Life Cycle Assessment
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Lecture – 30
Green Sustainable Materials (Contd.)

Let us look at the last module for this week 6 material. So, we will continue our discussion where we left with the previous module, which we were looking about green and sustainable materials. So, we will look some more concept in more details today. And the concept that we will be more focusing on in this particular material in this particular module is how to track the material flow in an engineered system.

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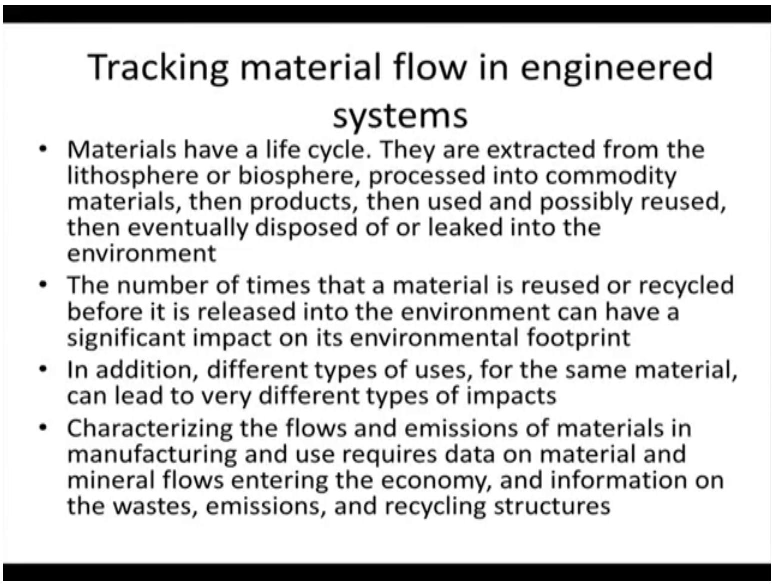

So, when we say engineered system, we are all engineers and most of us probe are engineers or we understand engineering system. Essentially when you make something when you make any mat any product the material has a flow. When we say material flow essentially we are talking about material from it is raw material which is your mining the raw material that we get after the mining activities goings to the it is melting point from there it will go to a even primary manufacturing plant then it will be go to secondary manufacturing plant ultimately the product will be made.

So, how the material is how to track it and. So, we will look at some of the examples over last few decades. And as you know many of these data is mostly collected in Western European countries or American countries. So, most of the times the examples we have to look at is from there. Unfortunately, in Indian context we do not have much data right now in terms of up to look at some of these stuffs. So, it would be nearly nice to look at some of the Indian examples, but unfortunately we do not have it. So, we will look at some of the examples from the US system which is the example which is readily available.

So, any material has a lifecycle. So, you already kind of like did a lifecycle analysis. So, you know what we mean by lifecycle, lifecycle means from cradle to grave. So, they are extracted from lithosphere or biosphere. Then it will be processed into commodity material then products then it will be used and possibly reused when we say reused means recycling. So, will look at how much of certain materials are being recycled and why it is not recycled we talk about those kind of stuff it also depends on the technology. So, eventually it will be either disposed or leak into the environment. So, the number of times a material is reused or recycled before it really gets into the environment that determines whether what kind of impact it will have before in terms of if significant impact on it is environmental footprint, different use of same material can lead to variety of different impacts.

So, it is for example, if you are using mercury in certain products, but mercury in a is in a form which is essentially in a solid form, even when it comes to the disposal stream if it is stays in solid form or it is bound up with some other material it does not leach of that easily. So, the impact will be much less, but if mercury is in a form which when released into the environment it gets reduced for some reason because methyl mercury and then methyl mercury can travel quite a bit because it is in it is a volatile form. So, that is then it is impact will be different less. So, same mercury may have a different kind of impact under different environmental system and in the under different use.

So, we will try to character in this module we will try to characterize the flow, and emission of material in the manufacturing cycle also like we will look at data on material and mineral flow which is entering the economy and what are what kind of waste emissions on recycling structure different materials have. So, we will take like 1 or 2 examples and try to understand that.

