**Advanced Topics in the Science and Technology of Concrete**
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**Life Cycle Assessment of Cements and Concretes: Part 1**

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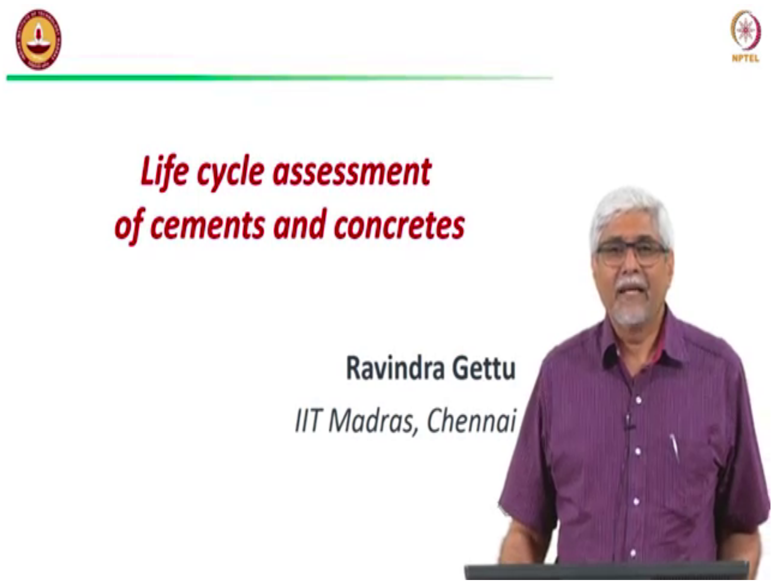


Welcome to this lecture on Life Cycle Assessment of Cements and Concrete, my name is Ravindra Gettu, I am a professor of Civil Engineering at IIT, Madras. There is a lot of discussion there is a lot of web going on there is lot of emphasis on sustainability, green materials, green technologies and so on. Now (what) the beginning or the first thing that we have to do when we talk about sustainability and green aspects is that we have to know what is the environmental impact of a certain material or technology.

So that is what we are going to talk about in this lecture will discuss how to go about doing life cycle assessment which gives us the numbers which relate to the environmental impact and in the next lecture we will take up a case study and we will compare different materials and see how the process that we discuss in this lecture can be applied.

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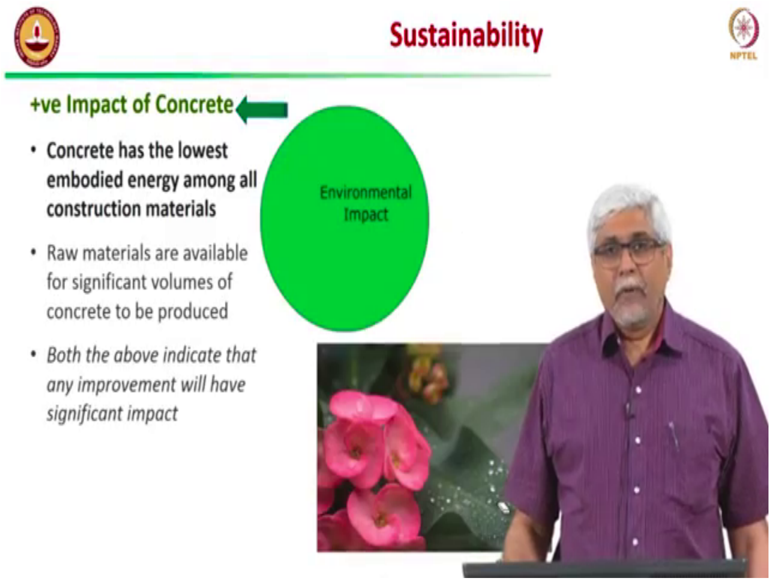


Now before we go on to looking at life cycle assessment lets look quickly at why it is necessary to assess sustainability and why do we have to give so much importance. Now whenever we talk about sustainability the first thing that comes to anyone's mind is the environmental impact and what I have done is to look at the positive and the negative impact because something can also be good or bad and we did not always focus on what is bad for the environment. So if you look at the positive impact of concrete and environment we know that concrete has the lowest embodied energy among all construction materials.

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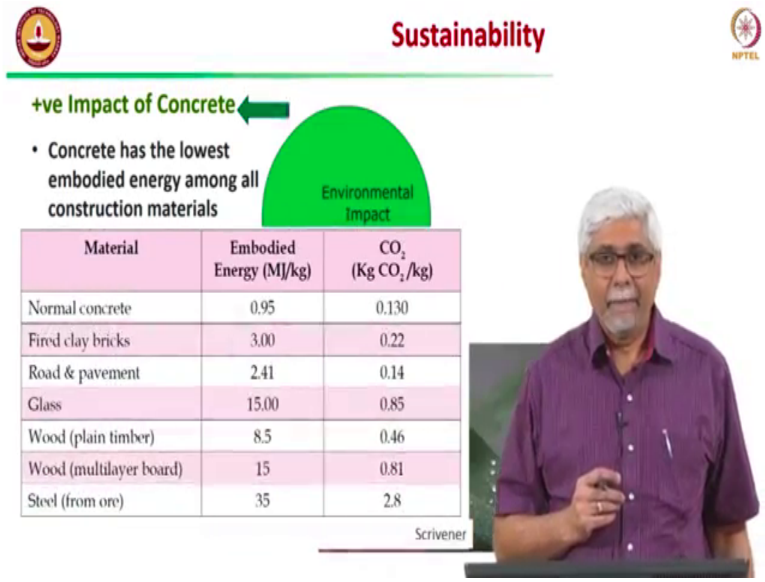


So if you go to this table that I have borrowed from Karen Scrivener it shows the embodied energy and the carbon dioxide emission for 1 kilogram of different materials. So you have concrete right at the top then you have bricks, road and payment materials, glass, wood and steel and we find that if you compare a unit weight of this different materials all of this being construction materials we find that concrete has the least embodied energy.

What is embodied energy? Embodied energy is the energy required to fabricate, to make to manufacture 1 kilogram of that material hence the CO2 emissions are what is given out has greenhouse gases during the production of that material and we find that concrete does very well in turns of this, this two aspects of environmental impact. Obviously the comparison of unit mass is not right to make a structure you will not use the same mass of different materials to make a equivalence structure so you have to keep that in mind that we have to when we are talking about a structure think about how much material is actually involved and then multiply by these unit factors to get the embodied energy in the CO2 emission.

So having said that we also know that for making concrete we need raw material, we need a lot of material to make the cement and aggregates to make the concrete this are generally available they are not going to run out of this type of materials. So that means that for a long time to come we are going to use concrete and concrete will continue to be the material which will have the lowest impact on the environment in terms of a unit volume or mass of the material. This means that we cannot forget about the sustainability aspects of concrete any improvement is not too small for us to do. So we have to look at how to continuously make improvements to decrease the impact, one is sustainability.

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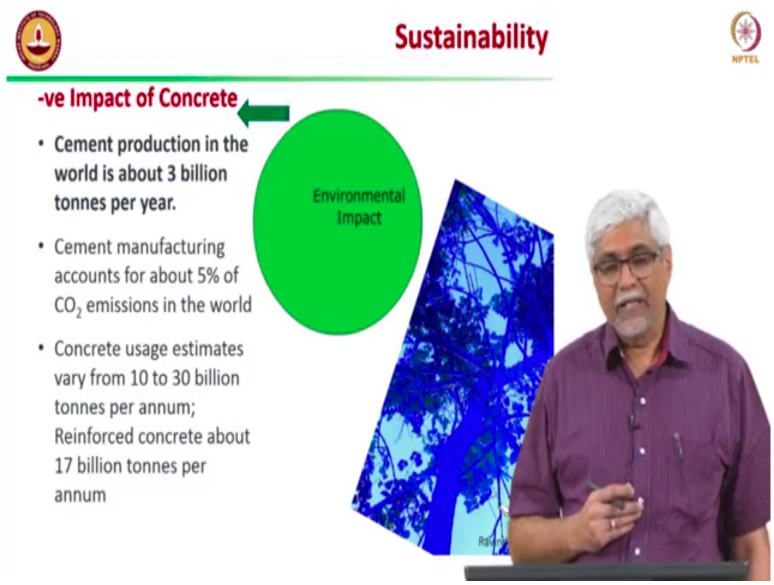


So having talked about the positive impact of concrete we also have to look at the negative impact. We use a lot of cement in the world we use 3 billion tons per year and this looks like it is always going to keep increasing.

