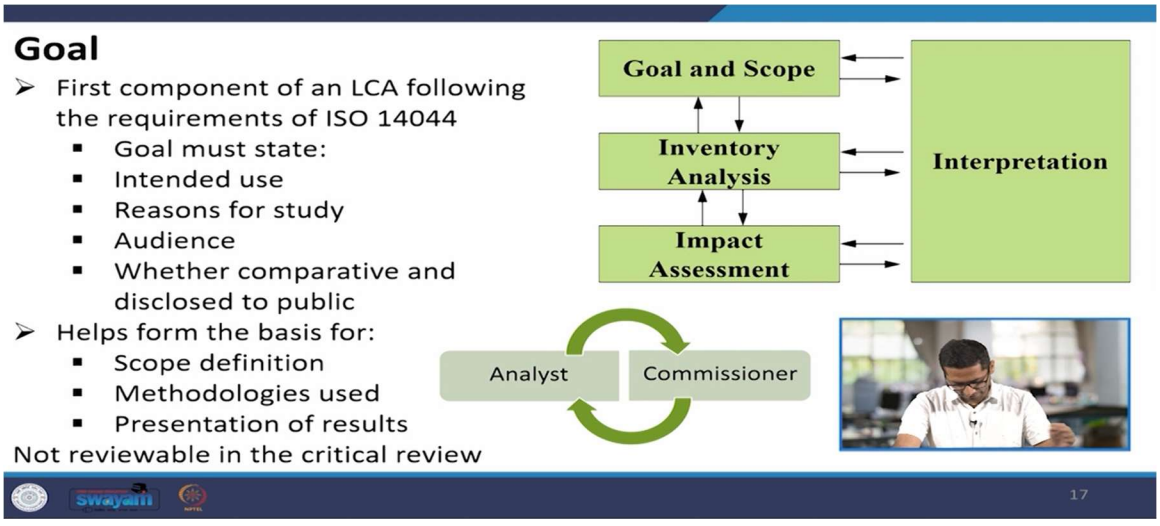
Indian Institute of Technology Roorkee, Roorkee, India

Week – 07

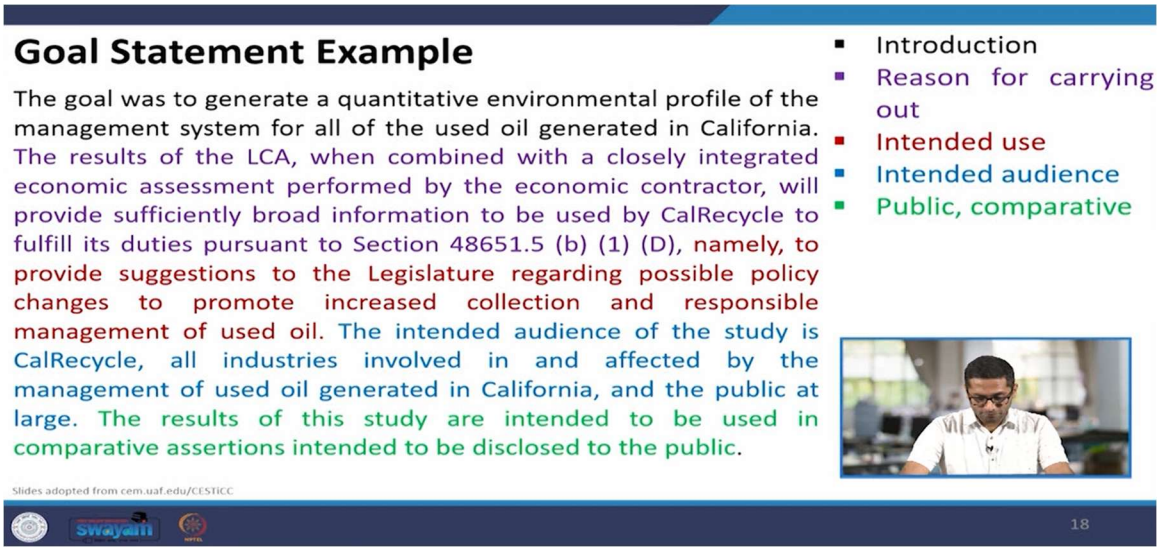
Lecture – 03

Lecture 34 - LCA Phases

Hello everyone. Welcome to the course Energy Resources, Economics and Sustainability. In the last class, we gathered some understanding about life cycle assessment or LCA. We tried to understand some of the basics, some of the underlying methodologies, what are the guiding principles, what are the limitations, why would you do an LCA and what are the drawbacks of a particular LCA, what are the future and directions in which the LCA could be improved. These are some of the things that we tried to understand. In from today's class, let us dive deeper into the LCA methodology. We will try to understand what does a different phase of LCA entail, why are they important, what could be the advantages of these phases, what could be the drawbacks and these are something that we will be discussing as we move further. In the last class, we understood that a typical LCA would consist of four different phases. This include the goal and scope statement, the life cycle inventory, the life cycle impact assessment and finally the interpretation phase. So, let us start with the goal and scope statement.



So, goal and scope is basically the starting component of an LCA and it is defined by the ISO guidelines as well. A goal must state the intended use, the reason why you are carrying out the study, who is the expected audience and whether the analysis is comparative, would you want to compare this with the previous results or whether it is an in-house assessment that is for the upper management, whether you want to disclose it to the public or for the government decision makers. Further, we would also want to put in the scope definitions, the methodology that we will adopt, the different assumptions that go into it and these comes in the scope. So, basically these kinds of activities would be done with a comprehensive discussion between the analyst who is doing this LCA and the commissioner who would be commissioning this kind of study. So, the analyst would put in the commissioner that this is what is doable and the commissioner would put in what are his or her expectations. So, there is a couple of discussions that would go on and that would basically be going for the deciding the goal and the scope statement. So, let us start with the goal statement. What is the typical goal statement that is going to look like?

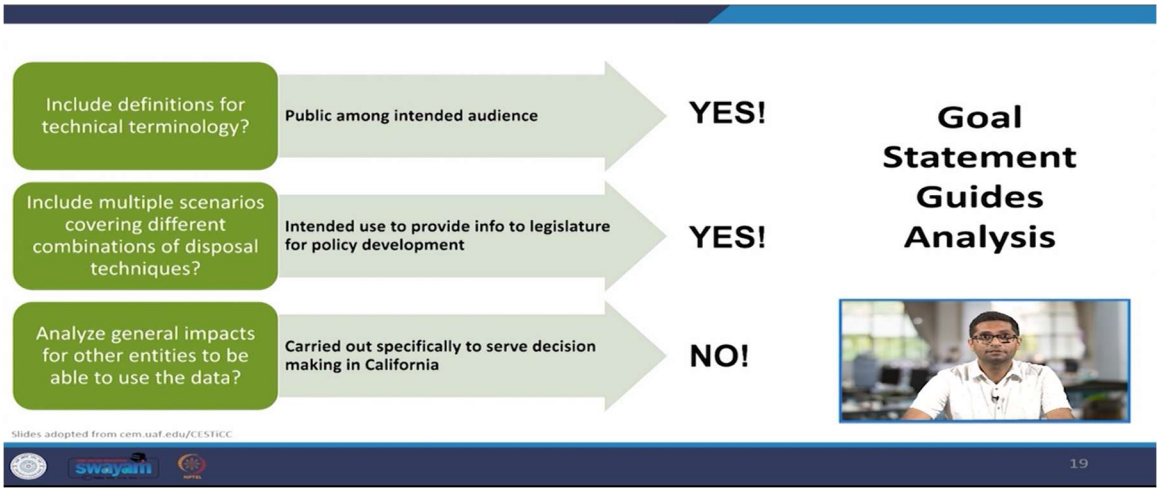


So, here in I am taken in a statement that is from an LCA study. The study was done by a company that was that is called CalRecycle. So, it is for the state of California in the US. So, this particular company it does is it collects the used oil from the different places and tries to convert this used oil into reusable biodiesel. So, it is basically going towards the circular economy and they wanted to understand that what could be the environmental impact of the things that they are doing. So, of course this is like a type of methodology