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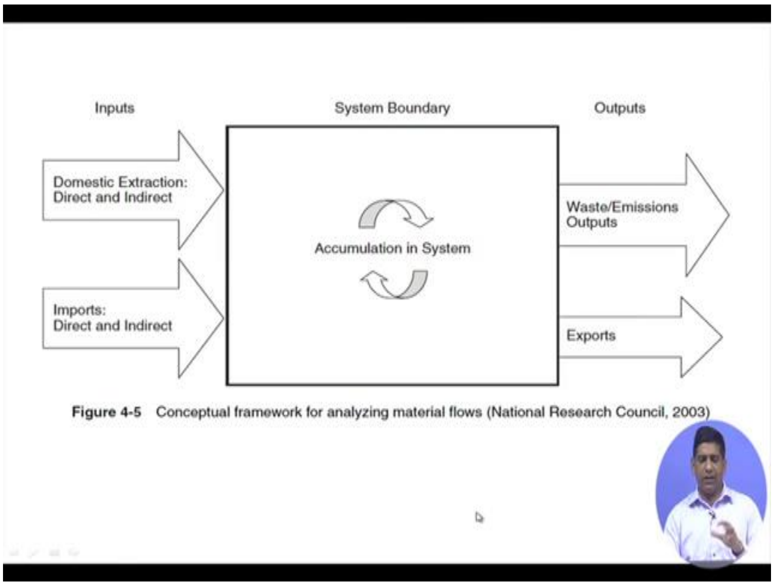

And similar things we will exist for other stuff. So, when we talk about in terms of the material flow we always a look at a conceptual model. So, what you are looking at here in this particular slide this particular diagram which is figure 4.5 again all these diagrams, came from that text book that I suggested sustainable engineering textbook at the very beginning of the class which is also there are a part of the course description.

So, you can you can access this book it is not very expensive like on amazon and flipkart etcetera on 350 to 400 rupees, it is a good book to have if you especially if you are interested in this particular topic or so most of the pictures came from there. So, just wanted to let you know that is why the figure 4.5 means the chapter 4 figure 5 from that particular book.

So, if you look at here. So, we talked about the system boundary that is what you see in the middle that is the system boundary, that we are looking at what is the system boundary. We are looking at any particular system it that could be a kind of for a particular material, but there is a there will be input and output. So, for any particular system, we are looking at celluloid from extraction to production of lead products and finally, there will be disposal.

So, in throughout the throughout the system there are some inputs coming in very beginning at the very beginning you will have the input of the domestic extraction direct or indirect there could be some imported extraction as well we are buying we are getting the raw material, we do that as you will see that most of the countries do import things and export things as well. So, that these are the stuff which is coming into the system boundary then we have some output is waste and emission outputs some waste is going out some emissions are going out and then there could be some exports as well which is like a exported out of that particular system boundary. So, if you think about the system boundary as the geographic region of India for example.

Now, if you look at let us see for our arguments sake let us see that the we are talking about lead, or will we are talking about iron we use lots of iron. So, we have some domestic extraction of iron, which is happening in the country we have some direct and extraction which is then we also import iron different quality of iron we do import iron in into the country as you will see in one of the figure later on. And then as part of the iron process there are several plants when we have Tata steel very nearby in Jamshedpur I am talking to you from IIT Kharagpur campus right now. So, there is waste and emissions coming out.

So, they do have waste going product Aldi slag which is it is again a very common waste from a tucked like steel manufacturing plant in at that is a one of the big waste stream that they are always worried about then part of the iron in the product form are they are also exported. So, so when we look at any material flow. So, if you want to see how much iron is there in the Indian context, we can look at all the inputs coming in and look at all the outputs going out and then we can see whatever is left is the accumulation into the system.

So, we will see some examples.