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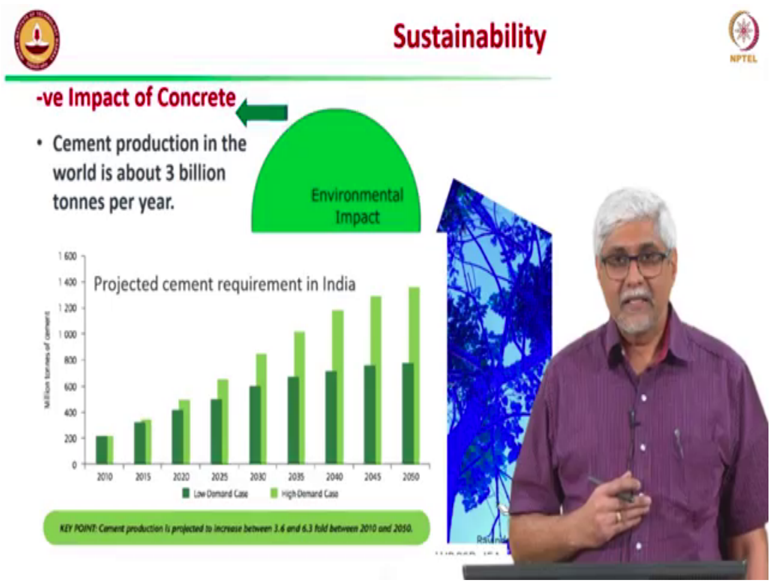


If we look at the numbers for India alone, it is projected that in 2050 we will be producing or we will be needing anything from 800 million tons to about 1300 million tons of cement. So this means that we require a lot of raw materials and during the process of the manufacturing of cement we need we are emitting a lot of CO2, 5 percent of the CO2 emissions in the world is attributed to cement manufacturing that means that 120$^{th}$ part of all the CO2 emissions given off in the world are coming from cement manufacturing.

Other than cement for concrete we need aggregates for reinforce concrete we need a lot of steel and the numbers are mind boggling 10 to 30 billion tons is the estimate per year of concrete usage, 17 billion tons of reinforce concrete per year. So this means that if we can save on material if we can use less material more efficiently and if me make the material last longer in the structure we will be reducing the negative impact of concrete (())(05:40).

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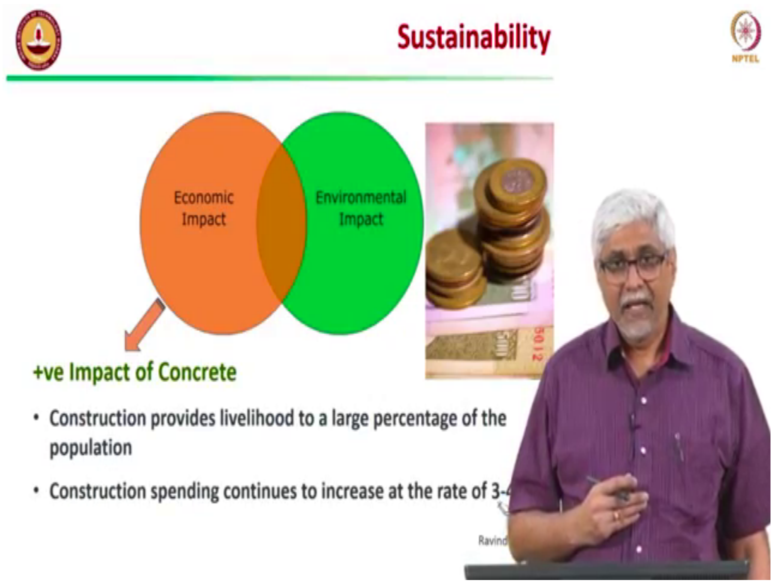


Having looked at the environmental impact what next for sustainability the economic impact. We cannot have something that is green very environmental friendly but very expensive to use, especially in civil engineering cost is very-very important so there is the economic impact to be taken into account. Again let us look at what is positive, what has concrete bring that is the positive impact to the economy. Construction produces livelihood to a large percentage of the population, in India other than agriculture most people are involved in construction lot of migrant labor and lot of unskilled labor, so the constructions a field especially with concrete where not much skill is required therefore lot of people find jobs in the construction sector at least in our country.

It also looks like the construction spending is continuing to increase it is estimated to increase by 3 to 4 percent so it is not that we have are going to run out of construction jobs or not have this feeding into the economy.

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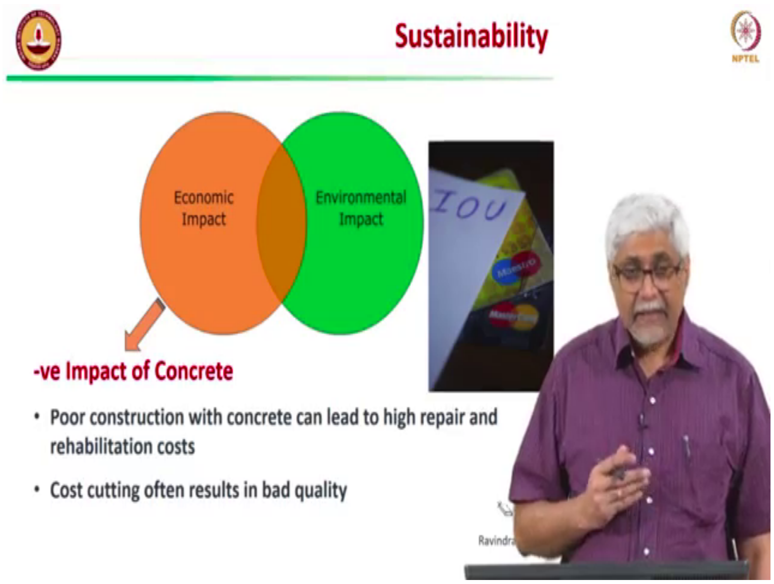


There is also a negative impact and if you think what are the things that could affect the economy negatively arising from concrete, one thing that pops up is poor construction. Concrete is not a standardized material like other construction materials are so therefore concrete could be a bad quality construction could be a bad quality this could lead to high cost for repair and maintenance for rehabilitation for setting things right.

So this means that there could be expenditure that is not contemplated and a recurring expenditure if construction is not done well and whenever we have a project where we are cutting down on cost normally we find that the quality of concrete is sacrificed. So this means that this type of structures will not last as long as they should or we need a lot of maintenance. So there is a negative impact of concrete as well. So we have talked about the two pillars of sustainability, environmental impact and economic impact.

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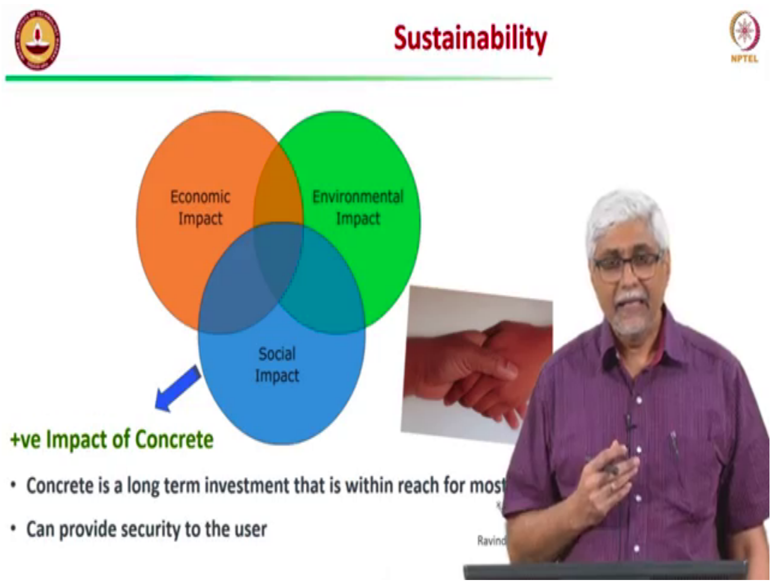


Then there is a third pillar which is very-very important that is the social impact. If you have something green, pro-environment, ecofriendly and economic enough we also have to understand that it has to be socially acceptable only then we can think that material or a technology or a process is sustainable. So the social impact is very-very important and what are the positive things that can from concrete? When we have infrastructure, when we have a house, when we have a home a building something that is made out a concrete is a long term investment it is within the reach of a most and it can last lifetime if not more.

So this is the positive impact it give security to the user, it makes us feel that we have something that is permanent in a certain way.

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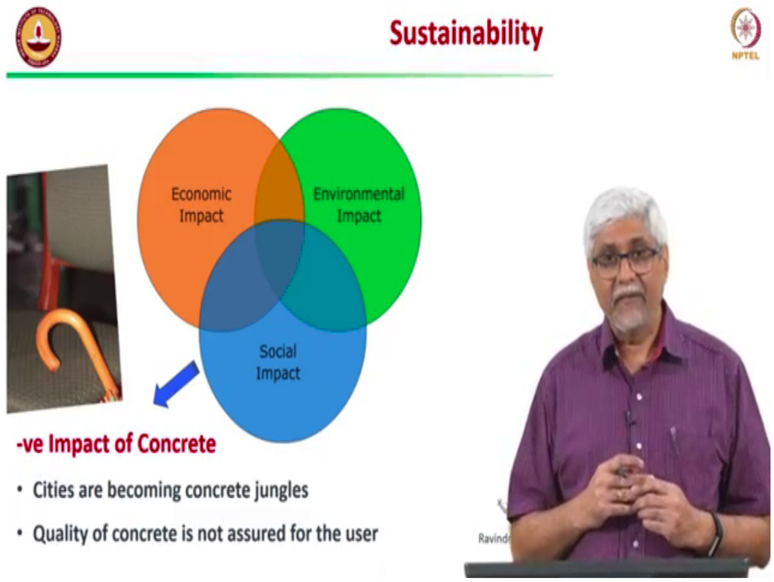


However, there can be negative impacts also, we are constructing a lot cities are becoming concrete jungles as they say. So this means that when we have to change our cities, when we have to demolish we are going to have a lot of trouble, we are going to bring down all this buildings and what are we going to do with the base that we have generate when we have demolition. Another aspect which also could be treated as a negative impact on the society and its way of doing things is that the quality of concrete is not always assure.