that is educated for the future, but it is also important to understand the environmental impact of such a pathway that has to be undertaken. And the goal statement that is given in their LCA is quite comprehensive that clearly list out the introduction, the reason why they are carrying out the study, what is the intended use of the study, what is the intended audience and whether this study needs to be disclosed to the public or it is comparative in nature or not. So, let us go by this goal statement one by one. So, the goal let me read it for you guys. The goal was to generate a quantitative environmental profile of the management system for all of the used oil generated in California. So, this basically gives a line of introduction what the organization is trying to do. Then why it is doing this LCA? The results of the LCA when combined with a closely integrated economic assessment performed by the economic contractor will provide sufficient broad information to be used by CalRecycle that is the name of the company to fulfill its duties pursuant to section so and so. So, basically what they are trying to do is they are trying to put in or being accepted by a legislature that is being brought in by the California government and they would want to bring in the numbers in the economic numbers and the environmental numbers. So, they are clearly stating that they would want to meet the legislative requirements of a particular government guidelines and for which they are doing an LCA and this LCA would be very closely linked to an economic analysis as well. What is the intended use? The use is namely to provide suggestions to the legislature regarding possible policy changes to promote increased collection and responsible management of used oil. They would also want these numbers to come out so that they can guide the legislature or the decision making or the think tanks to come up with particular policy that can help in future propagation of such a methodology that is good for the larger good of the society. Who is the intended audience? The intended audience of the study is CalRecycle of course the study who is conducting the study all industries involved in and affected by the management of used oil generated in California and the public at large. So, they are clearly stating that the primary audience would be the companies that are involved in the management of used oil particularly in the state of California and the people who are linked to it.

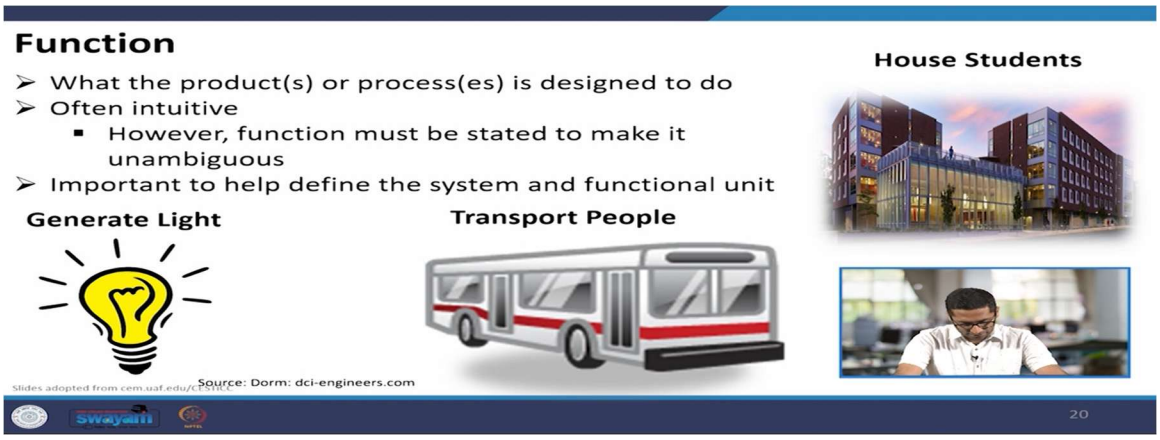
The results they say in the study are intended to be used for comparative assertions which means they would also want to compare them with the earlier studies or similar pathways

that have been suggested and it is intended to be disclosed to the public at large. So, the results are not something that are confidential that need not be going out. They are available to the public so that public can understand try to understand the methodologies adopted and can make their own decisions.

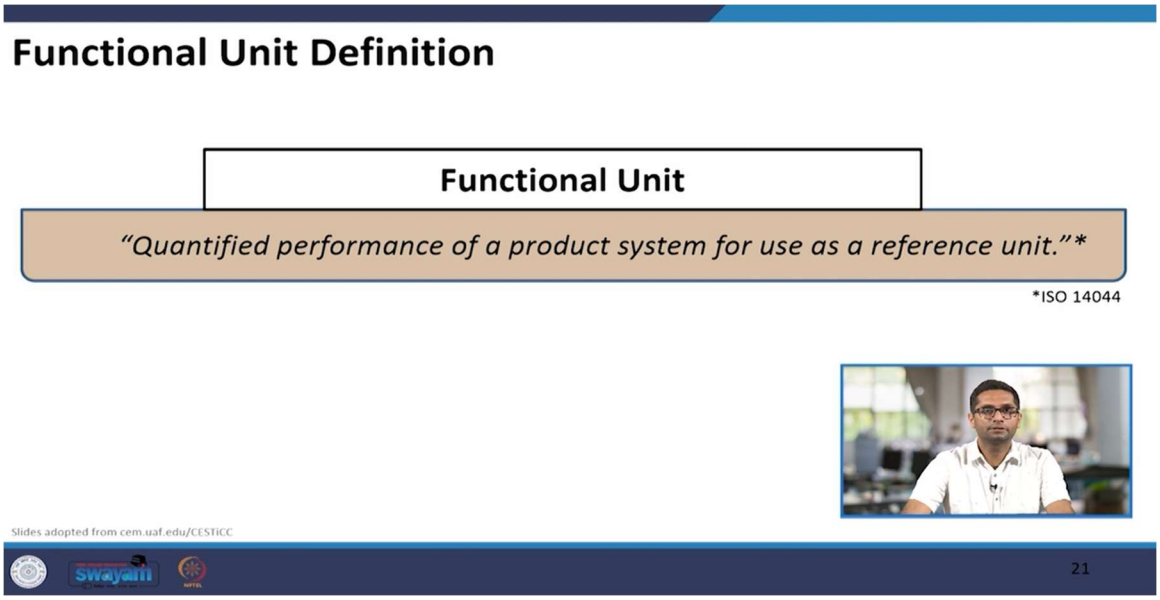


Further, we have been discussing the importance of goal and scope or putting the goal statement earlier but it is not always clear why is the goals very important. So, in the earlier slide we have tried to understand very nicely put in goal statement by a company called CalRecycle. So, does that answer a few questions or like how does the goal statement affect the different kinds of methodologies that you are undertaking. So, the first thing is like one would want to understand like in the results that I am putting in whether I should put in some technical jargon into the final results because like these are the jargon that could be something that is used quite often in the fuel recycling or the oil recycling industry but might not be very commonly known to the people in general. So, if I go with the goal statement it clearly states that public among the intended audience. So, the results are to be disclosed to the public that means that if I am including the technical jargons with respect to the conversion of oil or the different quantities or the qualities of coal I would also have to define these terms because the public is one of the readers of this particular study. So, this is where the goal statement makes an effect. It particularly defines what are the types of things that would go into the report. So, since this report is to be disclosed to the public I would also have to include the definitions of the technical terms that I will be using.

