Advanced Topics in the Science and Technology of Concrete
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Use of Life Cycle Assessment to Compare the Impacts of Different Cements and Concrete with Different Binders: Case Studies

Welcome back to the second lecture on Life Cycle Assessment of Cement and Concrete, so we are going to look at some cases with different binders so that we can use life cycle assessment to tell us whether a material is going to be more sustainable or less.

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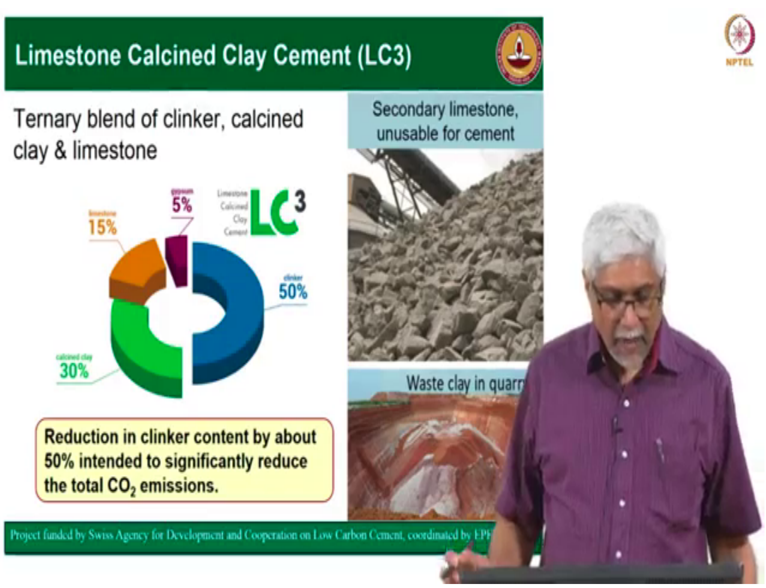

I am going to introduce material called LC3 it stands for Limestone Calcined Clay Cement, this is based on what that we doing on a project funded by the Swiss agency for development and cooperation coordinated by EPFL, Switzerland. So this cement is a new cement that we believe has a lot of promise because it can decrease the clinker content in the cement to 50 percent. It is a blend of clinker, calcined clay, limestone and a little bit of gypsum ok and basically we think that we can use secondary limestone which is cannot be used for cement and we can use clay that is even (())(01:14) in a quarry.

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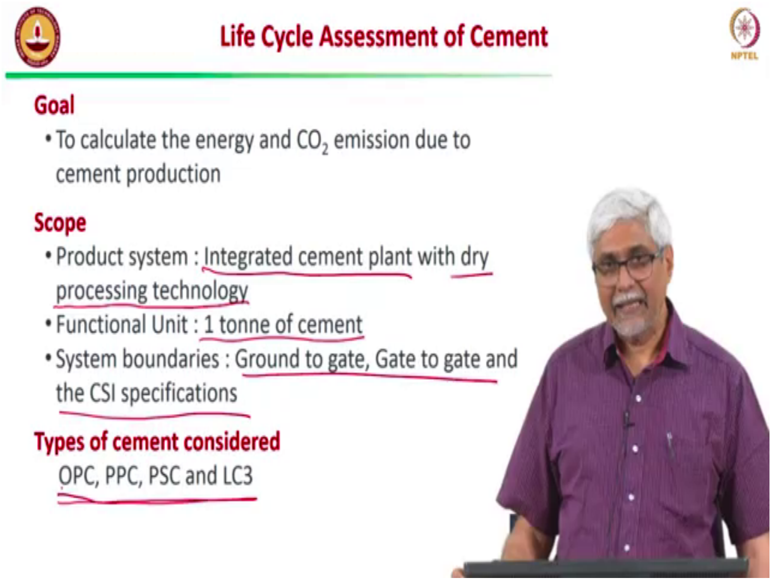

So the goal of the this case studies that I am going to explain is to look at the impacts that we emphasized in the previous lecture, energy demand and the CO2 emissions during the cement production. We will look at a case study of an integrated cement plant so an integrated cement plant is something which takes the limestone, clinkers, grinds and gives us cement at the end in bags and this particular case we are going to look at a typical plant with a dry processing technology which is already quite efficient in terms of sustainability parameters. The functional unit or what are numbers would look at is the emissions and the impact for 1 ton of cement that is called the functional unit and will be looking at the three systems that I talked about in the previous lecture.

Ground to gate that is from the mine upto the gate of the cement plant, gate to gate what happens within the cement plant and the CSI specifications which focus mainly at the clinkering process. We look at along with LC3 we look at three other cements, ordinary Portland cement which is mainly clinker 90 to 95 percent of ordinary Portland cement is clinker, PPC which is Portland Pozzolana cement mostly made with fly ash 25 to 35 percent of this cement would be fly ash, PSC which is Portland Slag Cement which has 50 to 60 percent of slag in the cement and then the LC3 that I talked about in the previous slide. So we are going to be looking at this from the point of view of sustainability and do life cycle assessment.

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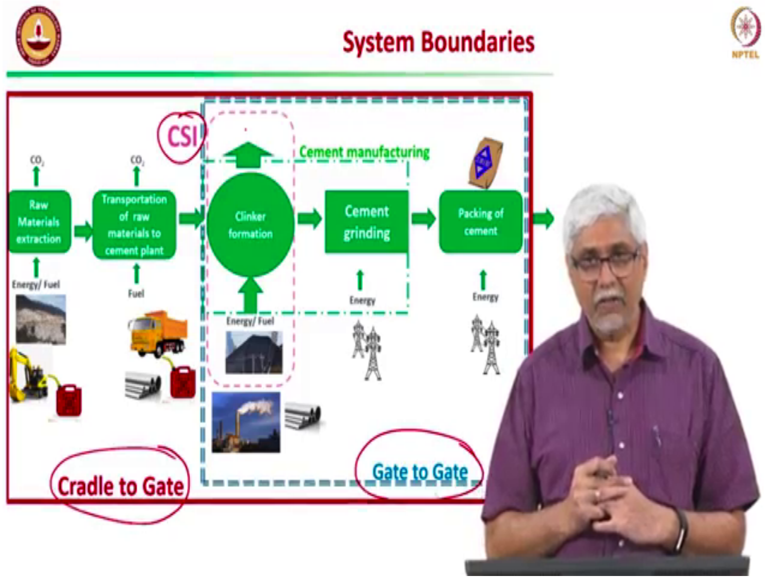

This is picture from the previous lecture where we looked at the difference between cradle to gate system which has everything in it all the processes that could be attributable to the production of cement, gate to gate is what happens within the plant, gate of the plant coming in, gate of the plant going out, raw material coming in and the cement going out and the CSI system which is only looking mainly at the clinker formation which the fuel is the most important process in the manufacture of cement. So this are the three different system boundaries that we are considering in this analysis.

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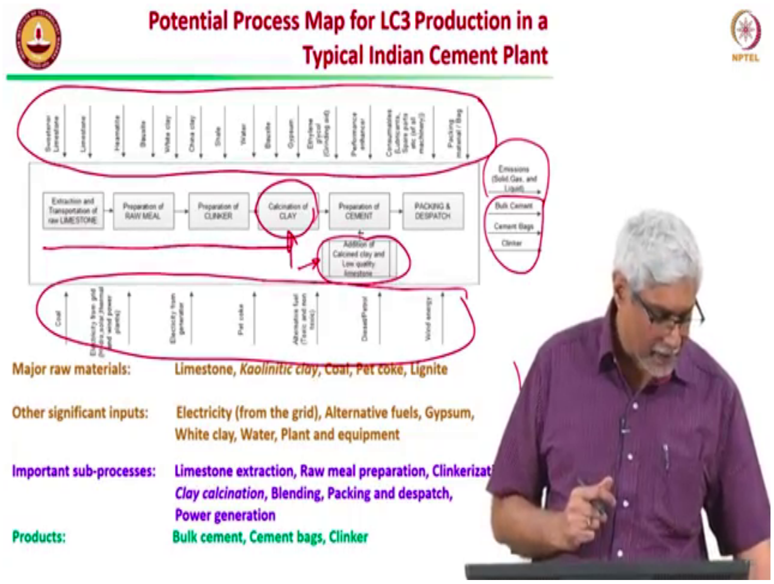

You saw the process map for ordinary Portland cement and Portland Pozzolana cement earlier. Now suppose we were to make LC3 in a typical Indian plant, what would happen? The processes that you saw before would be the same however we will have the calcination of the clay as a new process then we will add the calcined clay and some limestone in the grinding phase to give us the LC3 which is going to come out and also in this process there will be some emissions in and here or all the raw materials which will have to go in and this is the energy that will be required.

Ok and here we have a list of all this materials which are going to make an impact in the process ok. So what we have assumed is a typical plant with just these two different processes will be able to produce LC3 and it seems reasonable from the pilot production that has been done in India within this project that I am talking about.