Other construction products many-many other products have a certain standard they made in a factory it can be verified that they make in a certain way. Concrete as we all know can be made anywhere, it can be made at the sight in the plant transport and in so on. So the user who has not tested the concrete is not really ensured of the quality, so there is always a benefit of doubt that we have to give to the user, there is also the always this unknown or the feeling that something could have gone gotten wrong. However, we have to think about all this aspects when we look at sustainability.

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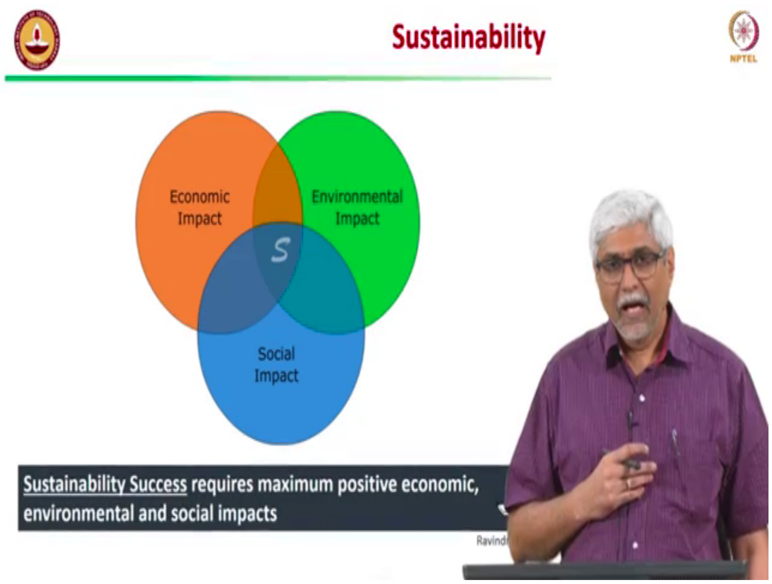


Only when we look at the economic impact, the social impact and very importantly the environmental impact we can say that the technology is successful in terms of sustainability ok. So this tells us that it is important to look at sustainability, it is important to understand what is the role of concrete in sustainable construction and very importantly this means that we have to come up with quantifiers, estimates of the different parameters that could tell us if the concrete is more sustainable or not. Very importantly we have to focus on the environmental impact just by decreasing the amount of Co2 of just by decreasing the cost of a certain material making something look good is not going to make something sustainable. We have to come up in numbers properly founded methodologies to show us if something is sustainable.

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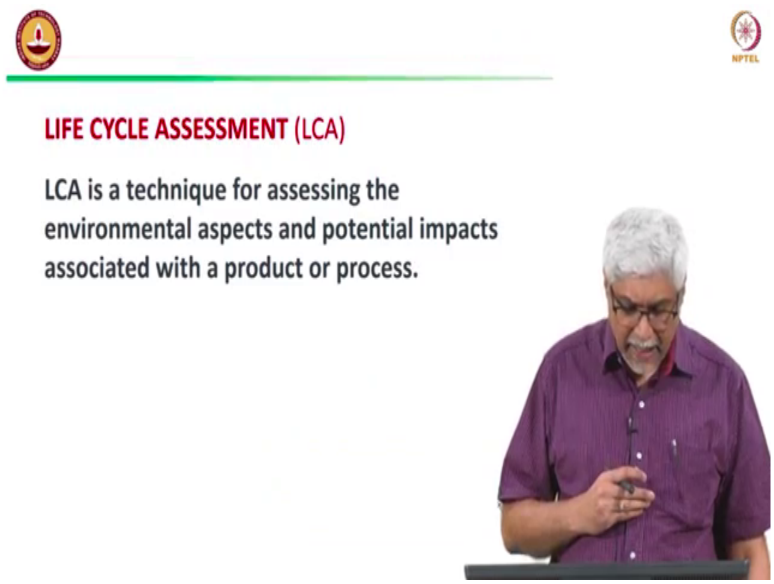


So the first thing that will have to look at or bring in to our assessment is what is called lifecycle assessment. It is a proven technology LCA for short it is a technique or a methodology for assessing the environmental aspects and possible impacts that are coming out or related to any product or process.

So this is a methodology that can be applied to anything we make or any process that we use for manufacturing and it takes into account all the different aspects that could harm or benefit the environment and come up with sort of matrix parameters by which we can judge whether a material is environmentally friendly during its whole life. So as the tittle says lifecycle assessment it is to look at the whole cycle of the life of a material.

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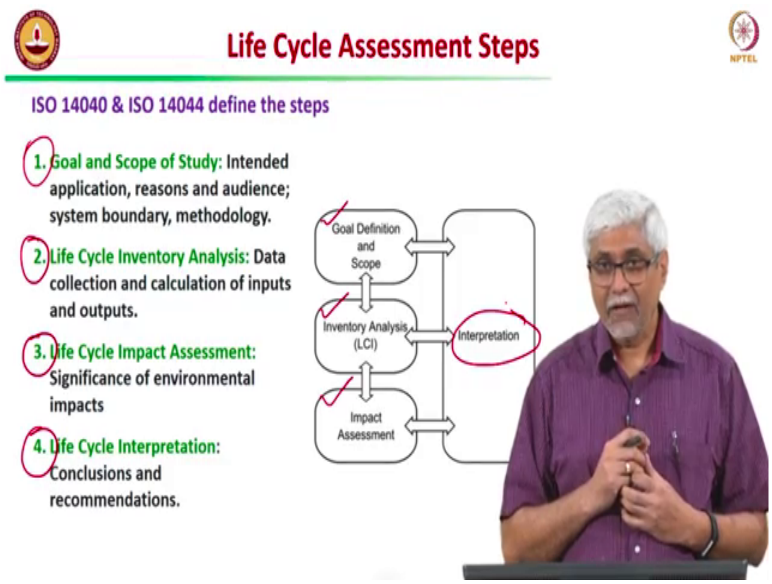


What are the different steps? The assessment follows the steps given by two ISO documents or a set of ISO documents like the 14040 and 14044, its starts with the goal why do we have to do lifecycle assessment? What is the scope? We have to understand what is the application, what are we coming up with numbers for, what we are going to do with the numbers? What are the reasons and who is going to look at this numbers? Then we have to define the system, what all are we going to consider in this assessment, are we going to start with the beginning when the material is coming out of the mines, out of the ground or we are just looking at what is happening inside a factory or a plant, what is the methodology?

Do we have a database ready? Or we have to look at how to get the data and so on. Then the next step is making a inventory, inventory like anybody knows who is being a shop or in factory. Inventory is a collection of what is there and what is not there. So in terms of LCA the lifecycle inventory gives us the data, tells us how to find data of everything that is coming as an input or an output. Whatever is going into the making of the product, whatever is going to go into the process and what are the what is coming out?

The product itself and along with the product what else is happening? Are emissions there? Are gases there? Is there a lot of dust being produced is there lot of debry and so on. So everything that is going into an out is needed. Then we have to put this together and come up with an impact assessment. The inventory is a collection of data we have to transform this data into impacts environmental impacts. How is this going to affect the environment and can we come up with numbers for this? Finally we look at this impacts and say what is our conclusion?

Is the product as good as we thought in terms of the environmental impact if there are two products which product is better, if there two technologies, which technology is better. So we start with a goal we say what is that we are going to achieve, get all the inputs outputs during the inventory, use those inputs and outputs to find out what are the impacts on the environment and then we have enough to do an interpretation and decide which is good and which is bad is it as good as we thought it was, where is that we have to improve the process or the making of a material to make it more ecofriendly or have less impact on the environment.

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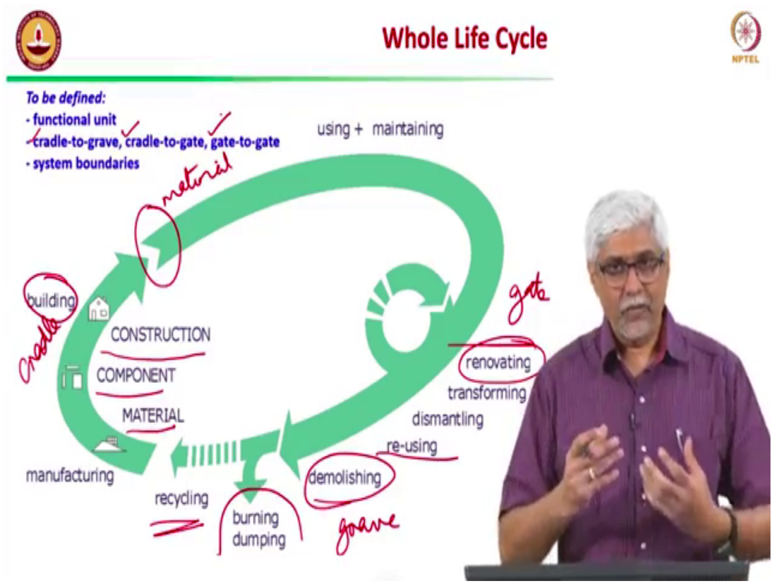


So this tell us the different aspects of a lifecycle, a material is born and then it is used and after sometime in any structure or any application we might have to renew it we might have to transfer it or we have to see how we can reuse it. in construction this is not very common but in many other technologies it is there that you can reuse something. Even in construction there is a possibility of reusing some aspects some materials some elements. Finally, we demolish structure when we run out of the service life, then what happens we might just dump or can we think of recycling.