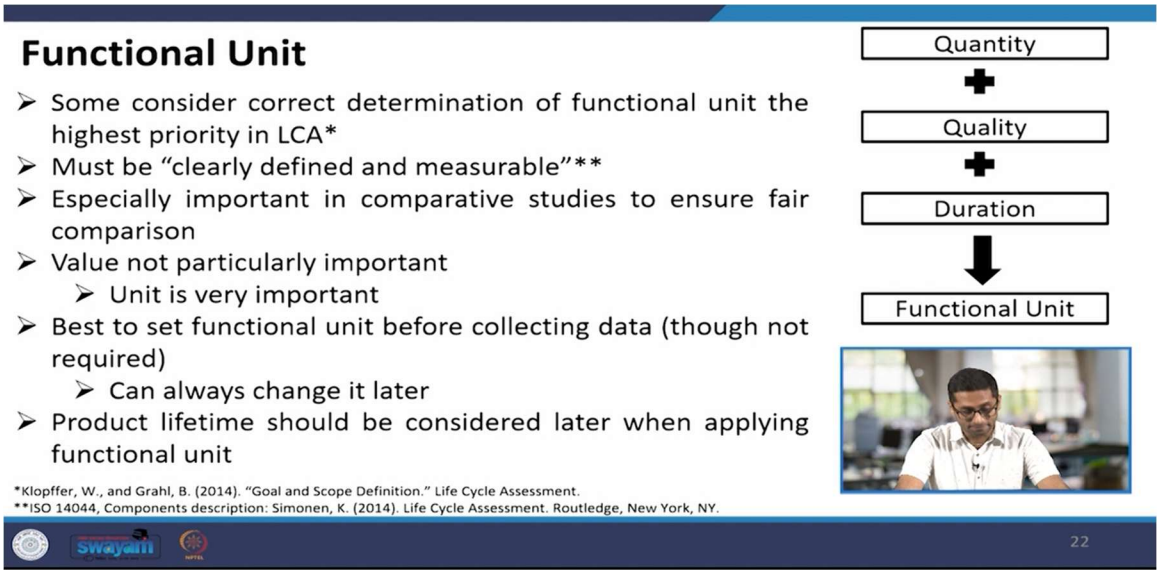
Further, should I include the multiple scenarios covering different combinations of disposal techniques? There could be multiple scenarios in which we are collecting the oil from different industries, there could be different sources, there could be different collection mechanisms, there could be different transportation mechanisms, there could be different storage mechanisms, there could be different conversion mechanisms. Do we do different kinds of scenarios to bring up okay this particular scenario might have more emissions, this particular scenario might have less emissions. Let us go back to the goal statement. The goal statement says intended to provide input to the legislature for policy development. Now, since my aim is to give in a comprehensive framework for the policy development it is imperative that I make few scenarios or multiple scenarios that compares the different kinds of supply chains and the different methodologies updated. So, this is again a way in which the goal statement is dictating the type like whether I should go with one scenario or multiple scenarios. Since in the goal statement I state that I would have to provide in guidance for policy development I would necessarily have to go with multiple scenarios to provide an insights to the policy makers so that they can come up with a constructive policy. Further, do I also analyze the general impacts of other entities to be able to use this data? Well, can means like do what the other impacts in other countries be taken into account as well? Well, the goal statement clearly states that it is carried out specifically to serve decision making in the state of California. So, if I am working in the California I might not want to put in the general impacts that are pertaining to the other regions of the world. So, it is a no. So, this is again a place or another way in which the goal statement is guiding what kind of assumptions that I would be taking for this LCA study.



Now coming to the function according to which functional unit is designed. So, this function would basically come in the scope definition of the particular LCA study that we are doing. It basically pertains to the different products or the processes which I am focusing on. So, if I talk about the function it is what the process or the process is designed to do. So, if I am talking about a light bulb its function is providing light. If I talk about a bus its function is transporting people. If I talk about a hostel it is to house students. But these might not be the only function they serve. A typical light bulb can also be used for providing heating requirements such a typical application could be incubators. A bus could also be used for transportation of luggage something that we see in the transportation buses in the airports. A typical student dormitory or hostel could also be used for holding student events. So, that is not the only function these kind of entities only serve. So, it is very important to put in the functions or the different types of functions that could be served by a particular entity and then bring up a function that we are interested in. So, it is very important to understand the system and the function. Let us do it as we move further.



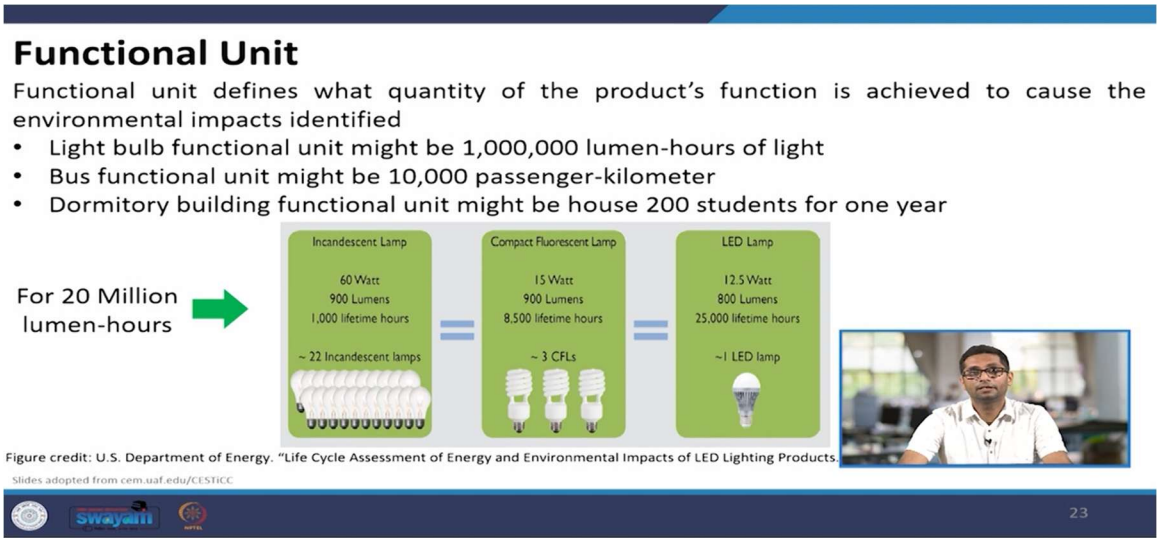
So, if I go with the functional unit definition for that is given in the ISO guideline it goes as it is a quantified performance of a product system for use as a reference unit. So, I would want to use this particular functional unit as a reference unit and I would be quantifying the performance of this product related to this reference unit.