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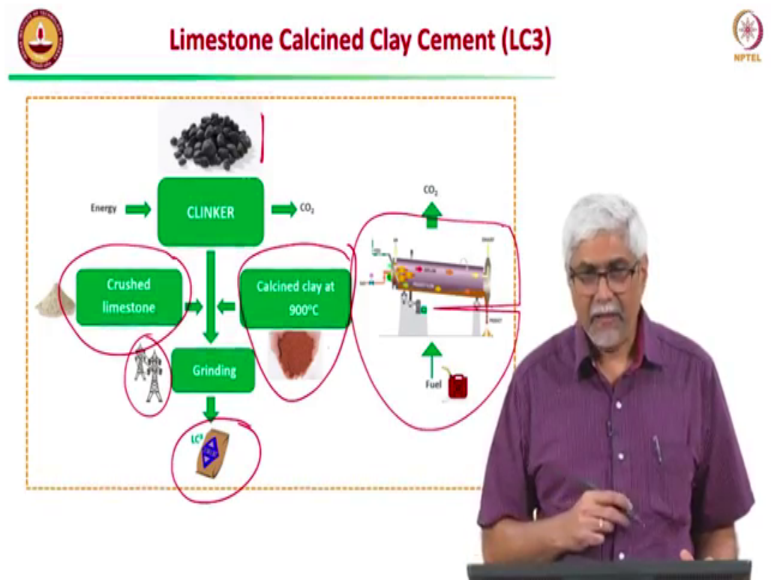

So the calcine the to make the LC3 we have to have clinker as usual we have it at 50 percent of clinker nodules of clinker that will have to be ground as we do in OPC. We have clay that has to be calcined to 900 degree Celsius so (())(05:19) clay that is calcine so we need some energy to do this also. So there will be some CO2 emission then we have crushed limestone again we need energy to crush the limestone finally to grind it to give us the LC3 product ok and we would need some sort of a kiln or some sort of a calciner to do this.

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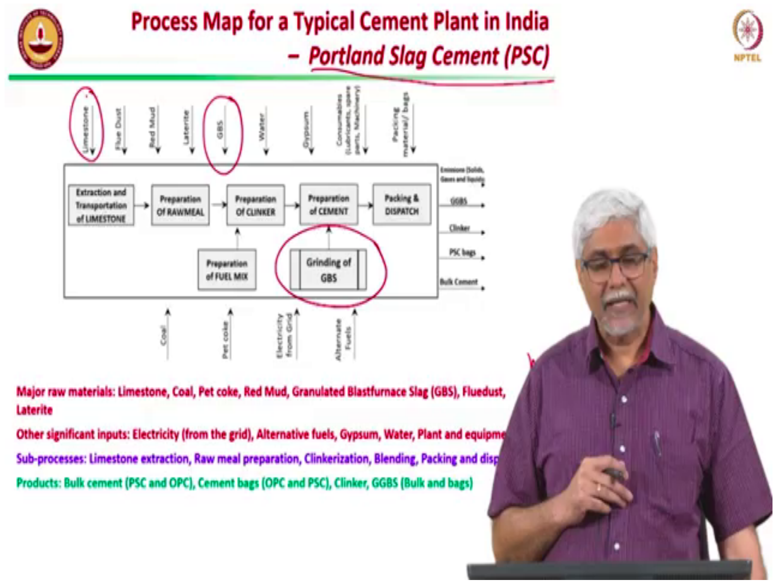

We will also talk a little bit about Portland Slag Cement PSC where again if we look at the process map we will have everything as usual but we will also have now GBS or blast furnace slag granulated blast furnace slag coming into the plant, this has to be ground and put into the production of the cement ok. So this would be the modification that will have to be for Portland Slag Cement and again you have here the components that have to be taken into account. So every time we are looking at a new type of material new type of cement in this case we have to see how does the process map change and as I said before first the process map then the each quantity for the function and unit that we said 1 ton of cement has to be determine then finally we do the conversion.

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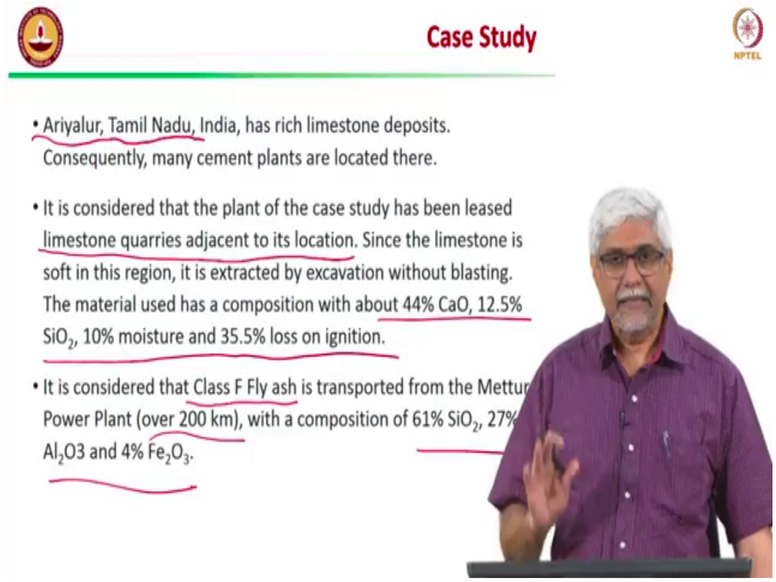

The case study that we are talking about would be a plant that is located in a place called Ariyalur in the state of Tamil Nadu in the south of India. It has many cement plants there because it has rich limestone deposits. In the case that we are considering we are looking at a plant that has limestone quarries very nearby and in this particular case we analyze the limestone, the limestone composition is this, 44 % calcium oxide, 12.5% silica, 10% moisture typically and about 36% loss on ignition ok. So this tell us what is the raw material which is going into the concrete and also how much energy has is required now to elevate the temperature so that calcium oxide is produced and it is also giving us some idea of how much moisture there is so what drying as to happen in the raw material.

In the case of PPC, the fly ash class F type fly ash is coming from a plant called the Mettur power plant over a distance of 200 kilometers and this is the composition of the fly ash.

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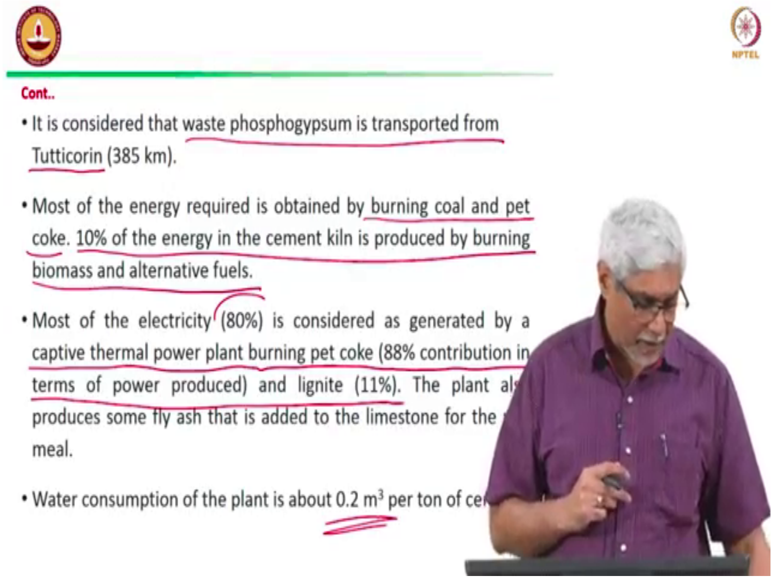

So this gives us what is the current state of the materials that they are using and will see what processes are being what are the processes also occur. This particular plant uses waste phosphogypsum from Tutticorin from the fertilizer industry phosphogypsum is a waste so that is taken and used in the cement manufacture. Again in this plant most of the energy is obtained from burning coal and pet coke about 10% of the energy is coming from burning biomass and alternative fuels.

So instead of using only fossil fuel they are also using biomass and alternative fuels. They have their own captive thermal power plant which burns pet coke and lignite to get give them 80% of the electricity required ok. They don't trust or they don't get all the electricity from the grid they have their own power plant to give them the electricity that they require and there is also a small amount of water that is required for the cement manufacture. So this gives us again the idea of what all is happening and hat has to be taken into the account.

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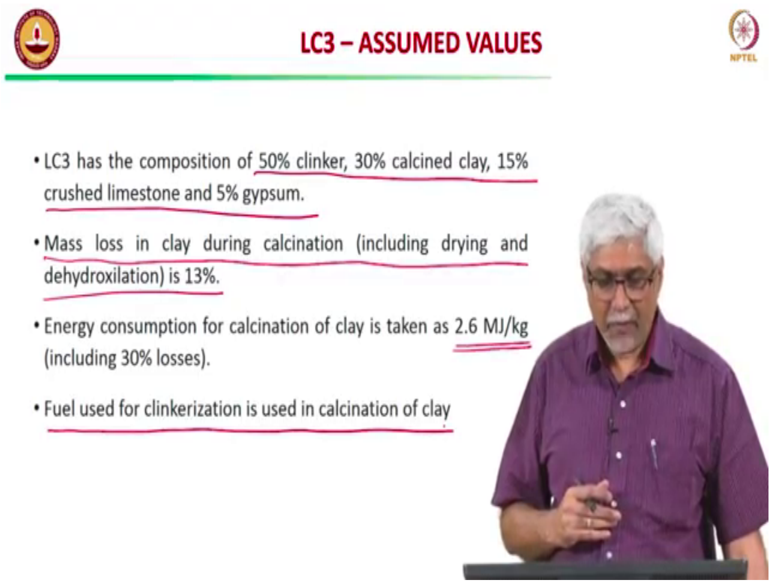

Now if in that plant we were to make LC3 will first have to know what is the composition so we have assumed based on our laboratory studies that this is the composition of the LC3, 50% clinker, 30% calcined (())(09:32) clay, 15% crushed limestone and 5% gypsum from lot of testing that of samples of clay that we have done we have assumed that the mass loss to be expected would be about 13%. We also had to make an assumption for how much would be the energy consumed for the calcination. Again we did tries in the lab, we added about 30% loss and then we came up with the conservative number of 2.6 mega joules per kilogram.