Now what I skipped was that for making a material we need raw material, we need components to come in and then we have the construction before we get to this stage. So if you are looking at a building this would be the cradle or the beginning often called the cradle and this could be if you are demolishing then this could be the grave if you are just looking at something that is going to be reused maybe this is the gate. So this are different concepts which come in we have to define what is the unit that we are going to look at, are we going to look at the material or something that is already constructed, are we going to look at a building?

So that would be functional unit then are we going to look at this whole cycle or part of the cycle, cradle to grave is the entire cycle, cradle to gate is until a product is finished for example we look at this soon is we make cement. When the cement goes out of the cement plant it is a gate if you are making concrete when the concrete leaves the RMC plant that is a gate. But if we want to look at the whole structure until it is demolish then we are looking at a cradle to (gate) grave. We can also look at gate to gate only what happens within a plant.

Only what happens within the concrete plant for example would be gate to gate, cement is coming in aggregates are coming in and you only worry about until when the concrete leaves. So that means it is gate to gate ok. So we have to understand what system are we looking at so this goes back to our goal, why are we doing this? Who are we trying to convince? What aspects are we going to assess and wed define the system. This is what we are going to consider and let that be clear right from the beginning.

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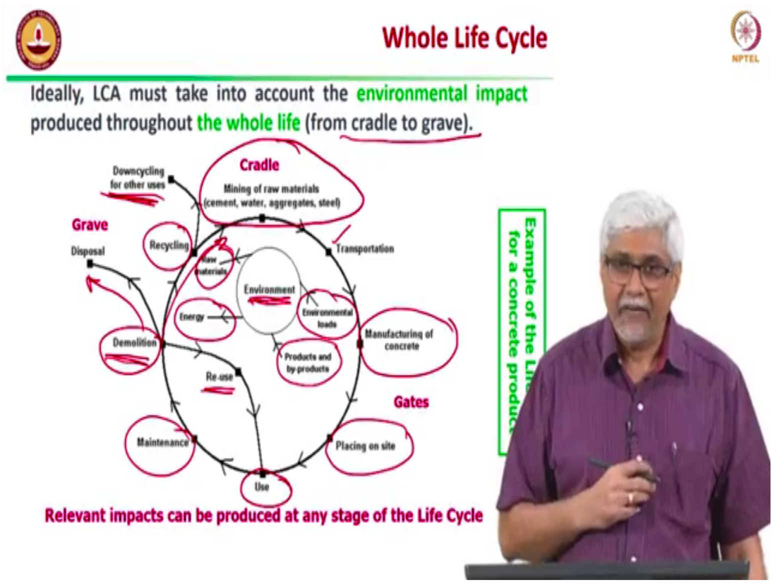


If we take an example of a concrete element or concrete product, ideally we should look at it from cradle to grave but this always very different (difficult) because there are many different ways concrete can be used many different ways, cement can be used and to track and to trace all the details is not that easy. So very often we look at the lifecycle of concrete from gate to gate or better cradle to gate. However ideally we should be looking at cradle to grave. So what does this mean? The cradle is the mining or the extraction of the material from the earth so if we are looking at cement we have to look at where the limestone comes from.

Where the fuel that is going to use in clinkerization is coming through. The transportation of this materials comes next we have to move this materials to some place and that means that we have to look at distances what is used for the transportation finally there is the manufacturing, fest of cement and then of concrete. So this could be a gate when concrete is sold to a construction plant to a construction site by an RMC plant that is a gate. Placing from the sight is another gate that means the concrete is made and put into your structure so we can say that there is a phase that has completed so that could also be a gate.

Then we have the usage the structure is used from many-many years normally and if not for more than 100 years so the structure is going on being used with sometimes some maintenance some repair, finally it is demolished they are exhausted the service life we don’t have any other use for the structure or this product often it is disposed sometimes and more often possibly in the future now another future people are trying to see if we can ruse concrete products also just like we would take steel we could melted again and use it or reroll it or use the section of steel as such, wood is a very good example you have old wooden structures where the wood pieces are taken out the timber is taken out and re-carpentered and used again.

We do not use this (do this) allot for concrete but maybe in the future it can other as per which could be possible is can we from the demolition material demolished material, demolition waste find something to recycle, can we put it back into the same cycle so that we get new concrete or can we down cycle can we find other uses for an example we have crushed concrete, we could use it as the base of a road that means we have down cycle, we are not putting it back into a structure which would be putting back into the same cycle but we are using it for something less important, so that is called down cycling but we are going for some other process.

So we see here that in this cycle and why raw materials are important? Because they are affecting the environment, taking away material from their environment, we require lot of energy because we have to transform the limestone, the aggregates into concrete and we have to move this concrete around we have to put it somewhere. So there are lot of products in generated by products things that are not going to be used at all but it comes as a by product and their environmental loads earlier I talked about carbon dioxide emissions thus this are environmental loads that we are giving something we are loading the environment which something that could hurt it in the future.

So this is an example of the life cycle and why we have to think about the different aspects when we are talking about concrete. So practical purpose is it may not be possible it is mostly very difficult to look at the aspects but it is good to keep in mind so that we know how we are harming the environment and can we benefit the environment in doing the (trouble) we are doing.

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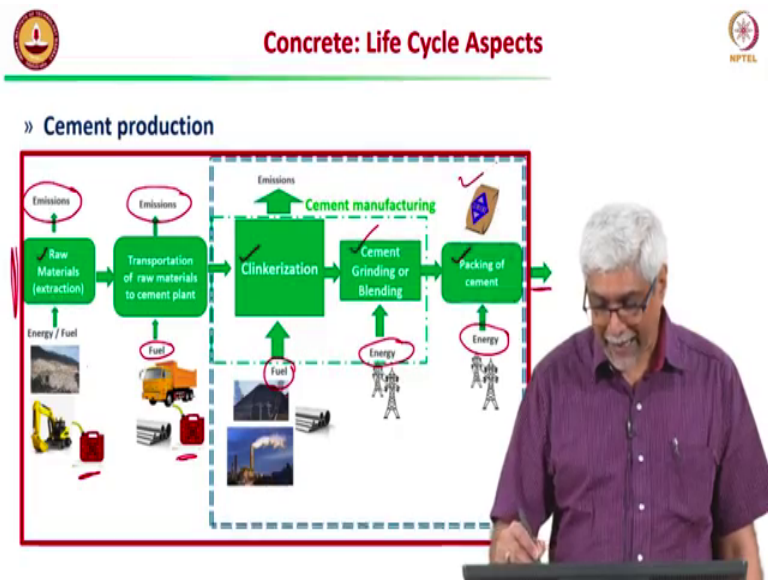


When we talk about concrete, we first have to think about cement, cement is the component of concrete which has the most impact we said before that 5 percent of the CO2 emissions in the world are given off by cement so it is very important look at cement closely and see how is that it is giving of so much CO2 emission, why is that we require so much energy. So when we look at the cement production this what you see is the in all the processes starting from the raw material extraction getting the raw materials which will make the cement which will make the clinker which will make the bags of cement that we see upto the packing and then delivery of the cement.

So to start with the raw materials we need energy, we need fuel, we need the raw material to get whatever we want to make the clinker and the rest of the cement. This gives rise to some additions. We transport the material, we can use trucks we use materials for with the truck has to we load of some materials this also has certain impact, the fuel everywhere has impact so all this gives rise to emissions also. So we have to understand what is the contribution of fuel. Obviously the closer the plant is to wherever you are getting the material from less is the impact of transportation. So that is why we see that in most countries in India typically we will find the cement plant very near a limestone quarry.

Because limestone is the material that is used most in making the cement clinker and therefore the distance between the quarry and the cement plant will be very low. However whenever we transport we will also give some emissions when fuel is transported also we are going to have emission we will be surprised to find that sometimes in cement plants coal is being brought in from the United States so it comes by ship and by road and so on. So it is not only the limestone which is being made but all the other things which go into making of the cement.

Clinkerization is the most harmful of the processes in terms of environment we need a lot of fuel we give off lot of carbon dioxide because the limestone calcium carbonate has to convert to calcium oxide so therefore there is a lot of $CO_2$ coming off with this conversion of limestone as well as the burning of fuel because we have to raise the temperature to 1000-500 degree Celsius then we have to grind we have to grind the clinker we have to grind the clinker to make cement and sometimes we also blend we can have cement which as to be blended with some other materials say fly ash to give us the cement that we are going to putting bags and sell.