So, let us try to understand some of the features of the functional unit that are important. Well, it is one of the most important things of defining an LCA. Some people consider that this is one place which tends to have the highest priority when doing an LCA. Because a wrong functional unit could lead to wrong conclusions altogether. It must be clearly defined and measurable. You should be able to define it easily, it should be able to be understood and it should be measurable. Because if it is not measurable how would you normalize the impacts according to this functional unit. Further, it is important that it is easily acceptable the functional unit can help you compare with other studies as well. Because there would be other studies, other LCA studies for the similar domains that have been done by other authors and other entities. So, it might help a comparative analysis or comparison with those studies as well. It is mainly the unit that is more important than the value. So, if we are talking about, if you took the example that we have seen in the earlier example like a functional unit for comparing the different light bulbs could be 1 million lumen-hours. So, 1 million 50,000 50 lakh could be the number that is not very important. It is the lumen-hours that is important. Further, if I am talking about comparison of the different transportation options it could be 10,000 passenger kilometers. So, it is the passenger kilometer unit that is more important. 5000, 10,000, 20,000 does not make much of a difference. And it is always best to set up functional unit before you start collecting the data. Although it is not always required but it is always better to select the functional unit and then go with data collection. Further, it has been

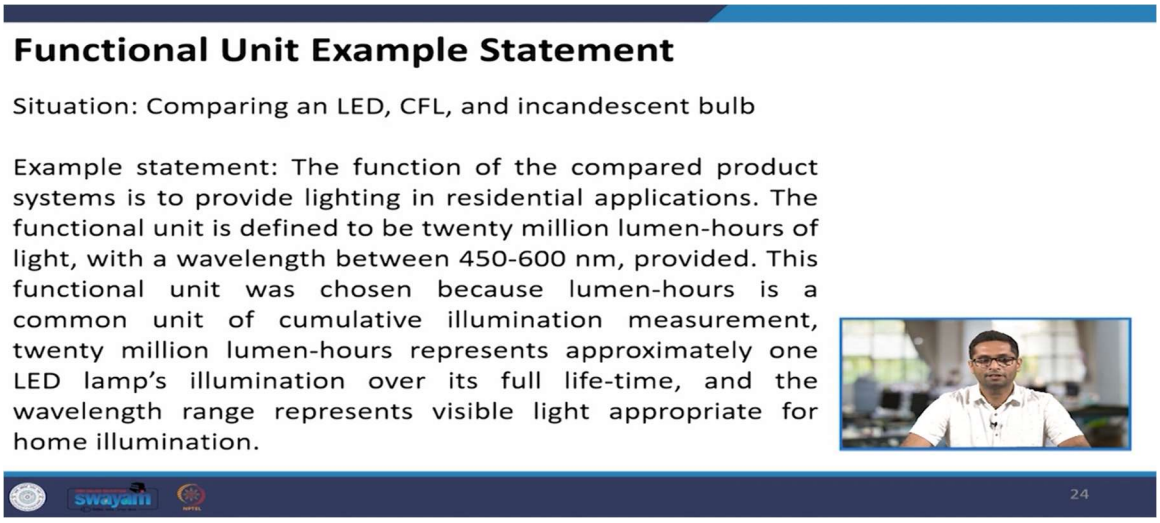
told that a good functional unit should have these three features. It should pertain to the quality, quantity and the duration of a particular entity. So, what do I mean? So, if I am going with a comparison of the different light bulbs. So, if I am talking about lumen-hours maybe 1 million lumen-hours. So, 1 million basically pertains or 1 particular lumen pertains to the quantity of light that is being generated, hours basically pertain to the duration. Quality aspect is something that is often overlooked.

So, a good quality aspect could be the wavelength or the radiation wavelength that pertains to the light. So, a good functional unit has been suggested should have these three features. It should pertain to the quantity, it should also pertain to the quality of that product that is being produced and the duration for which it is being produced. Say for the example of again everyone is talking about green hydrogen. So, there could be different processes that would be producing hydrogen at different purity and this is where the quality of hydrogen that is produced becomes of paramount importance.



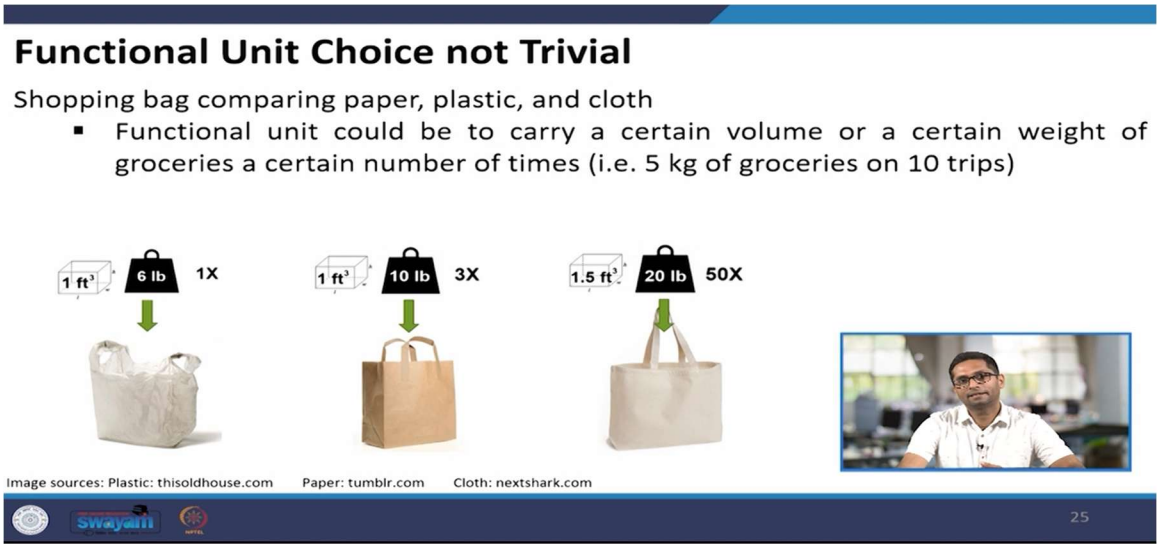
So, let us try to understand the concept of functional unit with the help of again the example that we have studied. So, let us take the example of a typical light bulb and a typical unit could be 1 million lumen-hours. Now, if we are comparing like three different options which could be incandescent bulbs, a CFL bulb and the LED bulb, we need to understand all the three options would have different power ratings. A typical incandescent bulb could have a power rating of 60 watts, CFL could be 15 watts and LED could be somewhat lesser maybe around 10.5 watts. Further, the light that they emit

could be very different. It could be 900 lumens for CFLs and incandescent bulbs but could be slightly lesser for an LED bulb. So, again there could be a wide disparity amongst the lifespan of these bulbs whereas an incandescent bulb could last maybe 1000 hours, it could be as high as 25,000 hours for an LED bulb. So, if you talk about the luminous, maybe if I am talking about a typical unit of 20 million lumen-hours, so one LED bulb might be able to provide the same amount of these kinds of function as compared to three CFLs and 22 incandescent bulbs. And this is where the importance of function unit comes into importance. It helps you do a justifiable comparison between different options which might not always be possible because the different systems would have very different dynamics. In a similar way, a function rate could for a bus or the different transportation options could be 10,000 passenger kilometres. Again, as I have told earlier, the number 10,000, 15,000 or 50,000 doesn't make much of a difference but it's the unit that is passenger kilometre that makes a difference. Again, you can see in here, we would have the element of passenger that basically refers to the quantity and kilometre basically also pertains to the duration because it's always a function of speed. Further, if you would want to compare the different dormitories or the hostel buildings in which you are living, a typical function unit could be 200 students that are housed for a year. So, this could be a function unit.