Ok so this is based on small trials because we still have not done a very large trial in the level of the large plant manufacture ok. We have assumed that the fuel could be the same for calcination clay as this being used for the clinkerization because we are assuming that he calcination is happening within the cement plant so there is no necessity to have specific fuel for it but this could be also something that could change when the LC3 is done in a large scale.

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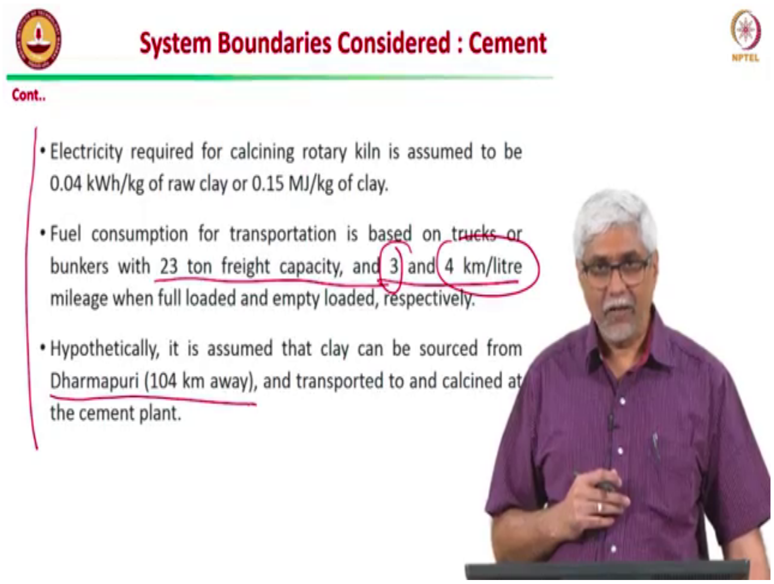

This is again information that we will require for the life cycle assessment, electricity required, fuel consumption. So what was done is our students talked to the truck drivers also to see how much of fuel is consumed and they found that when for 23 ton truck 3 and 4 kilometers per litter was the mileage that way they were getting when the truck was fully loaded or empty load.

So this also matters because the material is transported we need to know how much diesel is consumed so that we know how much energy is consumed and also how much CO2 is emitted. We found that there was a quarry in Dharmapuri 100 kilometers away that could supply suitable clay. So this are the assumption that we had to make to get all the data required for the fabrication or LC3 in a plant like this.

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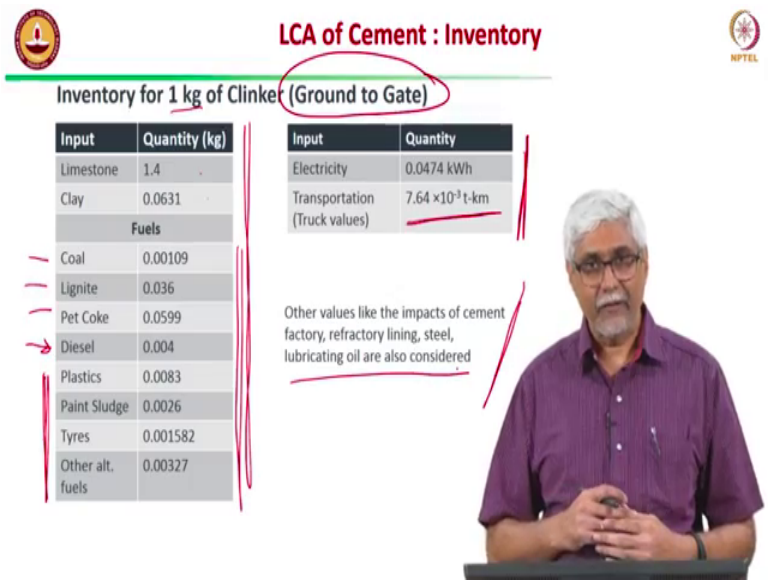

So we get a list and then we have to look at the inventory, we have to see the quantities for each of this materials. So if we consider the ground to gate system which again is everything from the mine to the gate of the plant so we get the quantities how much is required for a kilogram of clinker later on we look at 1 ton of clinker but this are all the materials that will be required. How much of limestone, how much of clay and all the fuels we looked at the fuels that are used in this plant particularly. You see that other than the coal, lignite and pet coke, diesel for the trucks and so on. They also use lot of alternative fuels plastics, waste plastics, paint sludge, tyres and other alternative fuels are also used in the (())(12:33) to produce the energy required for clinkering.

This is the electricity required and how many ton kilometers of travel was involved for all the raw materials you needed for producing 1 kilogram of clinker. Other impacts like the cement factory itself has an impact to make the cement factory something went in. So small part of that should be attributed to the cement each time so a ton of cement or kilogram cement also that small part has to go in. So all the other things lubricating oils, steel that went into the kiln manufacture all this also has to be considered.

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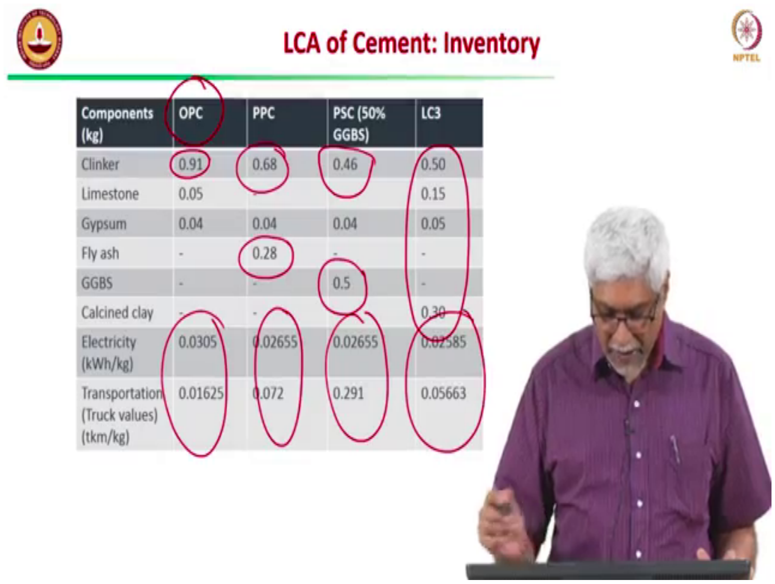

So in the previous slide we looked at what goes into making a unit mass of clinker. Now will this clinker has to go into the cement and will see what is the inventory for each cement. Ordinary Portland cement which has mainly clinker 90% clinker and some limestone which his called a performance enhancer and some gypsum and this is the required electricity and the transportation associated with it. PPC is Portland Pozzolana Cement which has in this case about 28% of fly ash and 68% of clinker so the clinker has reduced, fly ash has gone in to substitute part of the clinker. In Portland slag cement the clinker goes down even further 46% by mass is the clinker and we have GGBS ground granulated blast furnace slag which is giving about 50%.

In LC3 we looked at before what would be the composition 50% clinker, 30% calcine clay, 15% limestone and some gypsum and in each of this cases you see how much of electricity is required and how much of transportation is involved in the raw materials.

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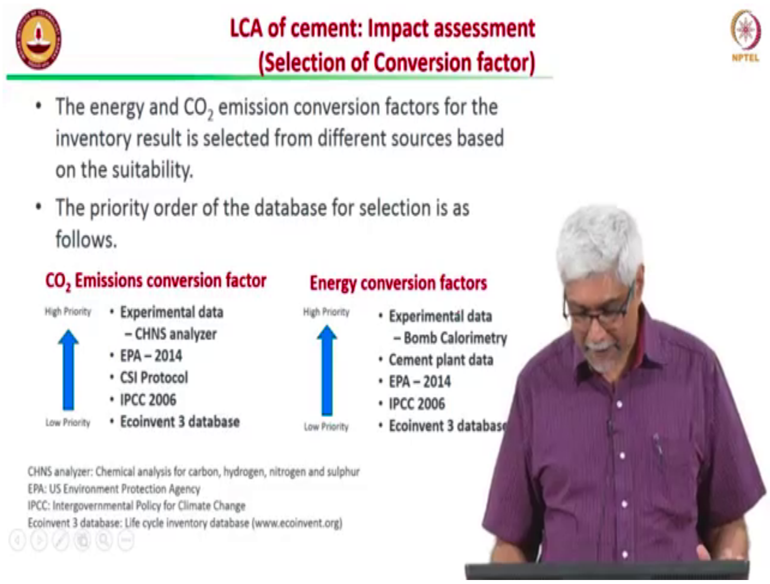

We have the inventory and now we have to convert this ok. So we go back to the slide that I showed you in the last lecture. We see how we can get appropriate conversion factors, we can use experiments we would like to use experimental data as much as possible. If we can get a sample of the coal, the pet coke or the diesel and then if we can analyze it to know how much CO2 emission are coming in and how much energy is being given off better. If not we have to go for a database and this is the priority that we suggest to be used going what data can be collected by ourselves to the last priority being a general global database. So this would tell us how to go from the inventory to the impacts.