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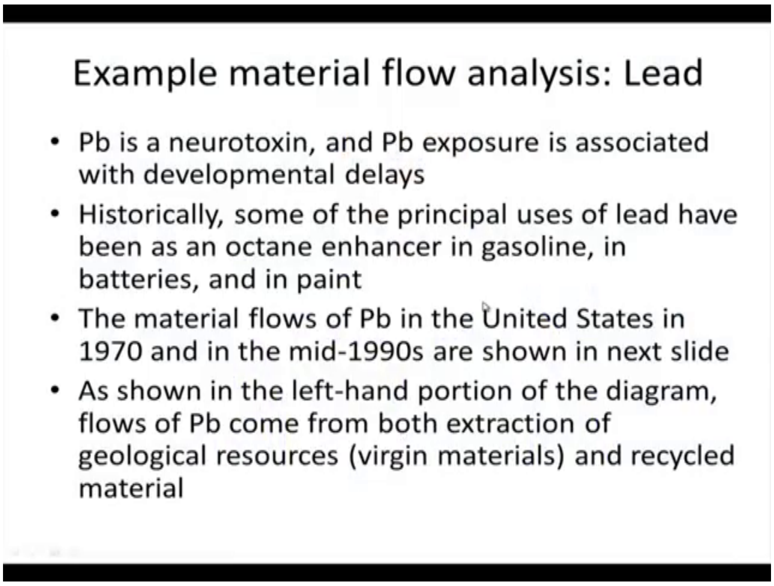

Let us say let us look at the example of lead we know the lead is a neurotoxin, we I think I talked you about that that that there is a is there is there are some hypothesis I would say that roman empire, they collapse because of the lead they were using this leaded vessel and this leaded vessel they were using lot of alcohol in that alcohol is lower pH. So, lead list out in those alcohol lead is a neurotoxin it effects the brain, and then that is lead to they are becoming crazy and the about fighting each other and then finally, they them for collapse.

Let exposure is associated with development delays we know that that is why we have unleaded gasoline I think I mentioned to you earlier in one of the earlier module, that we have unleaded gasoline because lead was a problem especially for a smaller kid it does effects the brain development. So, we do not want too much lead in anything. So, but lead has been used at octane enhancer in gasoline as we know that is why you have leaded unleaded, now which are only a reduced to be leaded gasoline used in batteries many of the car batteries they still have lead that is the lead acid battery it was used in paint lead based paint.

So, there are if you at the material flow and for recently for last few decades one of the major usage of the lead is in electronic industry your many of the electronics soldered that you do soldering when you put those chips on those you have your printed wire board and you put your different chips on top of that and the by the solder which should you attach this chips on the printed wire board it contains lot of lead.

So, at least it chooses to contain lot of lead until recently now we are trying to get rid of that and tried to go for other materials. So, if you look at lead usage in united states in we will see in next slide.

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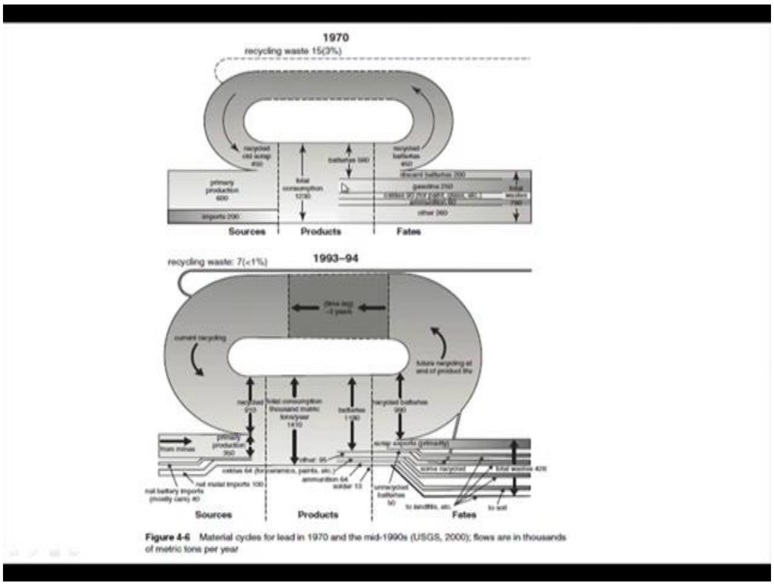

It is the left hand portion here it is if you can see there are on the top part is 1970 and the bottom part is 1993 94. So, here on the left hand side say is the sources in the middle we have the products. And at the end we have the fate of the lead. So, and same thing at the bottom sources products and fates. So, as you can see that graph has actually gone bigger in 1994 to 1917 more usage of course, more lead is being used in 94 is opposed 1917. So, that of course, because of like we have more it like a industrial process is going on economy has gone up. So, with all those things happening of course, more lead is being used.