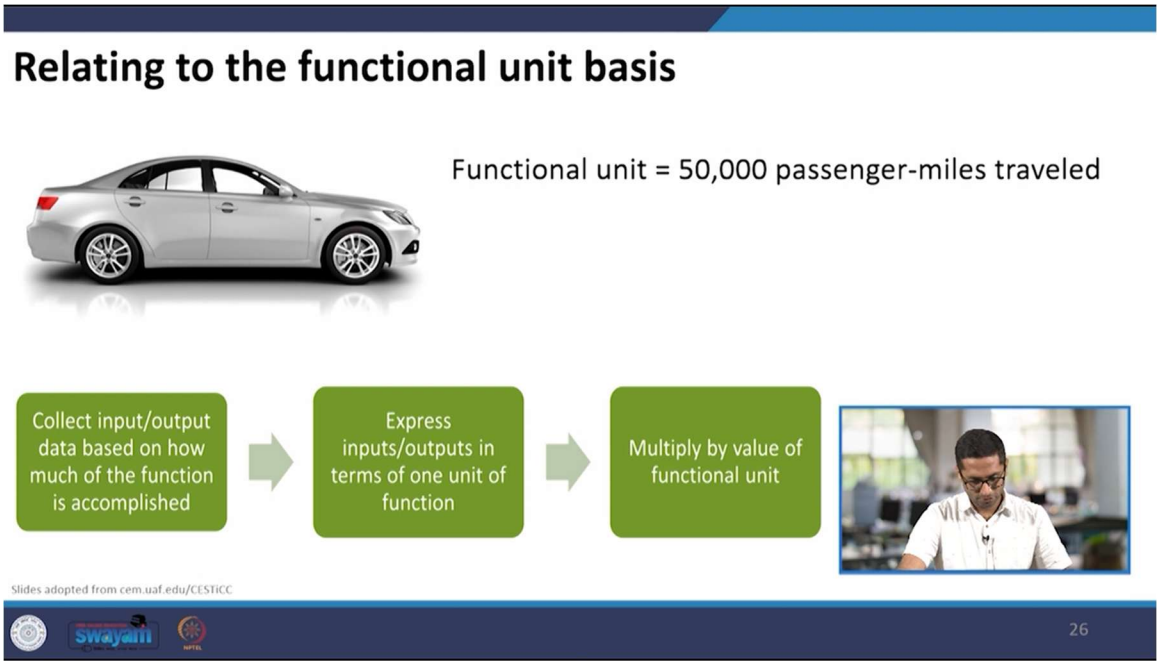
Let us try to understand the function unit with the help of an example. It's very important to state why have you chosen a function unit, what purpose that is served. So, here we have taken again a statement from an LCA which is trying to compare the LED bulbs, the

CFL bulbs and the incandescent bulbs. And let us try to understand their reasoning for selecting 20 million lumen-hours as a function unit. So, their first point in the function of the compared product systems is to provide lightning in the residential applications. So, they are putting in that what is the application for or the function for which the function system or function unit has been adopted. It's basically providing lightning in the residential applications. The function unit is defined to be 20 million lumen-hours of life with a wavelength between 450 to 600 nanometres provided. So, what they are now doing in the next thing, they are defining the function unit. The function unit is 20 million lumen-hours and they are going a step ahead also providing the quality. So, the quality of the function unit is that the light that is produced should have a wavelength between 450 to 600 nanometres. This function unit was chosen because lumen-hours is a common unit of cumulative illumination measurement. And 20 million lumen-hours represent approximately 1 LED lamp. So, they are also giving the reason why would have they have gone for 20 million lumen-hours. The reason is because that approximately gives in the type of illumination that you would get from an LED bulb and that is way larger than an CFL bulb over a incandescent bulb. So, that basically brings in a good comparison and the wavelength range basically represents the visible light for that is appropriate for home illumination and they are also giving a reason why this kind of quality has been indicated. So, here in we get a very good example where we have all the three features that is quantity, quality and duration including a function unit and this is what is expected in a good LCA as well.



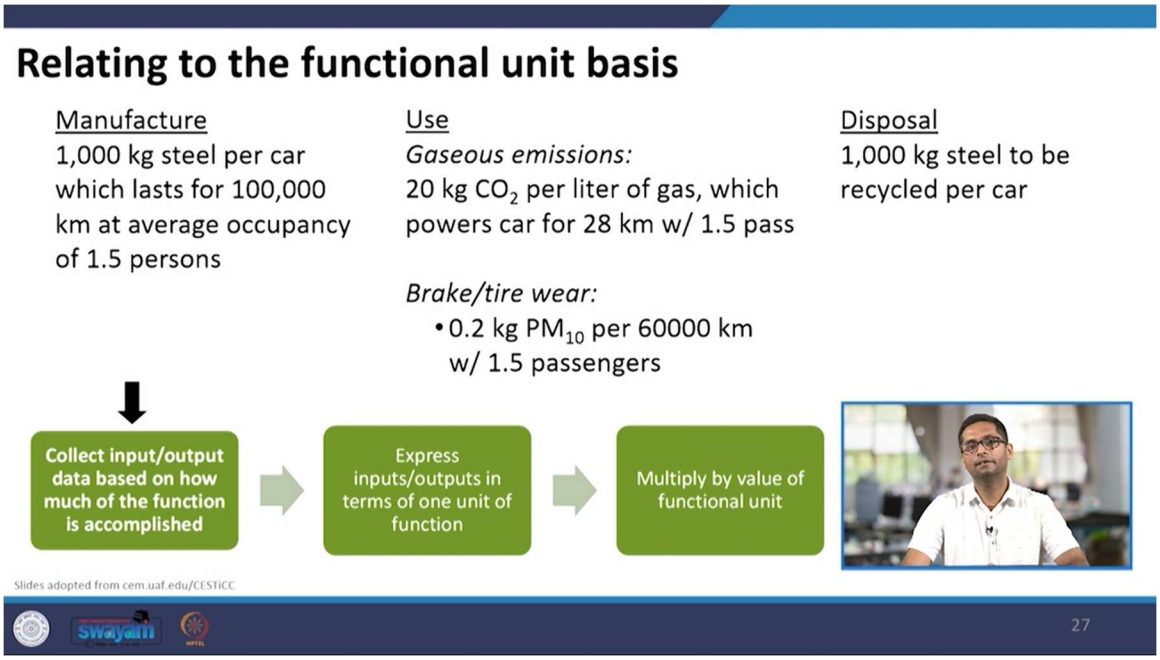
Further, it might come to you or some of you might think that the choice of the functional unit is very easy or very trivial. Let us try to understand with the help of another example that it is not very easy after all. Suppose the task that I have in hand is like I want to compare a plastic bag with a paper bag and a cloth bag. Now all the three different bags would have different weight carrying capacity, volume carrying capacity and the different types of lifespan in that like how many times they could be used. So, let us take a hypothetical case of course this is like we have just put in the numbers. So, suppose I am talking about a plastic bag, I can use this plastic bag at once, one time only. It might be able to have a volume of around 1 feet cube and the type of weight that it can put in is around 6 pounds. Compare that with a paper bag which I can reuse at max 3 times and the volume capacity of this bag remains the same.