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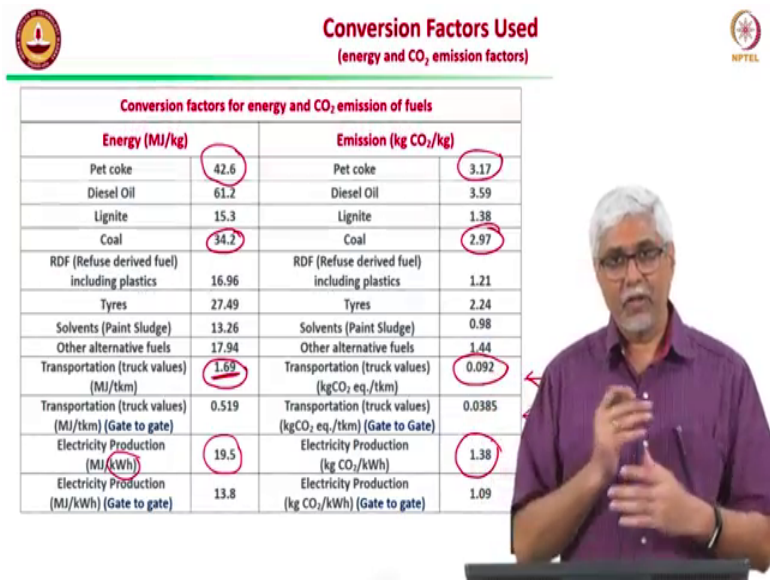

This are the different conversion factors that we have used in case you have to or you want to do some life cycle assessment and you are looking for conversion factors this could be good references to use. So based on our priorities for this particular case study for this location and type of material being produced this are the conversion factors that we have come up with. For example for pet coke this number means that 1 kilogram of pet coke gives off 42.6 mega joules of energy and 3.7 (3.17) kilogram of CO2 ok. So we will know how much pet coke was needed for making clinker and making cement then we multiply by this and then we know what is the impact in terms of energy and emission.

Similarly for coal and so on ok and for the other materials we have looked at. We also looked at transportation 1 ton kilometers of transportation with a particular type of truck means that we consume about 1.7 mega joules for transporting 1 ton for 1 kilometer, this mean that 0.9 kg of CO2 is also emitted to transport 1 ton of material for 1 kilometer ok. This is the ground to gate value and this is the gate to gate value. Similarly for electricity production, for 1 kilowatt hour of electricity we need 19.5 mega joules of energy to produce it. In this process we are giving off 1.4 kilogram of CO2 for producing 1 kilowatt hour of electricity.

Ok this numbers will change depending on where the plant is what your raw materials are and what are the sources of electricity and energy and so on ok. So it is very important we start with the case study look at the process map that is appropriate for that case study look at the appropriate conversion factors to come to this ok. So it is very important to follow this all the steps of life cycle assessment.

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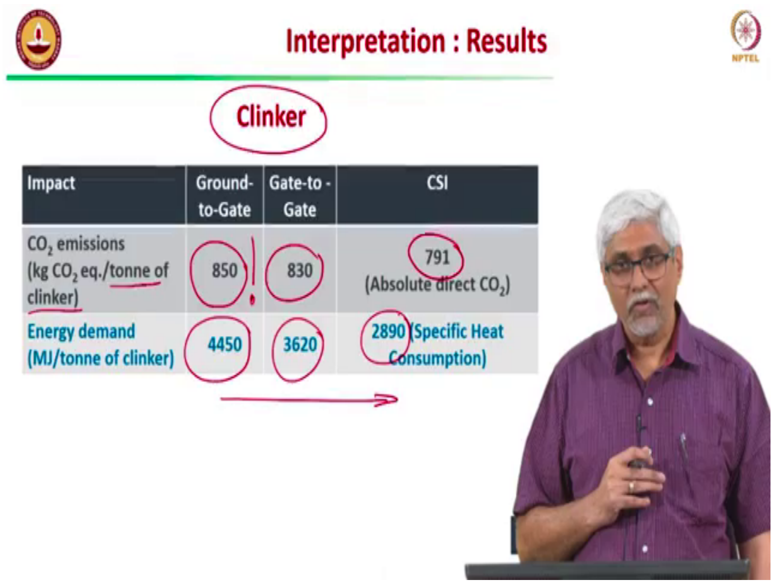

Finally the numbers, the impacts so that you can make a decision our you can compare. Clinker the impacts of the clinker for every ton of clinker to make 1 ton of clinker 850 kilograms of CO2 are emitted when we are looking at the ground to gate the complete system. If you are looking only at what happens within the gate obviously it decreases to 830. If we are looking only at the clinkering it decreases even further to about 790 ok the biggest or the most complete number is this which we have to keep in mind.

In terms of energy gain we find that that this is the energy we need so many mega joules if we consider all the processes, if we eliminate some processes obviously the number comes down and low ok but this means that every time we use a ton of clinker at least 850 kg of CO2 has gone out for this particular case study 4450 mega joules of energy have gone into making 1 ton of clinker ok. So this is a reference that we will use now we will take to looking at cement and what will come out as we go as long as less the clinker more sustainable the material because the energy in CO2 are coming down. Clinker continuous to be something that is drawing up most of the energy is emitting most of the CO2.

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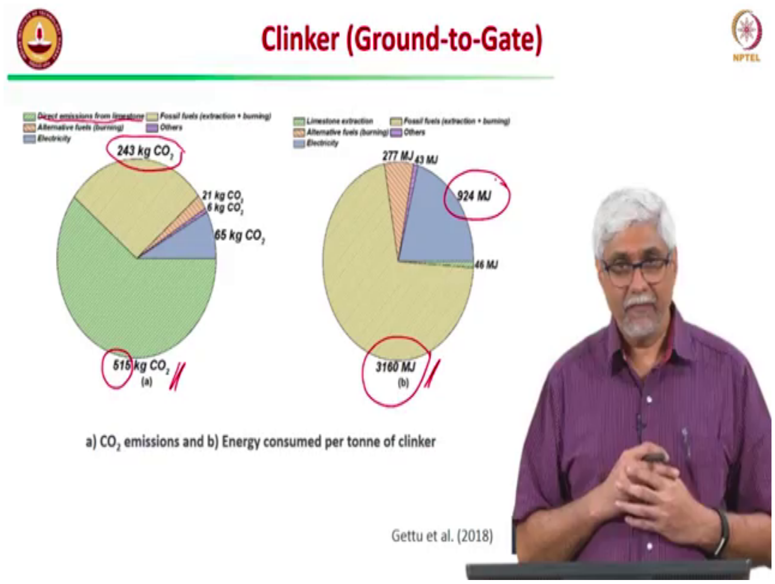

If we look at plot of the split up of the CO2 and the energy you find that the direct emissions from the limestone that is heating up the limestone and making calcium carbonate into calcium oxide is giving up a lot of CO2, 500 kg of CO2 the burning of the fossil fuels gives off about 240 out of the 850. In terms of energy the fossil fuels make up give about 3000 of the 4500 plus mega joules of energy required. So the clinkering is what makes up the clinkerization process what happens the kiln is a significant part of the impact ok.

This accounts for the electricity it is also a lot but much less than what we are getting from burning the coal or the pet coke ok so this gives the split on which are the processes that are govern and clearly the process that is most important is the clinkerization. If we can make it more efficient this the numbers would go down but it looks like we are already done our best in terms of cement plants most of our cement plants are very efficient and you cannot do much more. So the only option to improve the whole thing is decrease the amount of clinker itself.