So finally we need energy for all this process to get the product out into the market in terms of bags in India most of the cement is sold in bags but in other countries it is sold in bulk and transported by trucks or lories. So this gives the life cycle of the cement production the different processes and we will see if you can get into more detail of this. So this would be an example of a cradle to gate process, cradle because we take care of the raw materials, gate because we are stopping with a packing of the cement bag ok so this is an example of a cradle to gate.

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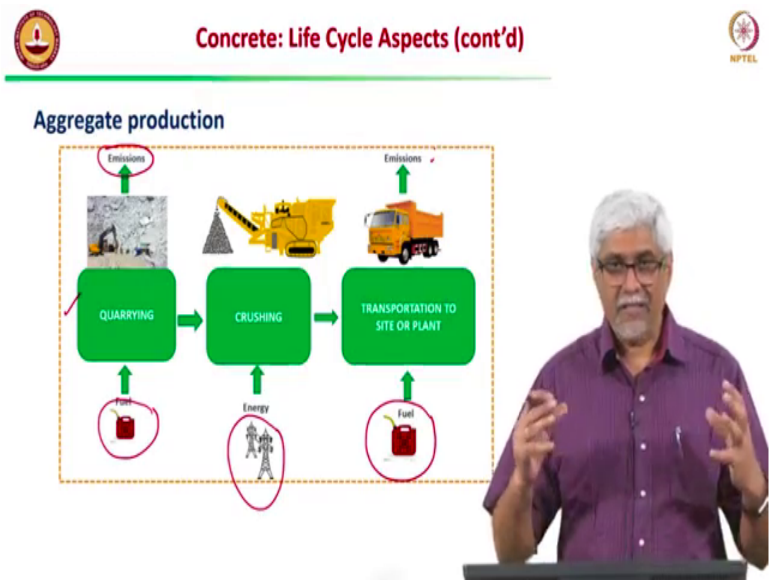


When we look at aggregates, as you know 70-80 percent of the volume of concrete is made out of aggregates, cement is very important, cement is the glue that holds aggregates together but we need a lot of aggregates normally in concrete. So this means that we have to extract stone from the ground we have to quarry, quarrying means that you need a lot of fuel energy for quarrying for crushing so this is going to give rise to emissions ok. Energy also is required electrical energy for crushing and so on. Then we have to transport again in transportation fuel is used the truck itself is used so the truck the manufacturing of the truck also correctly should be taken into account and then we had emissions, so this is the aggregate.

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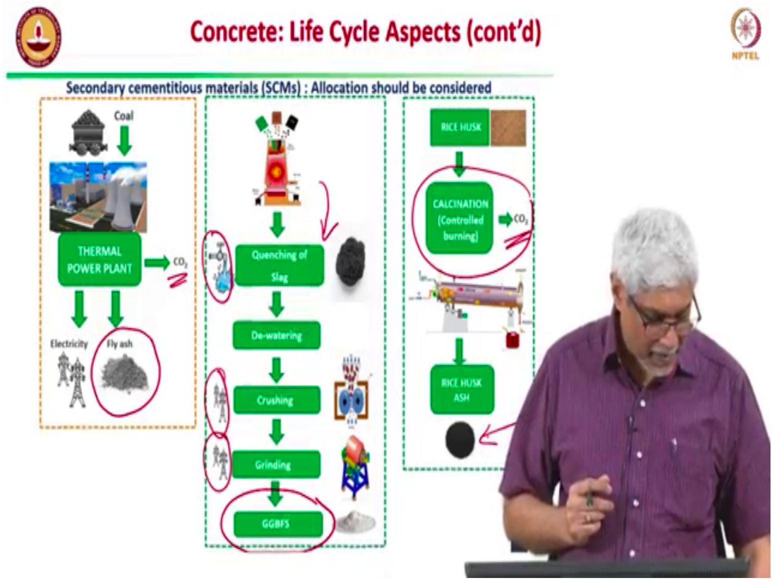


If we look at other materials which go into concrete other than cement, water and stone they use a lot of what are called secondary's cementations materials or supplementary cementations materials or SCM's and there we should try to understand that if it is a waste material how much of impact do we allocate to this materials. For fly ash which is very commonly used lot of our cement and concrete in India is made out of fly ash. Fly ash is a bi-product of burning cola to get energy, energy is the main reason why we burn coal but we get a lot of fly ash and in this process also CO2 is emitted.

So fly ash is considered a waste we do not generally assign any impact to it but there are other there are many researchers who are now saying that fly ash since it is being used to make concrete better it should also be allocated some impact. So we have to look at this. If we look at GGBF, GGBF is ground granulated blast furnace slag here you have it, this comes from blasr furnaces used for making steel and what comes out is slag, lumps like this which is quenched very fast it is cool very fast to make it amorphous or to make sure it doesn't crystalize because the amorphous slag is what is reactive in concrete we want to quench it with water so that it means water is being used.

Water is removed then it is crushed so that means we need energy it is ground to make the fine material that we use in concrete and all this also involve some transportation processes. We might have a material that is not very much used but in future is going to be used say rice husk, ash. So rice husk is what remains after we extract it what we can eat the rice from the paddy and that means that we have to burn it to get ash, calcination control burning is done obviously this is going to give up some CO2 and then we get ash. So this means that this also involve some energy to convert the rice husk into ash it also involve some transportation which we have to account for.

So when we are making concrete we have to take into account what is coming from the cement and what is coming from the aggregates and also add on whatever is coming from the supplementary cementations materials.

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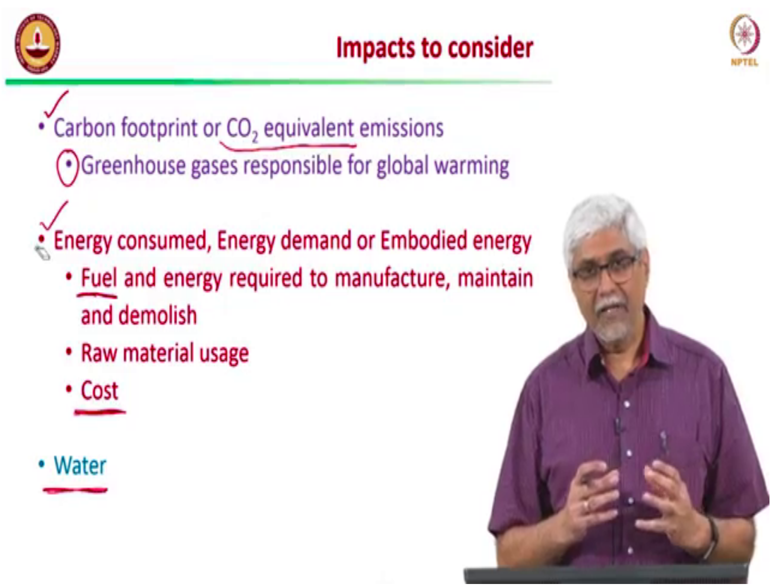


Once we do all this if we add all this different components that is we make an inventory we have to transform the inventory to something that is important to be thought of as an impact and see if this impact is going up or down or it is high or low. As far as concrete is concern as far as cement and its products are concern there are three things which are very important impacts that we could consider, there are many-many different impacts but for cement and concrete I feel that this are three things that we have to remember.

One is the carbon footprint where we started off with the amount of CO2 emitted while we are making a unit weigh or concrete or product of concrete or a building of concrete, why? Because this takes into account the greenhouse gasses responsible for global warming, the temperature of the earth is going up and one of the reasons are greenhouse gasses emitted mainly carbon dioxide. The carbon dioxide equivalent is a way of lumping together all such gasses in terms of a equivalent of carbon dioxide. So when we talk about carbon dioxide equivalent it also includes the other smaller amount of gasses that are given out and given in terms of kilogram of carbon dioxide.

So the first thing very importantly and most people included it in their assessment is the carbon footprint or the CO2 equivalent emissions when we are talking about a unit of material or a product. Next we have to look at energy, embodied energy, energy demand or energy consumed in making a material or a product or a structure, why? Because from producing this energy lot of fuel is needed, lot of energy is needed to manufacture so this means that we need a system to produce this energy we have factories which are needed to maintain high levels of energy in the production, this will require with this will be require not only for manufacturing but during the maintenance and for the demolition of a structure ok.

So the energy consumed or the energy demand or the embodied energy is very good indicator of how much effort, how much of fuel, how much of raw material that went in also and obviously cost also is related to the amount of energy. Some material or some process which requires a lot of energy means that it is also more expensive because we have to make the fuel we make the fuel reach the plant and use the fuel. So cost is also related to energy. Finally, something that I will not touch up on later in this lectures but I feel that is very important especially for our country is water.

In the manufacture of cement very little water is used especially in the modern plants however there are old processes older plants which use a lot of water. Obviously we use a lot of water in concrete we use water to make the concrete to cure the concrete, clean up and so on. So the water footprint just like the carbon footprint is talked about will be talked about a lot in future especially for what I call thirsty countries like India, we need to worry about water as well. How much of water we are using up and can we save on water can be reduced the amount of water that we are using for construction could be very-very important.

So mostly we will talk about carbon footprint and we will talk about the energy consumed as the two impacts that we will look at during the process of the assessment of cement and concrete for sustainability.