Whereas the weight capacity could be a bit higher in terms of 10 pounds of weight that it can handle. The plastic bag was 6 pounds of weight, a paper bag maybe can handle 10 pounds of weight. Further, if I talk about the cloth bag, maybe I can use this for 50 times before it wears and tears. The volume capacity would be a bit larger in terms of 1.5 feet cube and then the weight carrying capacity could be almost 20 pounds of weight. Now suppose I fix a functional unit in it where I say like the varying capacity, like I would want to compare the different kinds of bags for a volume capacity of 1 feet cube for 1 trip. So, in this case a paper bag would be almost 3x times better than a plastic bag. Whereas if I choose a capacity of like maybe 1 pound of weight over 1 trip, a paper bag would come out to be 5x better than a plastic bag because a paper bag has much more weight carrying capacity. So, in that case like the number of times or the number of betterments that you expect in a paper bag as compared to the plastic bag change just on the decision of a functional unit in it. So, the choice of function in it is not very easy. It has to take in a lot of considerations and again one function in it that could be good for such kind of unit could be 5 kgs of groceries for 10 trips. So this basically brings in the quantity aspect as well as the time aspect in terms of 10 trips.



Let us also try to understand like how would you normally use a functional unit, what is the role that is playing by a function in it in the long run. Of course like we have decided that we will be adopting so and so function in it for a study but how would be using this function in it as we move further in LCA.

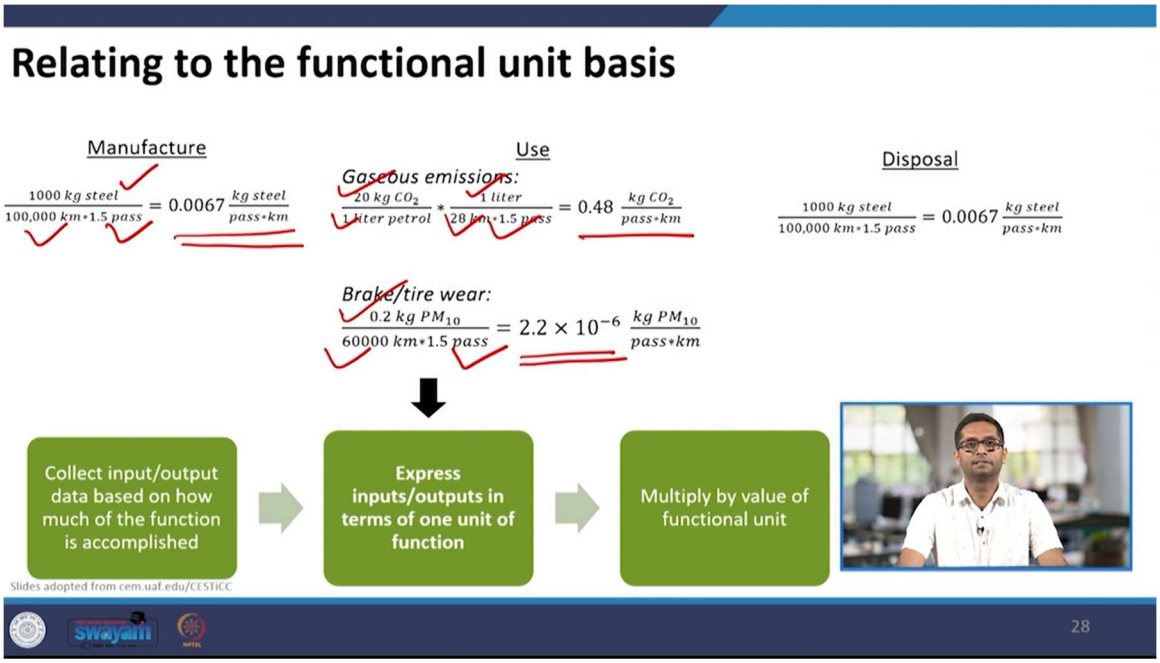
Let us try to understand that. Now suppose I would want to compare the different kinds of four wheelers. So let us take into account a luxury car and the functional unit that I have chosen for that car is 50,000 passenger miles travelled or passenger kilometres travelled. So what I would do is first thing is I would want to collect the different input output data on how much of the function is accomplished. Then I would express the different inputs and outputs related to the one unit of this functional unitand finally I would multiply this by the value of the function in it which is 50,000. So what I would have to do first I would be collecting all the possible inputs and outputs pertaining to this particular system that I am comparing. Then I would be understanding the different inputs and outputs for one unit of this function in it and then multiply with the number of functional unit or like 50,000 in this case. So let us go through this example one by one.



Let us take this particular car into example. So this car I have taken again a hypothetical scenario would involve the manufacturing phase, the use phase and the disposal phase. So in the manufacturing phase I am estimating that it would involve almost 1000 kgs of steel, one ton is the typical weight of a car. So I am assuming like all of it is steel, so 1000 kgs of steel per car and it is expected that this particular car would last for 1 lakh kilometers and the average occupancy for this car would be 1.5%. So sometime there would be 1%, sometime there would be 2% traveling in this car since it is a luxury car.

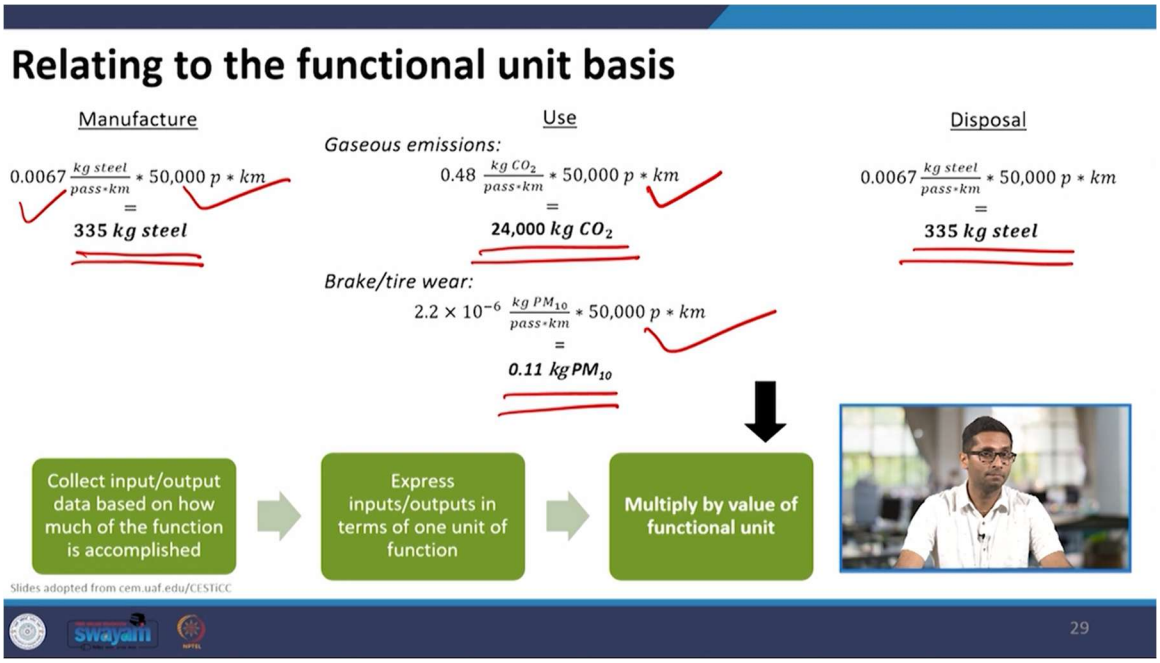
So on an average I have assumed to be 1.5%. So here in I am trying to quantify the different inputs and outputs. So this is with respect to the manufacturing phase. Now let us go to the use phase. So whenever I am using the car this would be emitting CO2 emissions in the tailpipe. So I am assuming that like it would be emitting around 20 kgs of CO2 per kg or per liter of petrol that it is choosing and it would power the car and the typical mileage of the car that I have taken on the higher side maybe 28 kilometers per liter. So gas here is another acronym that is used for petrol and again I am assuming it will be carrying 1.5 passengers. Further there would be some emissions by the particulate emissions because of the wear and tear that is happening in the brakes as well as the tires and this would be very small in amount and for this I have taken and assumed a number like it would be around 0.2 kgs or roughly 200 grams of particulate matter at 10