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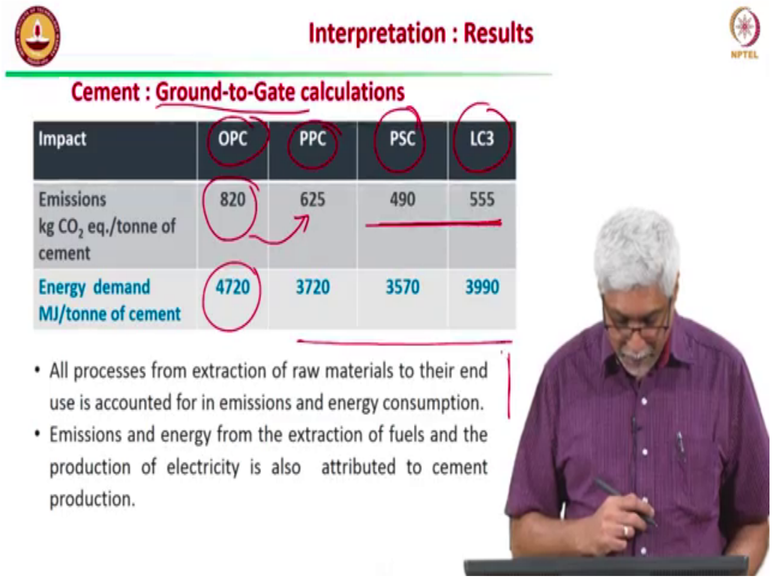

Suppose we go to cement we look at ground to gate ok this is the mine to gate or cradle to gate calculation we find OPC ordinary Portland cement with only 90% of clinker ok 90% of clinker very little limestone very little gypsum, 820 kilogram of CO2 per ton of cement ok. This is the energy required if we decrease the amount of clinker to say about 70% we add fly ash in and we get PPC the number comes down a lot 625 we have already saved about 200 kg of CO2 for every ton of cement. PSC here the clinker content is even more (even less) clinker content is only 50% in PSC and LC3 then we bring it down even more ok.

So clearly if we use less clinker in cement we save a lot from 820 we come down to 625 and we use fly ash by PPC we come down to around 500 when we use Portland slag cement and potentially with LC3 we could come down to around 550. As we use less clinker also the energy comes down we need less energy to make the cement because clinkerization is what is taking up most of the cement ok. So in this ground to gate we have included all the processes from extraction to the material coming out of the gate of the cement plant ok and the energy the extraction everything is included.

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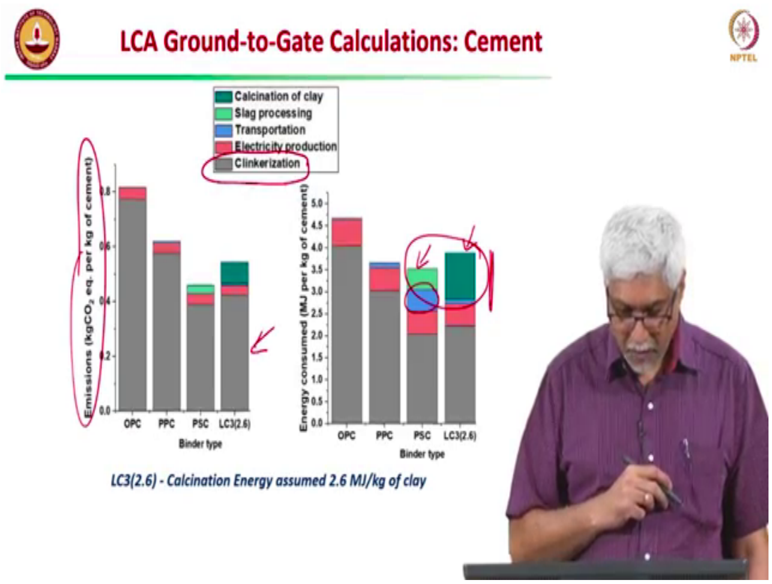

This is the same data in graphical form you see here the grey is the clinkerization energy in CO2 and you find that in all this graphs the grey part is the most that means that clinkerization is dominating the sustainability impact of the cement and we find that less the clinker the graph comes down. For slag, cement and LC3 we have some additional energy requirement because we have to grind the slag and we have to calcine the clay. So there is some amount of extra energy required some transportation also might happen but it is dominated in terms of CO2 emissions by the clinker ok so again less clinker better the cement in terms of the assessment that we can do.

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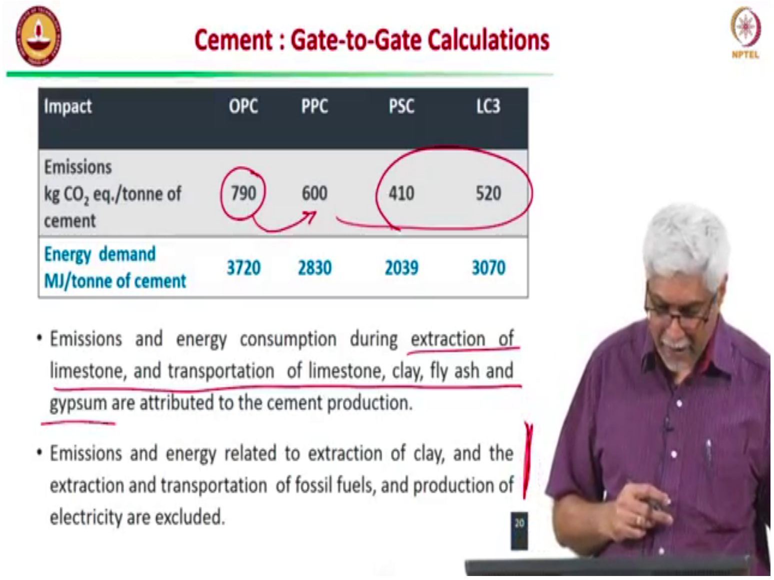

What about gate to gate? Gate to gate again is system where we have excluded what happens outside of the cement plant we include the extraction of limestone, transportation of lime stone, clay, fly ash and gypsum but we are excluding what is happening far away from the plant. Basically because that data is not reliable we do not know if the data is true or not and what we also find is that trends do not change, instead of 820 we come to 790 ok. So there is a small change because we have left out the processes there is a small reduction because we have left out processes like the extraction of the fuel and so on but the trends are the same.

We reduce from about 800 to about 600 when we go from OPC to PPC and we decrease further when we go for cements which only have above 50% clinker and the energy also reduces (()) (25:14) gate to gate calculations.

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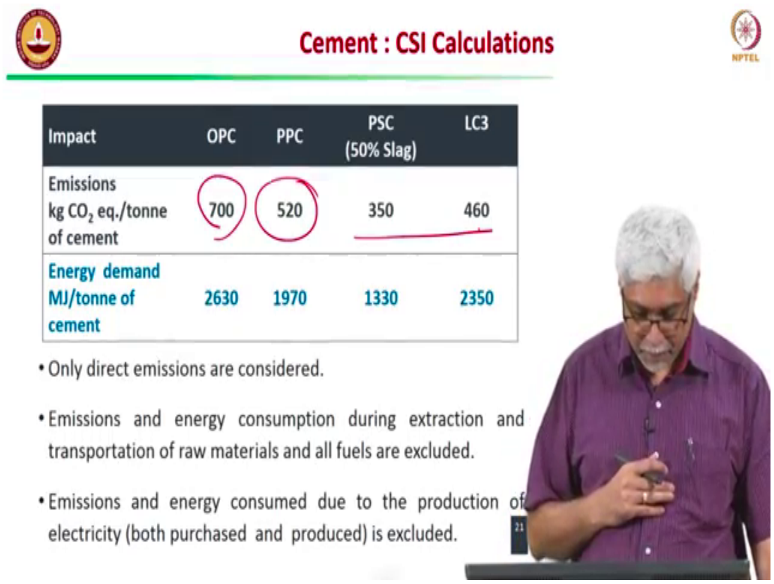

The third system that we were looking at is the CSI system which is focusing mainly on what are called direct emissions what is happening in the clinkering stage. So again the trends are the same we go down from about 700 kg of CO2 to about 500 and 400 with less clinker and again the energy goes down. So depending on which system is relevant for us we can choose one way of doing it or the other, depends on what process we are trying to improve we can focus on one system or the other the most academic system was generalized system is the ground to gate which includes everything which tells what is the complete impact of whatever we are doing.

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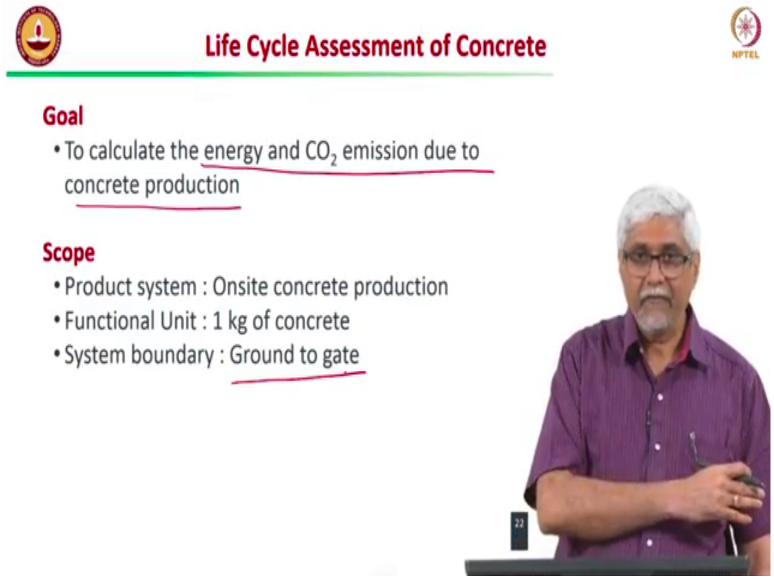

Now we look at the impact of the cement, cement goes into concrete and it would be also good to see what is the impact of the concrete because we finally use concrete as the building material in most cases. So we looked at energy and CO2 emissions in the production of the concrete we looked at a case of onside concrete production the cement is brought on to the site mixing is done at the sight and we are looking at ground to gate everything from the mine to the gate of the concrete plant.