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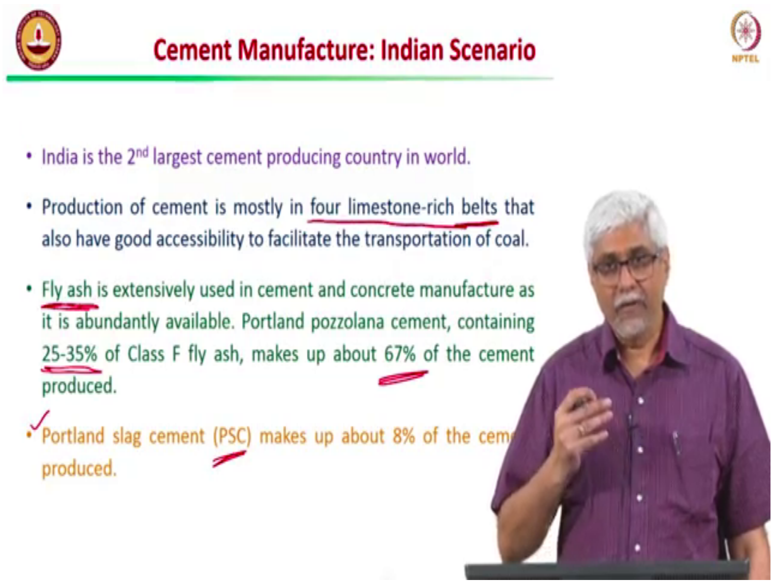


Why is all this important for India in particular? India is the second largest cement producing country I told you in the beginning of the talk that we are going to be talking about millions of tons of cement being produced in India the numbers are going to increase every year. Generally, most of the cement in India is manufactured in or near four limestone rich belts which also have the possibility of access of transportation a coal. We use a lot of fly ash about 70 percent of our power our electricity is made by burning coal so that means we have a lot of fly ash.

Cement having above 25 to 35 percent of fly ash makes up of about 70 percent of all the cement that we could use. So we use a lot of fly ash, lot of fly ash is collected from power plants thermal power plants and taken to be incorporated in cement directly. We also incorporate fly ash into the concrete in addition to cement many times. In addition, another waste material that I discussed previously was slag, GGBS used to make PSC or poclain slag cement currently about 8 percent of the cement produced.

So wherever we have steel plants we are going to add slag and this slag is quenched and ground properly can be used as a supplementary cementations material in concrete or directly in the cement to make PSC. So this is the Indian scenario we have to start worrying about it not doing a lot of studies to look at sustainability in terms of quantifying parameters in terms of matrix so this is the reason why we have to look at this very carefully.

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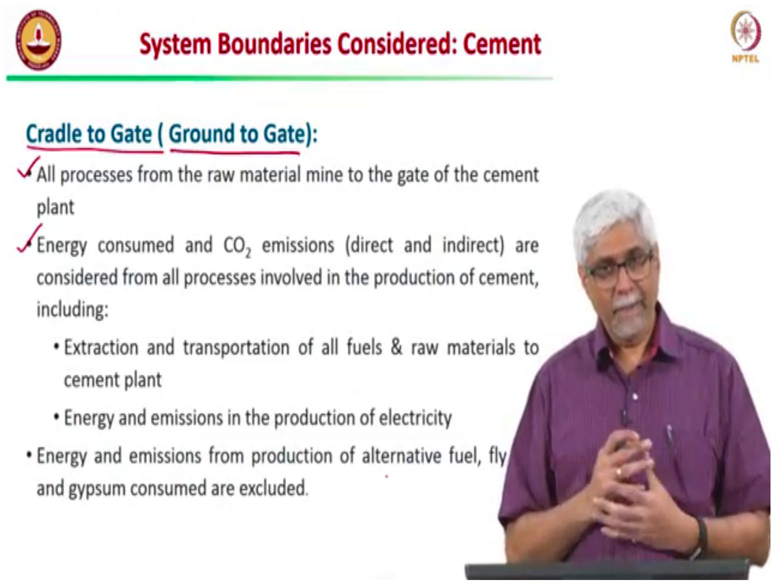


So we have to first look at the different systems that we could consider for cement I talked initially about the reason for looking at a cradle to gate system or a gate to gate system we have to see who is the audience and who we have to convince or what we have to take into account.

The first system or the most elaborate system most complete system is cradle to gate or ground to gate or also called mine to gate which takes into account all processes from the raw material mining to the gate of the cement block. All the system that will talk about finish at the gate, gate meaning when the cement goes out of the cement plant ok. So this cradle to gate approach takes into account all energy consumed and CO2 emissions direct and indirect, what is directly emitted or what could be due to extraction of something or some sort of a manufacturing process.

Everything that goes into the production of the cement including the extraction and transportation of the fume taking the material out, crushing the material transporting it to the plant and everything that is involved in production of electricity because electricity is needed for different aspects for running the plant for turning the (())(38:17) for the grinding and crushing and so on. What is excluded are the production of alternative fuels, production of fly ash that I mentioned before and gypsum which is also considered mostly as a waste material.

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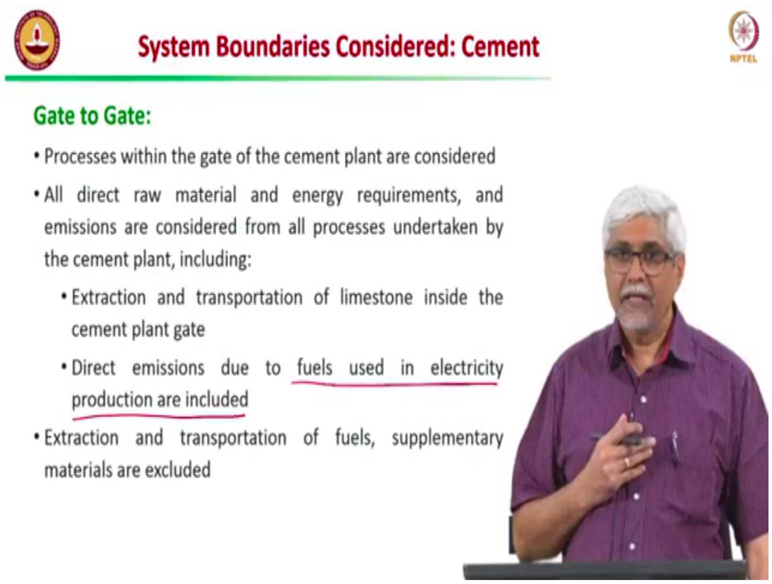


So the next system that we look at is gate to gate meaning we consider the processes within the gate, within the control of the cement plant only we take into account all direct raw material energy requirements for making the cement all the emissions that are occurring within the cement plant including the extraction and transportation of limestone which is the major impact and we also look at the emissions due to the fuel used in the electricity production also. What is not included are the extraction of the fuel transportation and the supplementary materials that are needed for the cement.

So mostly we look at what is controllable by the cement plant, what is occurring within the cement plant because that can be attributed directly to the cement and also there we will get reliable data then we look at ground to gate lot of assumption have to made on where the fuel is come from, how it came to the plant and so on. But when we look at gate to gate we can get reliable assurance of the data that we are using for gate to gate ok so this are the two ways mostly that calculations of the sustainability (())(39:47) of the environmental impact can be done.

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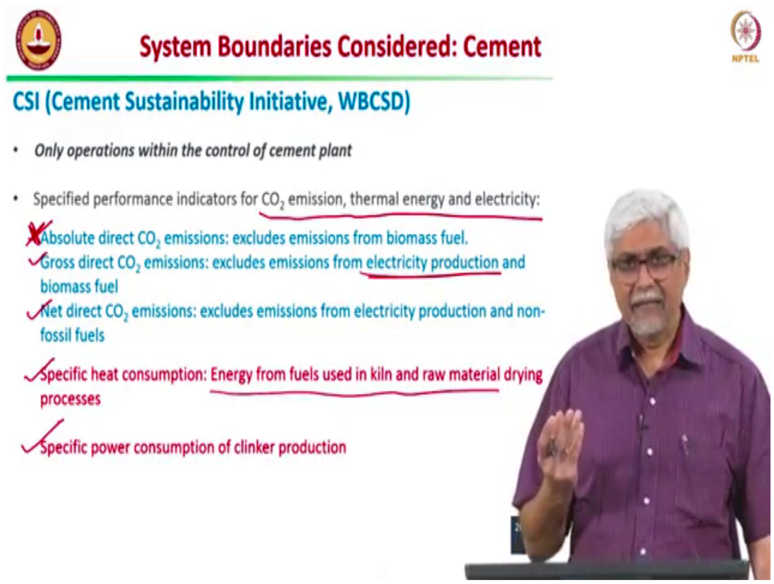


However there is also another system sort of which is called the CSI (sys) which comes from what is called the Cement Sustainability Initiative where a group of cement companies have looked at how to assess sustainability and they looked at operations within the control of the cement plant and say that let us try to focus on this and see if sustainability can be improved by improving this operations. They have also come up with certain performance indicators for the CO2 emissions, for thermal energy and electricity and this are some of them.