So, but if you look at in into the recycling of lead it was 3 percent. So, recycling rate was 3 percent, but recycling rate in terms of since the total production has gone up our recycling rate is actually gone down to less than one percent. So, actually we were doing better in recycling in 1970 as opposed to 93 94 in terms of the to in terms of the percentagewise total wise we are a still doing lot of recycling more recycling in 1993-94 because the consumption has gone up.

So, on the left hand side you see the input coming in input is from the mines from the battery imports or metal imports. So, that is your kind of the import coming in if you look at the 93-94 side part of it. Then we have the product we make different kinds of products like a ammunition solder that is you see solder which was talking about the numeric batteries, it like internal consumption those things are over there then we have mosphate where some of these are being exported some of are being recycled, some goes to the land fuel then we have some is actually in the product we do not how much it will tie it based on it itself life it will come back. So, that is called future recycling at the end of the product life current recycling. So, those this is how the things are moving and we can we can look at the material cycle for each and every element in more detail based on what data we have.

Similarly, the things over here are a bit little bit not that complex because we do not have the solders and other things in here. We did had ammunition some oxides some gasoline you see the gasoline in 1970 we do not say it gasoline usage of lead in 93-94 because we banned use of gasoline. So, we can draw these kind of diagrams to understand what is happening with one particular material how much how much it is the input coming into the system boundary system boundary usually we can take as a geographical boundary of a city sorry geographical boundary of a state or a country and we can look at the net in net input net output and whatever is not will be the accumulation the difference between the 2 will be the accumulation in the system

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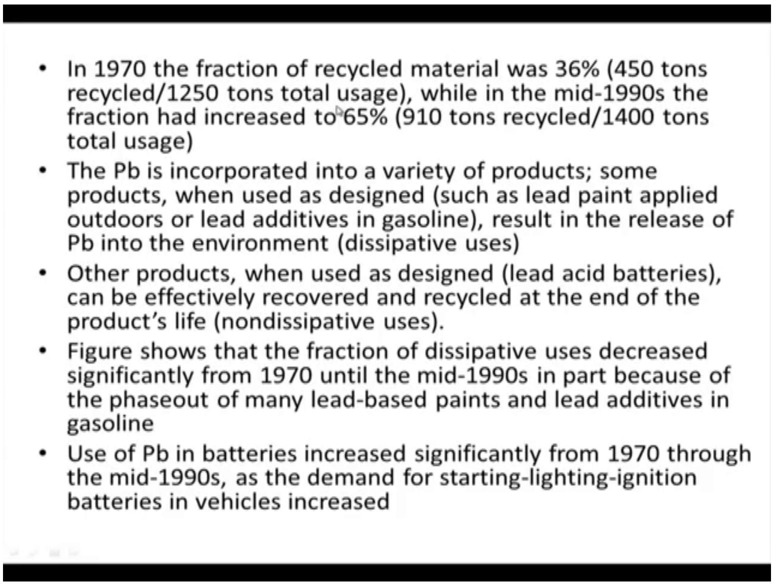

So, there kind of some important points from the previous slide 1970 the fraction of recycled material was a36 percent. So, 450 tons out 100 and 1250 tons of the total usage coming from recycle. While in mid 1990 the fraction has increased to 65 percent. So, we did had a more 900 and 10 tons of recycled plus 1400 1400 tons of the usage lead is being used in variety of products lead based paints lead additives in gasoline. So, that is leads to more usage of lead in in different product means more potentially more released into the environment.