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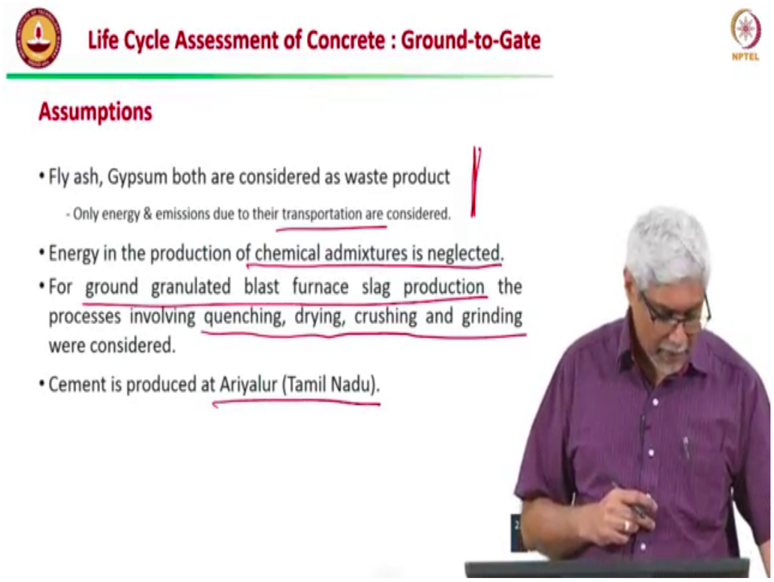

We make some assumptions we continue to look at fly ash and gypsum as base products so we do not allocate any impacts to them except for transportation, chemical admixtures is neglected because it is very small quantities and even if we use their the major numbers don't change and there is a lot of unreliable data that we have to use. For the GGBS we take into account the quenching, drying, crushing and the grinding because this is also we look before at this case we said that there is a lot of energy which is going into all this processes that has to be taken into account. We assume that the concrete was made in Chennai and the cement was coming from Ariyalur which we considered in the previous case where we assess the cement.

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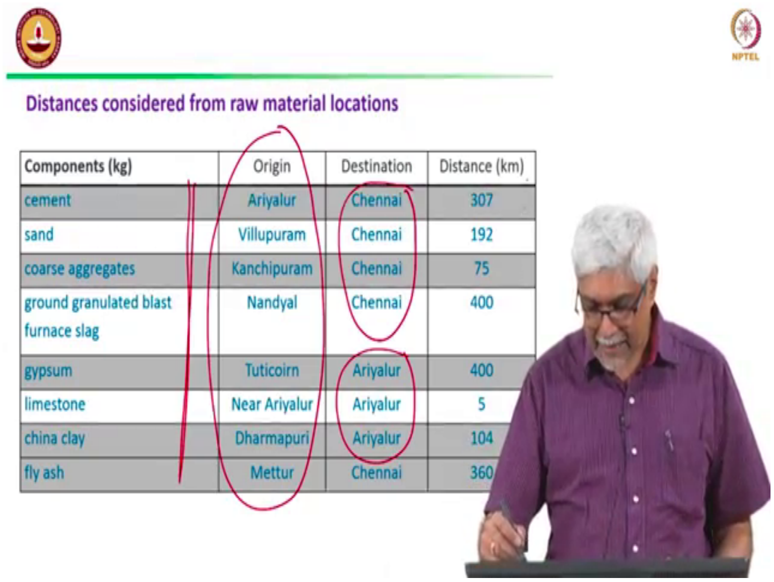

So having made this assumptions we can look at the distances because we also have to calculate what are the what is the energy consumed for transportation as well as the CO2 emissions associated with transportation. So as you see here we look at all the components of the concrete we look at the distances realistically for making concrete in Chennai ok so you see that the concrete making materials are coming to Chennai the cement is made in Ariyalur so the cement is transported to Ariyalur and then the cement comes to Chennai and this are the distances that we will have to consider.

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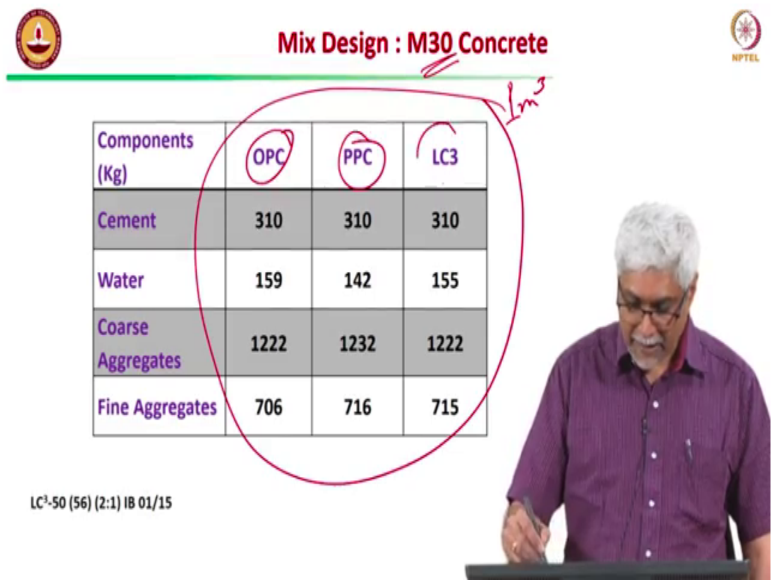

Components (Kg)	OPC	PPC	LC3
Cement	310	310	310
Water	159	142	155
Coarse Aggregates	1222	1232	1222
Fine Aggregates	706	716	715

For making the concrete we consider two types of concrete, 30 mega Pascal strength concrete or an M30 concrete having the characteristic 28 (())(28:19) cube strength of 30 mega Pascal this would be a typical mix design for each of them this is coming out of our lab work, cement, water, coarse aggregates and fine aggregates components for each for 1 meter cube of M30 concrete. Ok so this is the amount of material that will be required to make 1 meter cube of M30 concrete with OPC with PPC and with LC3.

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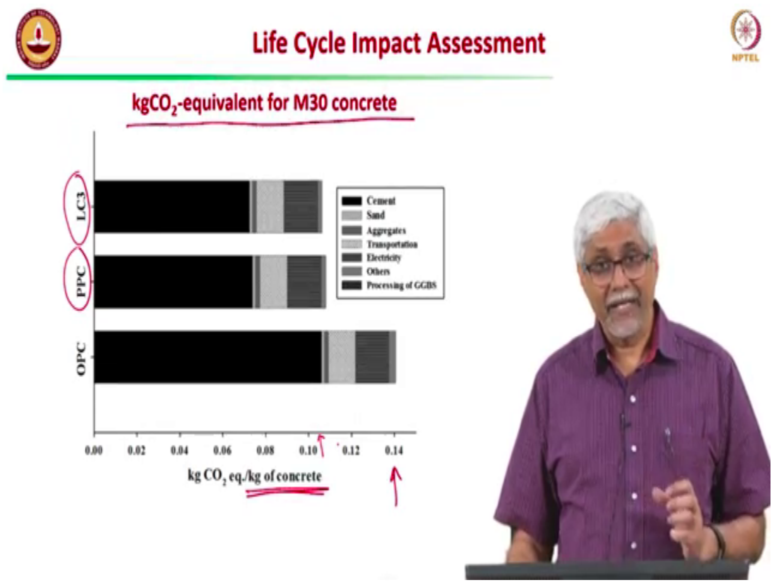

And when we look at the impact this is what we get. First looking at the emissions the carbon dioxide emissions we find that for 1 kilogram of concrete there is an emission of about 0.14 kilogram CO2 this comes down drastically to around 0.1 when we look at concrete made with LC3 and concrete made with PPC ok for every kilogram of concrete we are saving in the order of about 40% in turns of CO2 emission if we use OPC instead if we use PPC or if we use LC3 instead of OPC. For every ton of M30 concrete we would save about 40% of CO2 if we use PPC or LC3 instead of OPC. So that is quite significant in terms of the concrete itself.