First there is something called absolute carbon dioxide emission which almost include everything except the biomass that is used as fuel that is waste from agriculture from food industry from households if it is burnt that is excluded because it is felt that it is waste anyway and is difficult to characterize because it is very non-uniform. Then we have something called gross direct CO2 emissions which excludes this electricity production in addition to the biomass. So what happens so the electricity production is excluded because the cement plant may not be able to control that or there is variation in the source of electricity.

Then there is something called net CO2 emissions which excludes the electricity production and every other fuel that is non-fossil I believe here the understanding is what is bad is the fossil fuel so anything that is non-fossil fuel is an alternate which is always better we should encourage the cement plant to use it and therefore they exclude the CO2 emissions from known fossil fuels. But for our purposes I think this would be the best to look at because it includes everything and it could tell us about all the CO2 that is emitted from the different process in the cement plant.

In addition they look at energy in two ways the specific heat consumption is the energy from the fuels used in the kiln and the raw material dry for a unit material unit of the material like ton of cement. How much is the energy that is needed in the kiln and for drying of the raw material for a ton of clinker so that is the specific heat consumption. Higher it is that means the process is not as efficient and it is harmful to the environment. So if the specific heat consumption is lower that means the material is more environmentally friendly.

Then they also look at electricity, the specific power consumption of the clinker production and see if this could be minimized ok so the CSI system looks at operations only during the control of the cement plant leaving our leaving away something that could be needed but not in the control of the cement plant and not attributable 100 percent (())(42:59) cement plant. So this are the three systems that one could consider for when we are assessing cement.

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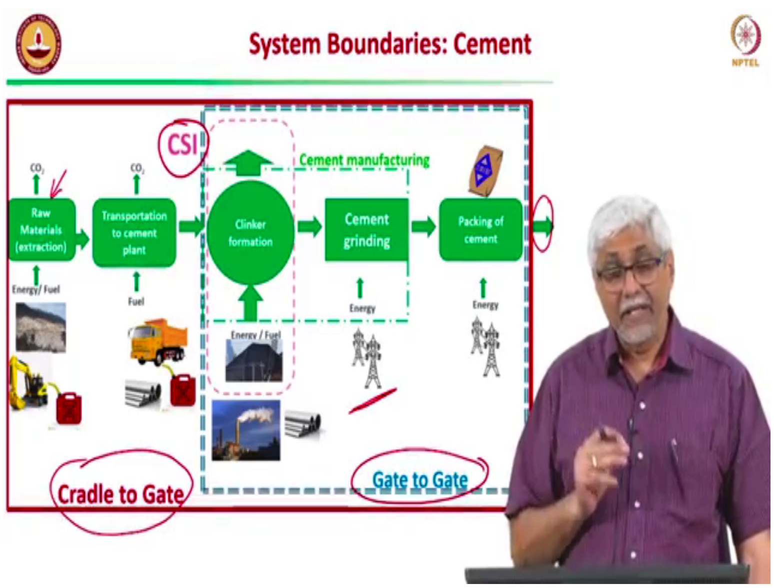


Figuratively or in graphical form this is what I have talked to you about. We have everything which his the cradle to gate from the extraction of the material that is needed all the materials needed from the for the cement to when it comes out that is the gate that would be the cradle to gate approach the largest system the most elaborate system the most complete system but however will have to make some assumptions in terms of where the material was extracted how it was transported we may not have all the data so some reliability is lost, some assumptions are made in the cradle to gate approach.

The gate to gate is what happens in the cement plant associated with the cement plant and mostly within the control of the cement plant. So this means that we take into account the energy needed all the electricity needed we take into account the fuel needed for the plant itself for construction of a plant we need energy we need some fuel, we need raw materials. So this is also taken into account and attributed in a small quantity to the cement itself. So this would be the gate to gate approach we take everything as it comes into the cement plant everything that is inside the cement plant and going out. The CSI approach is mainly looking at only the clinker formation and not taking into account the other things.

So they are looking mainly at what we will see later is the most important process which is the clinkering which has the most impact. So they focus only on that and their indices are talking about only what is going into the kiln, how much electricity, how much raw materials, how much fuel are going to the kiln for the clinkering. So this are the three different systems that one can talk about. The CSI being very particular to the cement industry coming from this initiative.

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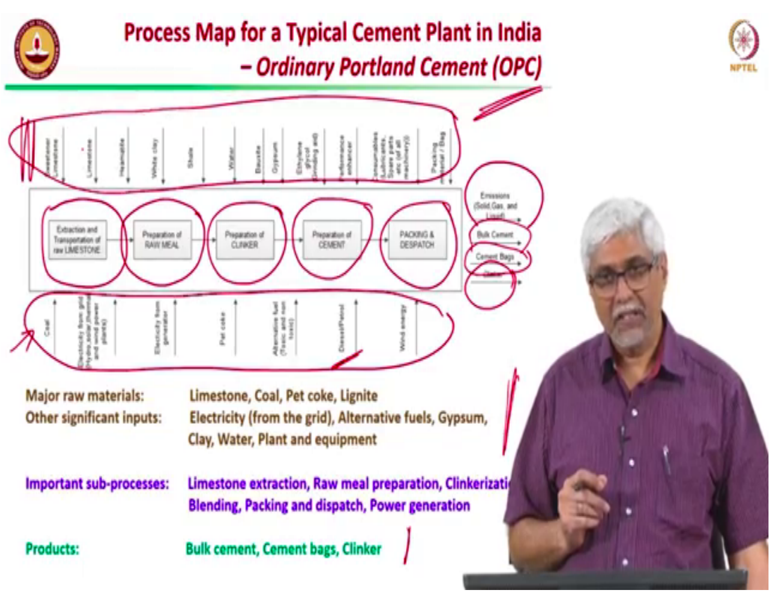


So once we have decided which system we have to now go to a plant because in India and in many other emerging countries we do not have databases that are ready to use. So one has to go to a cement plant talk to the cement company see their reports and try to get a inventory. So what is an inventory? We look at all the processes happening in a cement plant we have talked about extraction of the limestone, transportation of the limestone, raw meal is prepared, raw meal is what goes into the kiln ok whatever is going to gives us the clinker is in the raw meal.

The clinker is prepared that means the raw material, the raw meal is heated up limestone transforms to calcium oxide and gives us nodules of clinker then this clinker has to be ground with gypsum to give us cement and then this cement is sent out. This would be the typical process for ordinary port land cement in a plant in India. So this requires all this inputs to come in limestone sometime hematite, white clay, shell so on and some water as well gypsum and we also need a lot of fuels coming.

We need coal we need electricity, we need diesel for running the trucks for the transportation and so on. So lot of energy is also required. So here you see all the raw materials going in this are all the raw materials which are going in, this is all what is coming in as fuel and energy. So this is the input to gives us the cement. What comes out is the bags of cement that we are very much used to there is also bulk cement that is used in infrastructure a lot. Sometimes clinker is also sold to other plants which can be grinding the cement making the cement by grinding only.

They buy clinker from some other plant and then they transport the clinker and they grind it near a city which does not have a cement plant or integrated cement plant nearby. Other than this products that we want where also giving off a lot of emission we are giving a lot of gasses it could be in any form which could harm the environment so we have to look at those outputs also ok. So below we have a list of normally inventoried material what is going into the cement, electricity and so on. What are the processes and what are the outputs? So this would be typically a process map that we will have to prepare.

Next what we will have to do is to look at the numbers for each of this for say a ton of cement or a ton of clinker will have to see how much of each went into the products. How much of energy was required for each of this processes and what came out in addition to the cement also we had emission that also has to be quantified. There the (trans) the process map is transferred to an inventory. The process map is a list of all the things that are happening, the inventories how much of each is happening, what is the quantity of each raw material unit of energy that went. So this would be for OPC.

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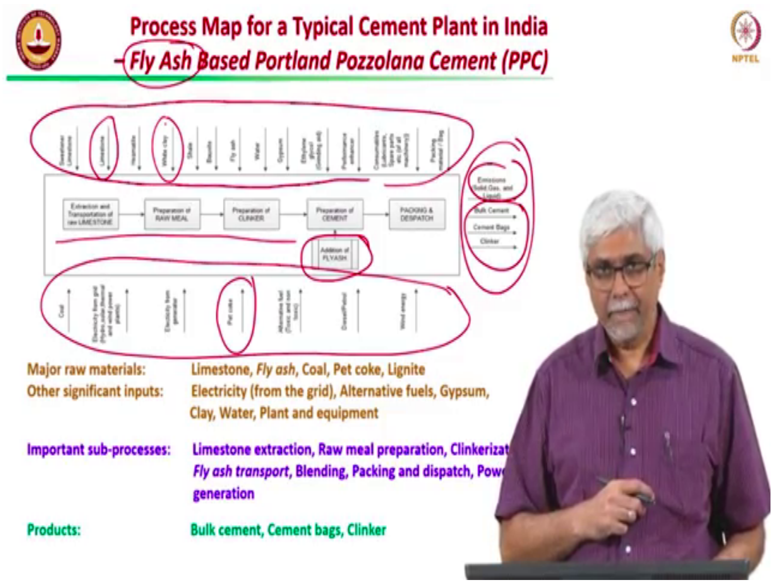


suppose we have PPC Portland Pozzolana Cement mostly in India it would be fly ash based. We would have all the inputs that we looked at all the raw materials that we looked at before in addition we have fly ash which is brought in the preparation stage when the clinker is done the clinker could be ground along with fly ash have blended after grinding with fly ash and then also we have all the energy component which is required for making the cement and then you have the output, we have the emissions and then we have all the products that we can use.