The other products like lead acid batteries can be effectively removed in recycled at the end of product life these days' lead acid batteries it is almost00 percent recycled in many developed countries even in developing countries, when you go for newer battery you basically give your old battery and then that can potentially be being recycled. The figure also shows that the fraction of dissipated uses decreased significantly because of the phase out of the lead based paint or lead additive in gasoline use of lead in batteries have increased significantly as demand for starting lighting ignition batteries in vehicles have increased.

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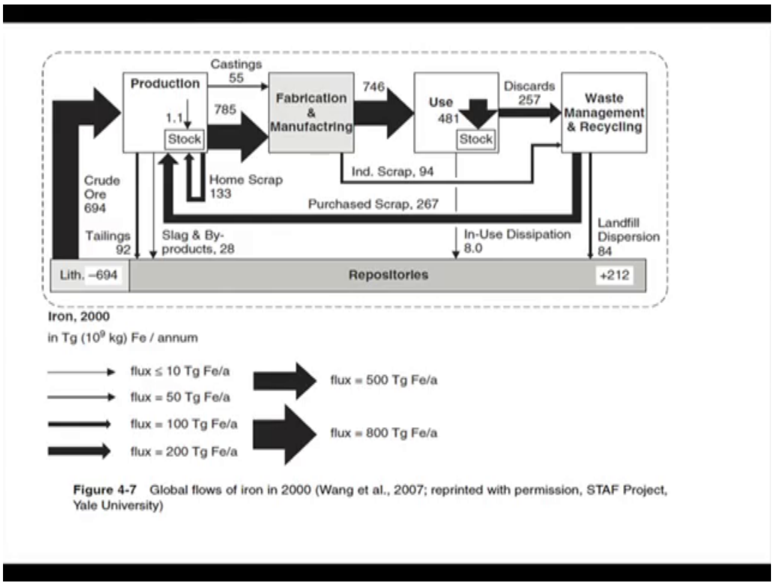

So, that is kind of gives you an idea of how things have been moving in terms of for certain metal.

So, now if you look at a different metal which is let us look at a global flow of iron and we will we will try to see this in different kind of scenario we will look at iron in 1970 and then 2000 it is it is no sorry it is a global flow will look at the global flow of iron and then we will look at the flow of iron from the US context. So, globally in year 2000 again the numbers will go up now because more and more India china Brazil these companies are booming economies since 2000. So, more and more demand for iron is there. So, we to build lot of steel structures. So, in 2000 in 10 to the power of 9 of kg if you look at that particular unit we are loo and the different the things that you see over here the you see lots of arrows in this picture and at the bottom you can see the region which tells you which arrow means what. So, thinner the arrow means lower the data. So, very thinnest one is the flux is less than 10 to the power of 10 like a teragram or tetragram per iron per annum.

Then when you little bit thicker 50 then 100 200 500 800 and based on that you see the arrow or bars over there, so there are repository of iron we talked about that in the previous module that there are different types of reserves from that reserve, you will get some iron coming out that would be crude oil crude ore some iron tailings then the production of the iron production will be there, same size in the production phase again some may go back into the repository in terms of the waste and other stuff then you do the casting goes to the fabrication and manufacturing then to use discard waste management recycling then from waste management part of it can go to the land landfill dispersion part of it can be recycled purchased scrap and go back to the production then could be some industrially scrap which kind of go back over here. So, as there could be some home scrap which can go back to the recycling system.

So, this kind of gives you an idea of how the iron is under different kinds of different systems in terms of it is global usage global flow. Same thing will look at for the US in a minute.