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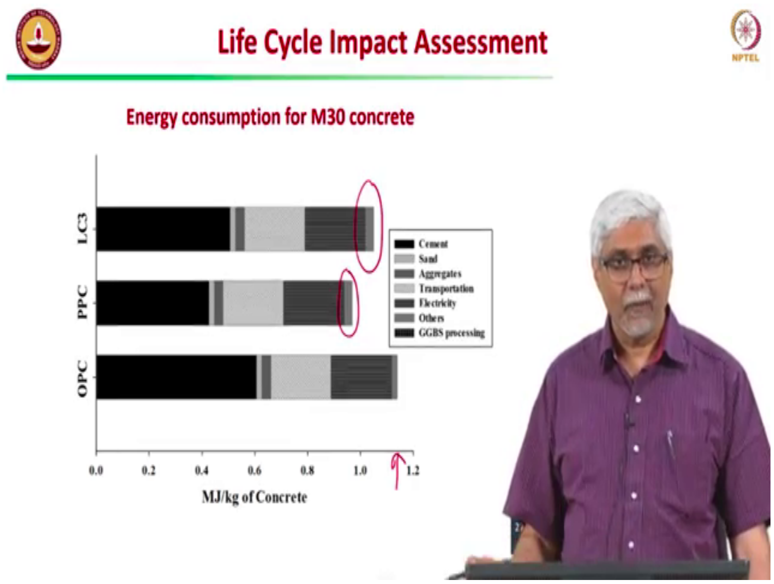

This is the energy consumption again you see that there is a trend similar to what we saw in cement the energy required for an OPC M30 concrete goes down slightly when we have LC3 gain because we have reduced the clinker and even more when we have PPC because LC3 require some energy for calcination of the clay which is not required for PPC.

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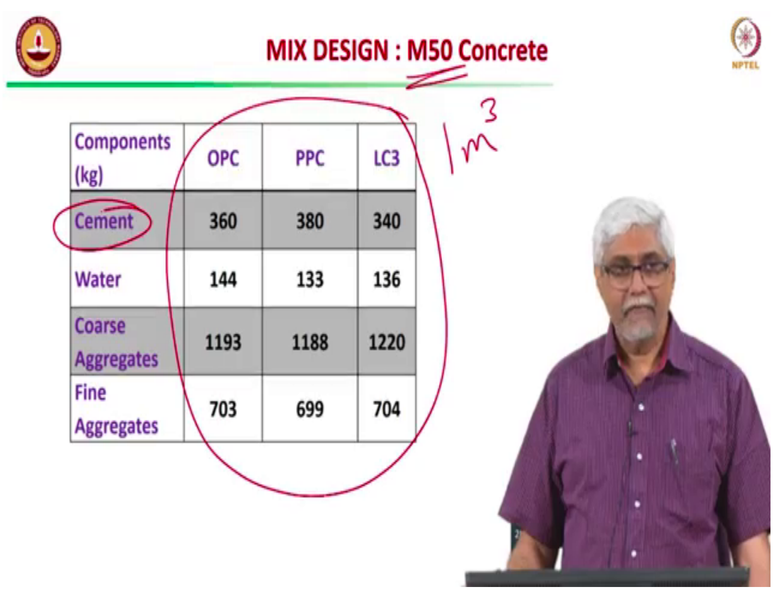

Components (kg)	OPC	PPC	LC3
Cement	360	380	340
Water	144	133	136
Coarse Aggregates	1193	1188	1220
Fine Aggregates	703	699	704

Suppose we take M50 concrete, 50 mega Pascal concrete again we are looking at 1 meter cubed of material and this are the raw material required cement, water and stone for making the M50 concrete.

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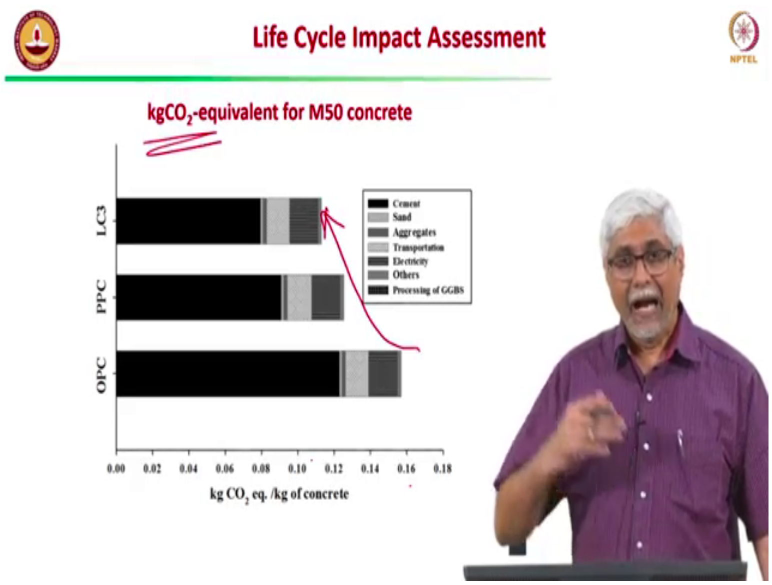

So again we can calculate the impact first looking at CO2 we find that there is reduction, instead of OPC if you use PPC decreases LC3 even more and if we compare the two concretes we find that the higher the grader the concrete more effective is the use of a blended binder in reducing the CO2. We go down from a 0.16 to maybe about 0.11 when we are going from OPC to LC3 concrete ok. So there is a significant decrease as we improve the grader the column. Higher the grader the concrete we save more if we go to a blended cement.

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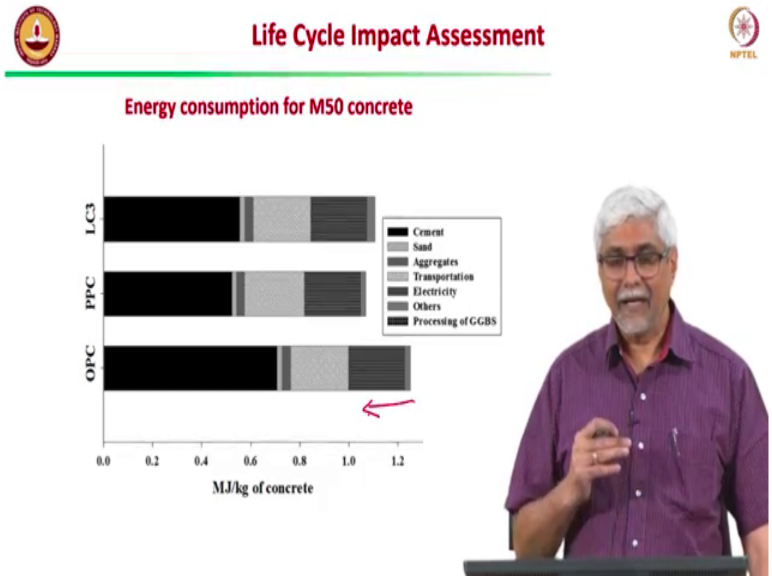

This in terms of energy again you see that there is a decrease if you use a blended binder from OPC to PPC or LC3. So we have studied the impacts of what would happen when we have a blended binder you consider two cases LC3 as the binder instead of OPC or PPC as the binder instead of OPC and we find in both the cases there is a substantial decrease in the carbon footprint or the CO2 emissions when we have OPC substituted by one of this blended cements.

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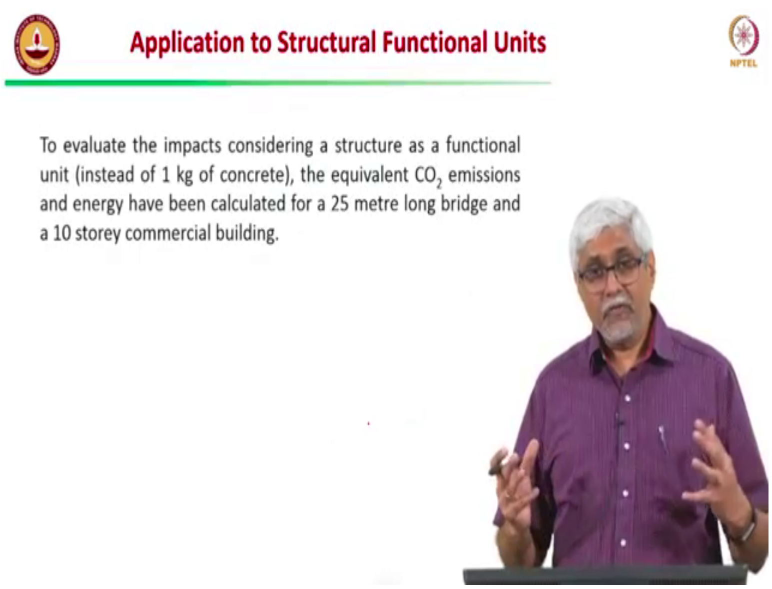

Suppose we want to look at entire structure, sometimes when we talk about a kilogram of concrete we really don't know are we saving a lot or not. So what we have done to end this analysis is to look at a structure itself as a functional unit instead of 1 kilogram of concrete or 1 cubic meter of concrete let us take a whole structure and see how much would we have saved, how much can we save if we change from OPC to PPC or LC3. So we have considered two structures one is 25 meter long bridge so we got the drawings and we analyzed what how much material went in similarly for a ten storey commercial building.