So again here you see a process map for a plant that is producing PPC Portland Pozzolana Cement again what we have done is looked at all the processes and seen all the inputs and all the outputs. Next stage then would be the inventory we will have to find how much of each was used for a unit of the cement to be produced. How much of pet coke was used, how much of limestone was used, how much of clay was used for making the 1 ton of clinker? Ok so that would give us the inventory.

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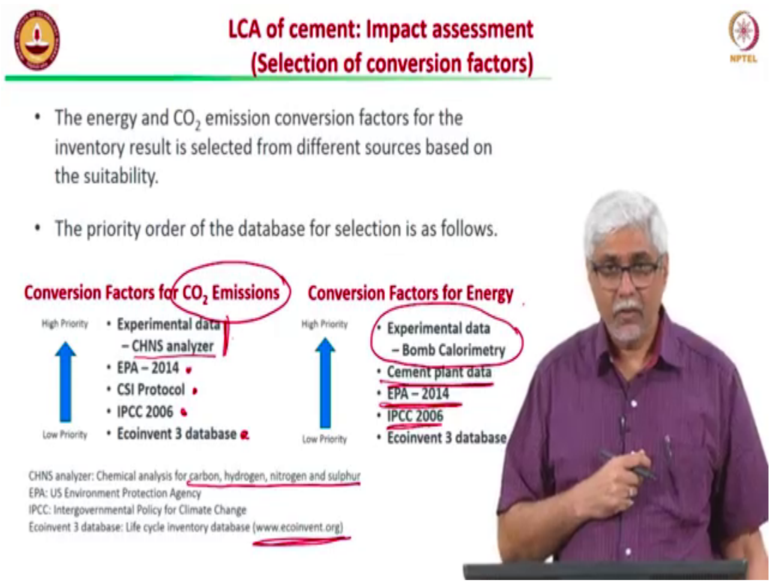


From the inventory will have to convert those numbers to impacts and we said in the beginning that there are two impacts which are important for cement and concrete, energy, energy demand or embodied energy and the CO2 emissions. So will have to convert the inventory into these impacts, 1 kg of coal means what? How much of energy and how much of CO2 emissions? So this is not very easy it is not something that you can take of a database especially for countries like us which do not have a lot of history in life cycle assessment. So we did a lot of thinking we look at looked at a lot of literature and we did a lot of assessment and we have come up with this set of priorities for getting this conversion factors.

So for CO2 emissions for converting the inventory data to an impact what we have said is the best way is to get a sample of the material say coal and do a what is called as CHNS analysis, so what does CHNS analysis do? It tells us how much carbon, hydrogen, nitrogen, sulphur is so then we would know when we burn it how much carbon dioxide is coming? How much of So2 is coming? How much of So3 is coming if there is NOx how much it would be? So the best way is to get a sample of the material from the plant itself and do a CHNS analysis.

Sometimes you may not have maybe it is a minor quantity then we have to go to some databases. So the priority is if this is not possible we say we go to EPA 2014 database, what is that? The EPA is the United States environment protection agency so they have given some conversion factors. If what you need is not even there then we go to the CSI protocol this is the cement sustain ability initiative protocol and if that is also not there then we go to what is the IPCC database, IPCC is an Inter-Governmental Policy for climate change they also have a database and that also is you don't have the data then we go to a very popular database called Ecoinvent 3 this is coming from organization called Ecoinvent we have given you the website here.

So this would be the priority highest priority for what you can measure directly, least priority from a general database which may not have relevance to your region or your plant ok. So this is how we go above the analysis. Similarly, for energy, we say that if we can experimental data is best so we would take a piece of coal some pet coke or diesel and do Bomb Calorimetry so Bomb Calorimetry gives us how much energy is produced from a fuel. So we will know exactly for unit of that fuel be diesel or coal or pet coke how much energy is coming out.

The we know how much energy was used, if that doesn't work we can go to cement plant data because cement plants are also very conscious about the energy that makes cost to them it means raw materials storage to them they want to minimize so they are tracking very closely the amount of energy that is required and how much is being produced. Then we go to the EPA this is the U.S environment projection agency data then the IPCC and then the Ecoinvent, so this is again the priority. Priority is always given most to the data that is generated closest to the case.

If we can get a material and directly do the test we give it highest priority, the least priority is given to a global general database because that may not be relevant that is more of an average more of some samples but not relevant to the particular step. Ok so this gives you the entire story of how we should go above doing life cycle assessment. We first define the system we find out whatever goes in and out by a process map then we get quantifiers quantities for each of this input output then we get the inventory and then we have to convert to get the impact.

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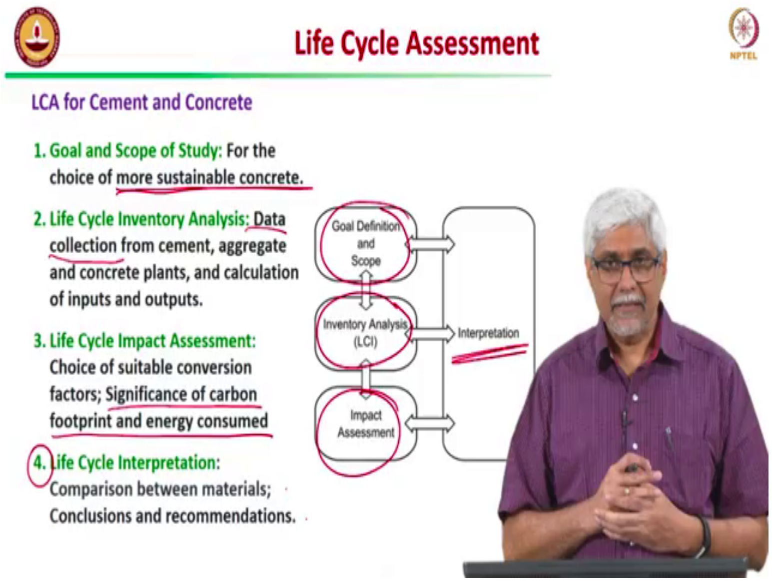


So to conclude this lecture for LCA for cement and concrete our goal generally or the scope is to make more sustainable concrete we have many choices we can change the binder we can change the aggregate, we can do many modifications to the concrete. The goal then of life cycle assessment becomes how do we make this concrete more sustainable. What do we have to do? We have to get data because in India we do not have a lot of data available we have to go to the plants cement plants mainly aggregate plants, concrete plants and see what is that which is going into unit of the material and what is coming out.

Calculate the inputs and outputs so we have the goal, we have the inventory. Now we have to see what is the impact which satisfies our goal? Generally for the life cycle impact assessment we need to convert I told you how we can choose the conversion factors we have come up with this priority that we feel is good for Indian conditions another emerging countries where database are not very readily available. We convert the inventory into the impact and generally for concrete and cement we feel that this two are very much required.

The impact based and the carbon footprint, the CO2 emissions and the energy consume to make (())(56:21) then we would be able to do the interpretation. Compare different materials, give conclusions recommendations so there the impact assessment will help us in the interpretation ok. So this gives the whole picture of how life cycle assessment should be done. In the next lecture I will take up some cases of different binders and then we will see how to get the numbers so that we can compare the different materials and see which is coming out better or worse.

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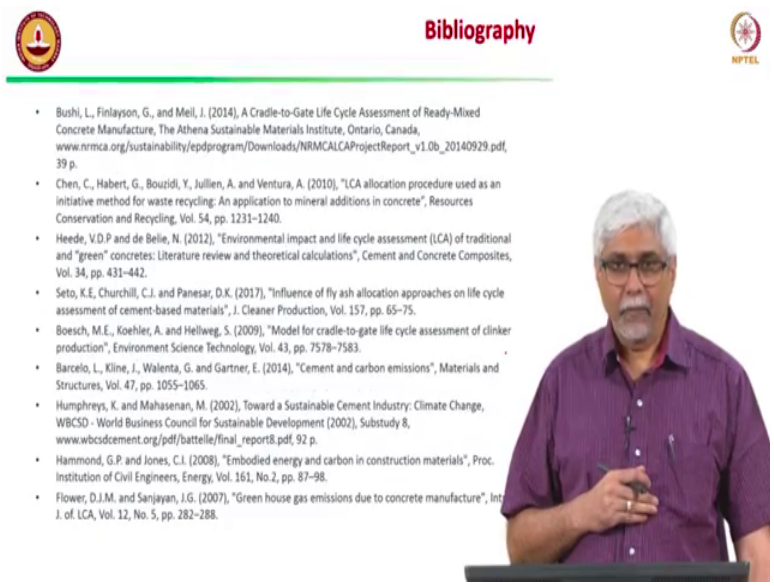


In the next few slides I have a lot of bibliography that you can use for references most of them quite easily available so you can see all this papers and reports to get more information of the on the life cycle assessment of concrete, thank you.