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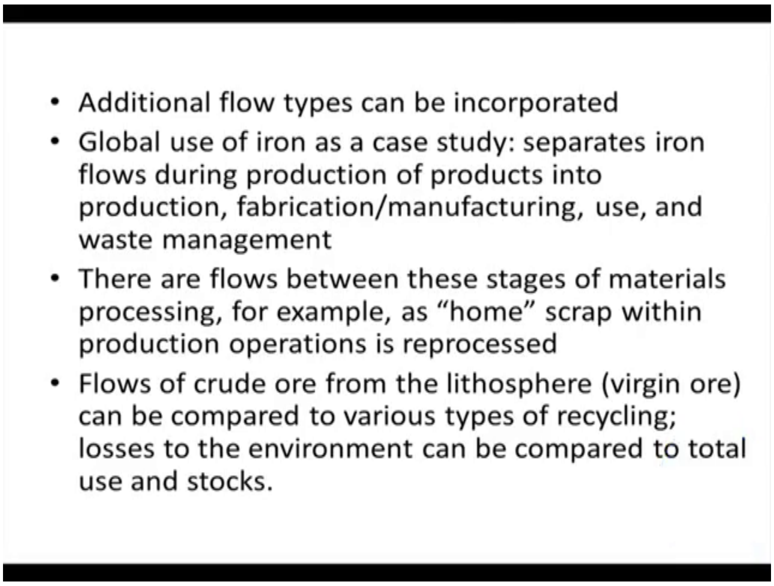

So, there are different types of flow types we looked at dif based on the different arrows that you saw global use of iron is a case study, but iron flows during production of in production of products into production fabrication manufacturing use and waste management. These are flows between this stages of material for example, home scrap within the production process you are reprocessing it flow of ore from lithosphere can be compared with various type of recycling losses to environment. So, those are different things we can look at.

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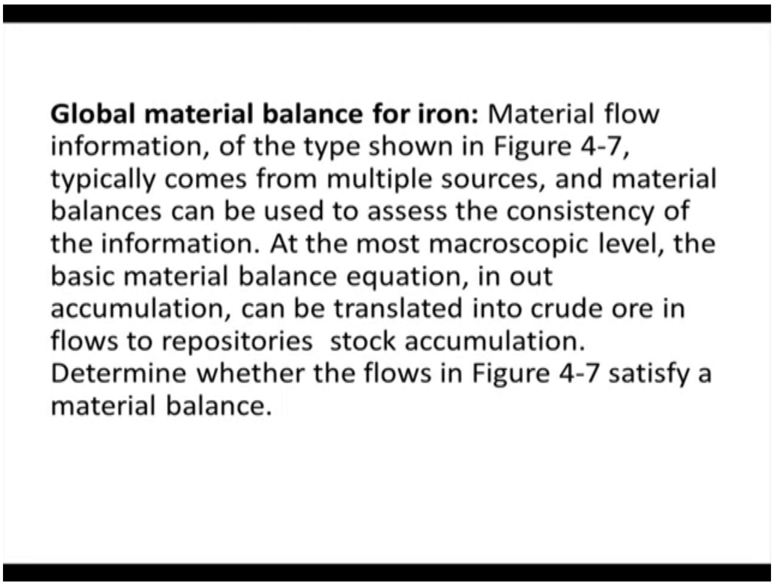

So, if you think about the previous slide that we had where we look at this figure 4.7 the material global material flow for iron they typically comes from multiple sources. So, if you we can do a material mass balance mass balance is a very important concept which probably you are aware of, it is if you are not outs encourage you to kind of go to any environmental book and look for mass balance you will find something to read about that. So, it is essentially conservation of mass that is what we are trying to look at. So, material balance we can be assist to assist the consistency of information we can whatever information we have we can do it conservation of mass and come up with that information.

At the micro microscopic level basic material balance equation, we can it can be transferred into crude oil flow into accumulation determined whether the flow is satisfied material balance or not. So, essentially what we are telling is after you get all the data regarding the mass bal regarding the material flow you draw that conceptual diagram after drawing the conceptual diagram do the mass balance on it to cross check whether the material the data that you received it make sense or does not make sense. If it does not make sense; that means, you need to go back re revisit the data and try to correct it.