micrometer per 60,000 kilometers of car travelled with 1.5 passengers. So here I am choosing like there could be some particulate emissions that are happening from the wear and tear that is happening in the brakes as well as the tire and this has been assumed to be very less almost 0.2 kgs and that happens for per 60,000 kilometers travelled by the car with 1.5 passengers. Further at the end of the life of the car maybe after 1 lakh kilometers it will be disposed of it will be scrapped and 1 kg or 1000 kgs of steel is recycled back. So this is with respect to putting down the different kinds of inputs and outputs. Now I would have to express all these inputs and outputs relative to one unit of the function. So the function that I was taking discussing earlier was 1 passenger kilometer. So I would have to normalize this impacts per 1 passenger kilometer.



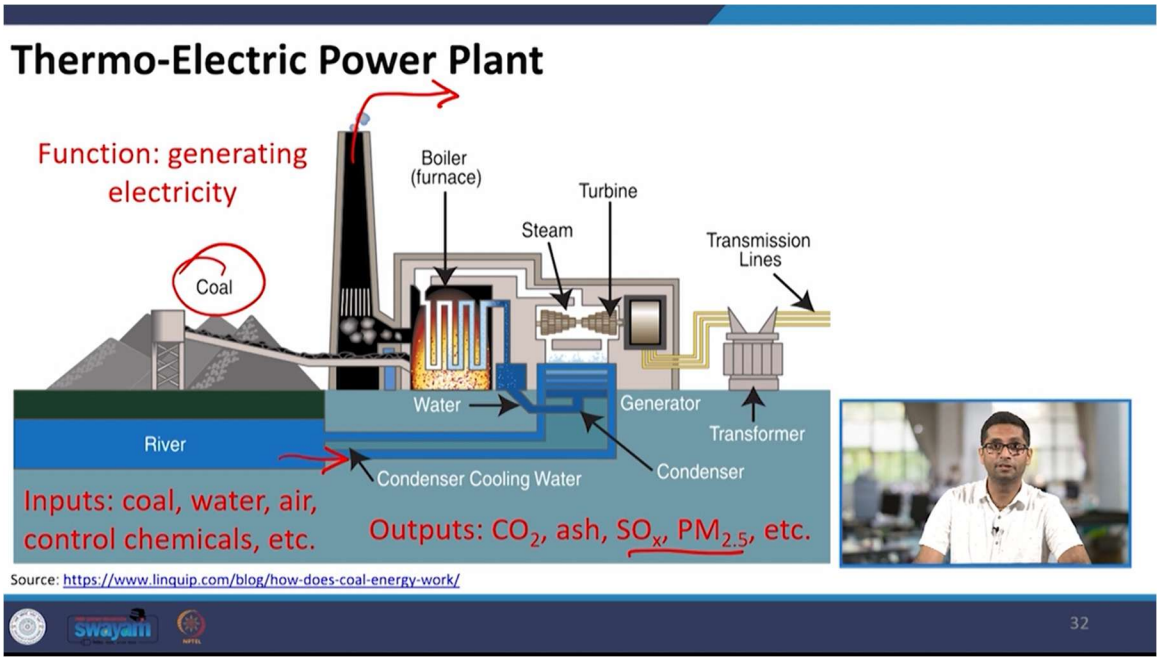
So let us do that. So in the manufacturing phase so I would have 1000 kgs of steel and I would be using this 1000 kgs of steel over the lifespan of a vehicle which basically traveling 1 lakh kilometers with 1.5 passengers on an average. So I divide this 1000 with 1 lakh and 1.5 this gives me the kgs of steel per passenger kilometer. So these are the relative amounts of the input for the manufacturing or relative amount of steel that would go for 1 passenger kilometer. In the use phase I am emitting 20 kgs of CO2 for 1 liter of petrol and again for this 1 liter of petrol the car is able to travel 28 kilometers which is the mileage and it is also carrying 1.5 passengers. So multiplying all these numbers gives me

0.48 kgs of CO2 that is emitted to the atmosphere per passenger kilometer. Now 1 passenger kilometer was again the 1 unit of the function that I have chosen. Something similar I would want to doing from the particulate matter emissions from the brake and wear and tear. So it was 0.2 kgs of PM10 particles divided that with 60000 kilometers since it is an assumption that for every 60000 kilometers of distance travelled the amount of wear and tear that will be happening would be around 200 grams of 0.2 kgs and multiplying that with average number of passengers which is 1.5 passengers and this gives me the number which pertains to the particulate matter emissions from this particular car per passenger kilometer. A similar thing I can do for the disposal the weight of the car remains the same 1000 kgs of steel 1 lakh kilometers multiplied by 1.5 passengers and the same amount of steel is getting recycled or disposed. Now the next step would be to multiply these numbers with the functional unit number which was 50000 passenger kilometers.



So this is what I have done in the next part of the algorithm. So we initially had 0.0067 kgs of steel per passenger kilometer multiplied that with 50000 passenger kilometer. So this is the amount of steel that I will be using in a manufacturing phase for this amount of which is 50000 passenger kilometers. Similar multiplication for the emissions of CO2 as well as the PM10 and this gives me the number of emissions that happen for 50000