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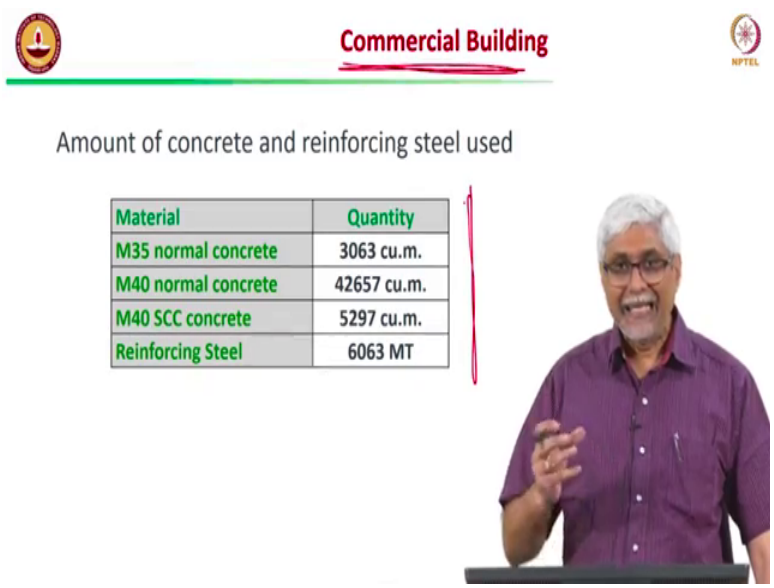

So for the commercial building e are considering a case where this was the material usedM35 concrete, M40 concrete and steel so we calculated the impact of this materials in turns of a unit mass or a unit volume of this material then multiplied by the quantity to find out what was the impact finally.

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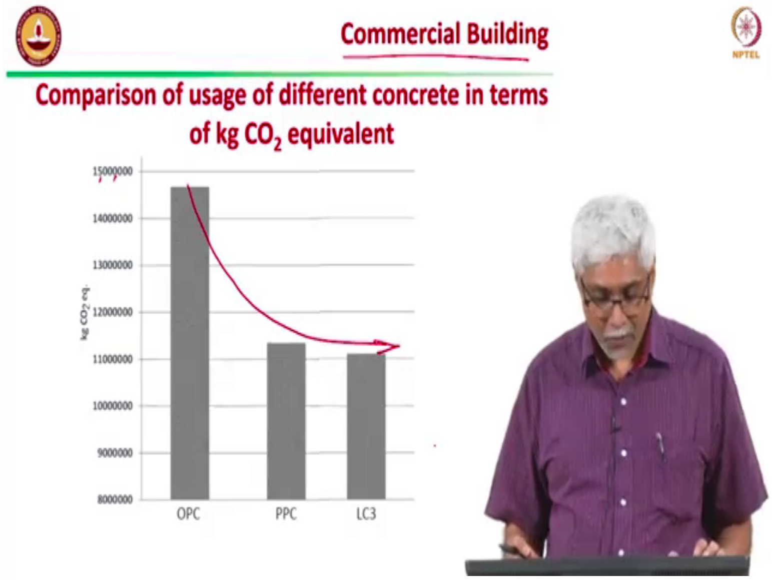

So in the case of the building we found that the changing the ordinary Portland cement binder to PPC or LC3 brings down tremendously the amount of CO2 emitted. So here we are looking at 15 million kilograms of CO2 almost for this building of ten storey when we use only OPC. It comes down to 11 million kilograms of CO2 ok. So there is a drastic reduction when you consider the whole structure for every structure if instead of using your OPC we can use a blended binder we will make a tremendous difference in terms of reductions of CO2.

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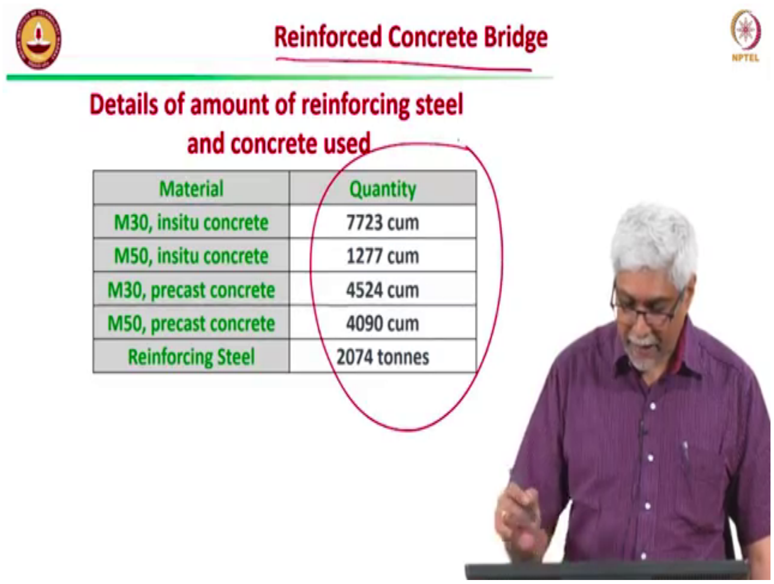

In the case of reinforce concrete bridge again this is the these are the quantities of materials used and let us see what is the impact.

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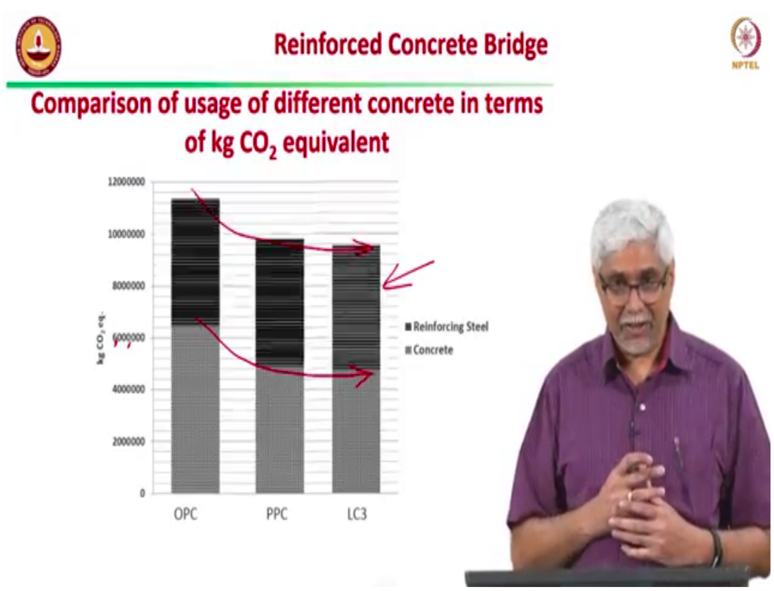

Here what we did we also you added the effect of the reinforcing steel, if it is only cement this is the change if we add cement and steel still it is almost the same because the steel impact does not change ok. So we go down from about 6 million tons, 6 million kilograms of CO2 for the bridge to about four and a half of 5 million kilograms of CO2. So again we see a large difference in just one structure. So it is very important that we not only look at a unit mass of a material but also what we can do is an entire structure, how much benefit we will get to assess how sustainable it is to change the binder or to change your concrete.

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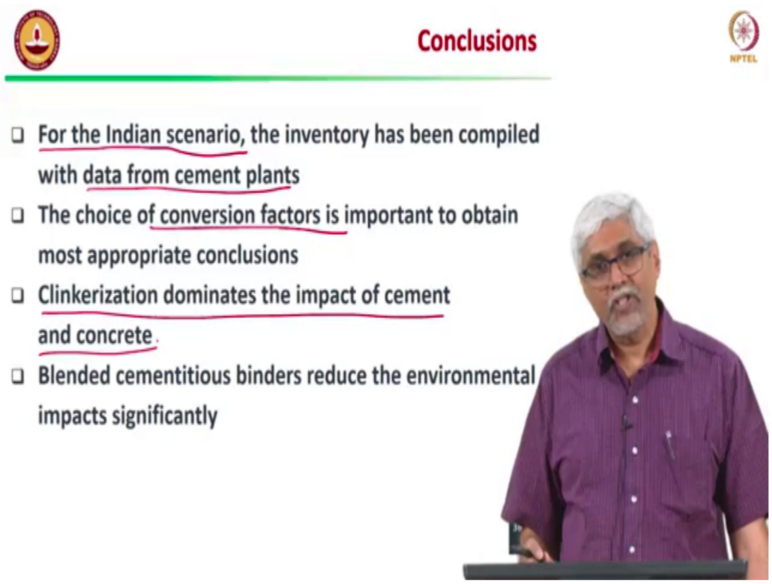

So to conclude what is very important for the Indian scenario and for emerging economies like India it is good to get the inventory done from data directly from (data) cement plants not to use a database that has been developed elsewhere but because it need not be relevant at all. We have to find what are the best conservation factors ok again we cannot use data that is just published or calibrated with in cases which are not relevant best always to is to do experiments and determine the chemical nature and the energy content like what we said before (CHSN) CHNS analysis or bomb calorimetric the least priority should be given to global databases.

Best always to derive the conversion factors from test that we can do ourselves. General conclusions clinkerization as expected and we have shown you numbers of how much it dominates the impact of cement and concrete more clinker worse for the environment in terms of CO2 emission and energy. So les clinker in the concrete better less clinker in the cement better. So blended binders are much better for sustainability is what comes out clearly in the life cycle assessment. So that is all that I had on life cycle assessment I hope you have learn something and seen the need to go for such type of assessment for in turns of sustainability of concrete and cements and the same procedure can be applied to other construction materials also, thank you.