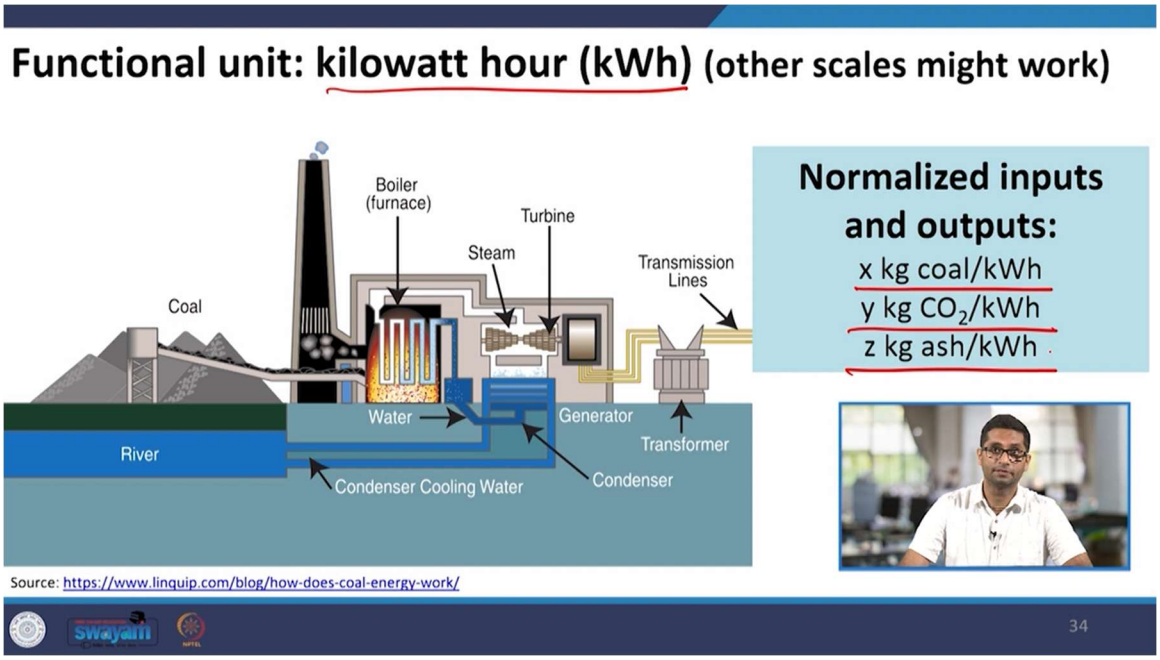
passenger kilometers. A similar methodology for the disposal phase again which remains same as the one used for manufacturing. Again one can say that like you can calculate all these numbers at once of course you can do if these flows are very small in number but as the number of emissions and the number of process stages increases as you would typically find in an LCA process it becomes very difficult and you would have to use many specialized software or excel based sheets or tools like MATLAB to accomplish these tasks. Let us also try to understand these aspects with the help of another example.



So suppose let us take into account a typical thermal based power plant. So what is the function of this power plant? It's basically production of electricity. So what does this plant do? We would have the coal going in and the coal is used for burning or the coal is combusted.

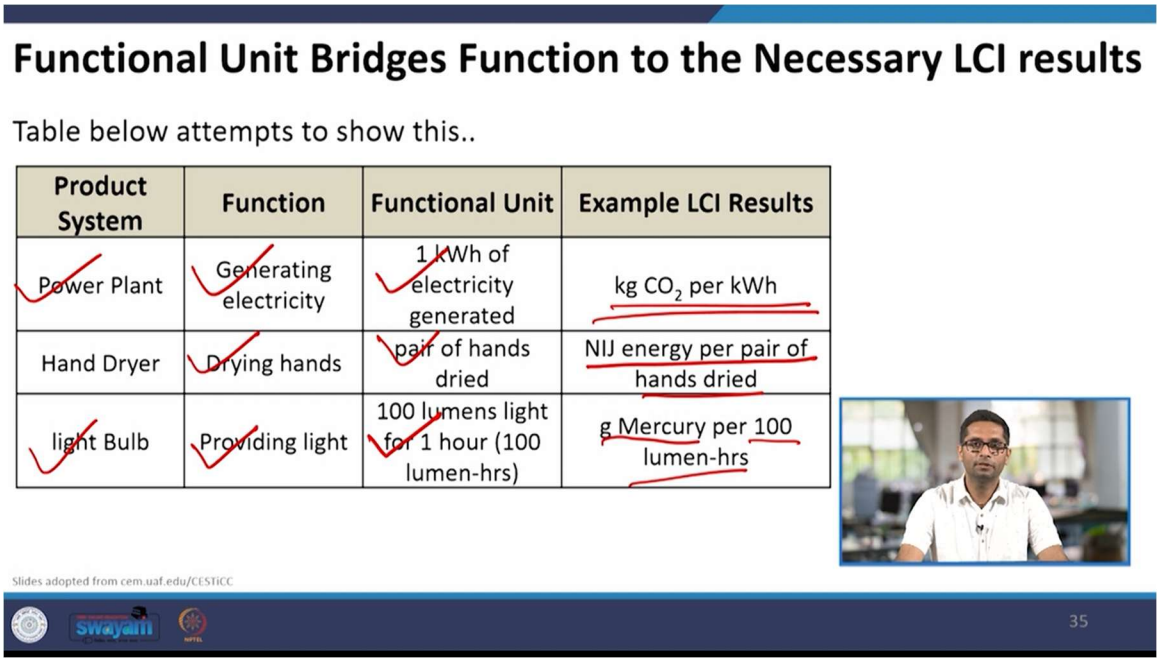
The combusted coal is used for raising the temperature of water which is converted into steam and this so we have this once through boiler where you have the water coming in. So we would have the water in here and this would be raising steam and then the steam is being used to run the turbines which is coupled with an alternator producing electricity and this electricity is going to the grid. Of course you would have the condenser and the cooling water coming in. So if I talk about the different inputs and outputs that go into this rather typical power plant. If I talk about the inputs, the inputs would basically be the

coal that is the basic feedstock for production of electricity that is what is producing heat. You need water as cooling water. We have discussed these examples earlier in terms of the environmental effects as well. You would need air for combustion and there is no combustion possible without the availability of oxygen. Then you would also need some kind of catalyst, some kind of chemicals that help in controlling the chemicals and there could be some other kinds of lubrications and other small amount of chemicals that would be going in. If I talk about the outputs, the outputs would particularly be the CO2 emission or the stack gas emission and this would also have the different SOX and particulate matters coming out in here. Another emission that would come up will be the ash that is created or the left over from the coal and that needs to be disposed off again. So there would be a different variety of inputs and different variety of outputs going in for this rather typical coal based power plant.



So if I was to ask like what would be a good function unit that could be helped to normalize all the inputs and outputs. Well there could be many choice people can say maybe one ton of coal, one million cubic meters of water, it could be a million tons of ash, it could be 1000 kgs of CO2 that is produced, there could be anything. But one of the most typically used function unit could be 1 kilowatt hour of electricity because that is the primary function of this power plant. The power plant exists with the aim of

producing electricity and a way to quantify this electricity could be 1 kilowatt hour. So 1 kilowatt hour basically brings in both the quantity aspect as well as the time duration because when we are talking about kilowatt hour it is basically an energy unit. So the functional unit for this particular could be 1 kilowatt hour, there could be others, it could be 1 megawatt hour, 1 gigawatt hour as per the convenience of others. And what I would be doing later on I would want to quantify the amount of coal that is getting used per kilowatt hour of electricity. The amount of CO2 that is produced per kilowatt hour of electricity and the amount of ash that might be produced per kilowatt hour of electricity. So this is how I would be using the functional unit, I would be quantifying all the emissions with respect to one unit of electricity produced.



And there could be different function units that could be coming up for different kinds of systems. So suppose I am talking about a power plant, a typical function for that power plant would be generating electricity, a good function unit would be 1 kilowatt hour of electricity generated. One typical example of the type of result that I would be getting would be the kgs of CO2 per kilowatt hour of electricity that is generated. Suppose I would want to compare different hand dryers, the function would be drying hand, the functional unit would be the pair of hand dried and what could be the result? It could be the net energy per pair of hand dried. A typical example for the light bulb would be

providing light, it could be 100 lumens of light for 1 hour or 100 lumen-hours and a typical result could be maybe grams of mercury that is emitted per 100 lumen-hours.

So these are some examples to make you understand the importance of functional unit. It is not a very trivial task, how that is used for normalizing all the impacts for the different inputs and outputs that happen throughout the life cycle of a product and process that is being considered. With this we end today's class. In the next class we will be putting in more emphasis towards discussing the system boundary, how do we understand the system as a whole and what are the different types of consideration that need to be put into it. Thank you.