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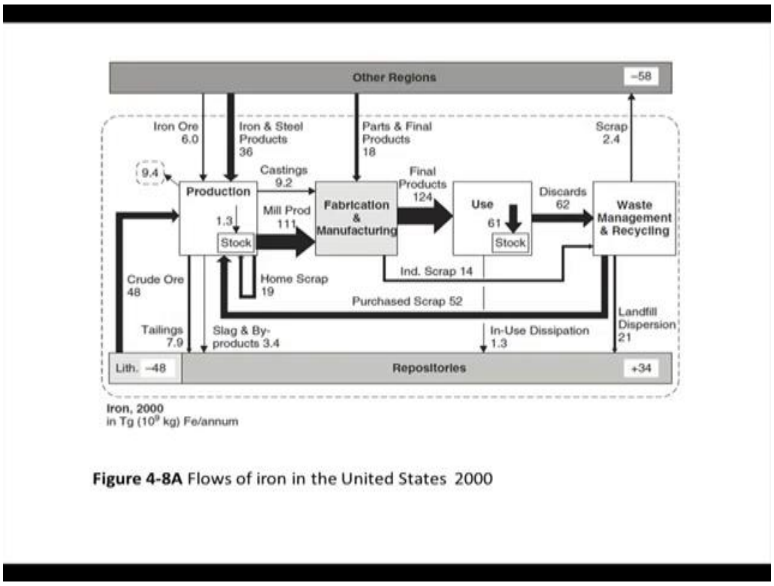

Now, same picture, but just for the US industry and here you can see since, it is for the US on the top we have another bar over there that is essentially for export or import. So, things that is coming from outside that is why we have been we are showing it on outside of the system boundary the dotted line is your system boundary and things outside of the system boundary is what is what it is says on top other reasons. So, that is your coming things coming from out of the system boundary.

So, here again some crude getting into the production fabrication use disposal, so those things are there some scraps going in some industrially scrap landfill disposal slag and byproducts and from top from the other regions like from other not in US from outside US we are getting some iron ore coming we are also getting some iron steel products we can getting some final products and then we are also sending up some finally, scrap to some scrap from US is also going abroad for managing that is scrap or recycling it or whatever. So, that is kind of gives some idea about the material flow for a one particulars the previous one you look at the global material flow this one kind relates to for one particular country.

So, we can have similar material flow done for different materials for a particular country.

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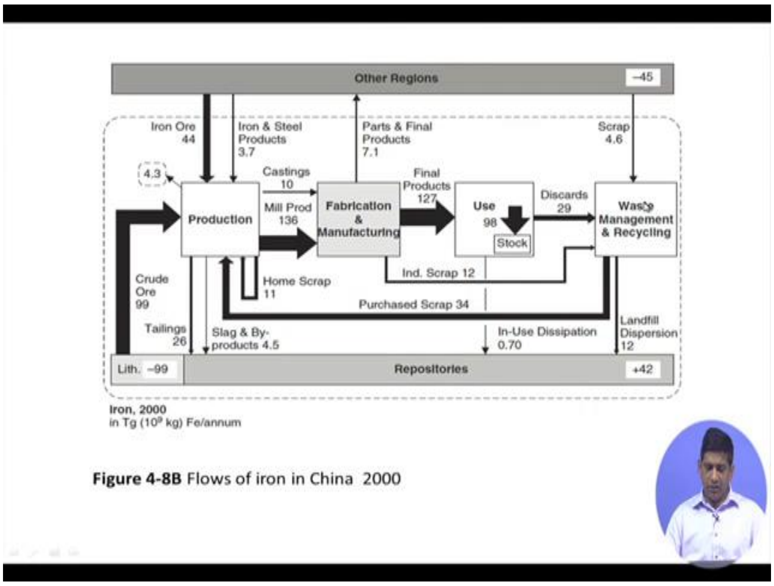

Figure 4-8B Flows of iron in China 2000

So, same way same thing if you look at the china, example china we know it is a booming economy again you see is all those channel is also importing some iron some iron steel products it also exporting things it also sending some scraps overseas. So, that is and then of course, it is taking things from the repository and also putting some things on repository in terms of the slag byproducts landfill dispersion landfill disposal and all that.

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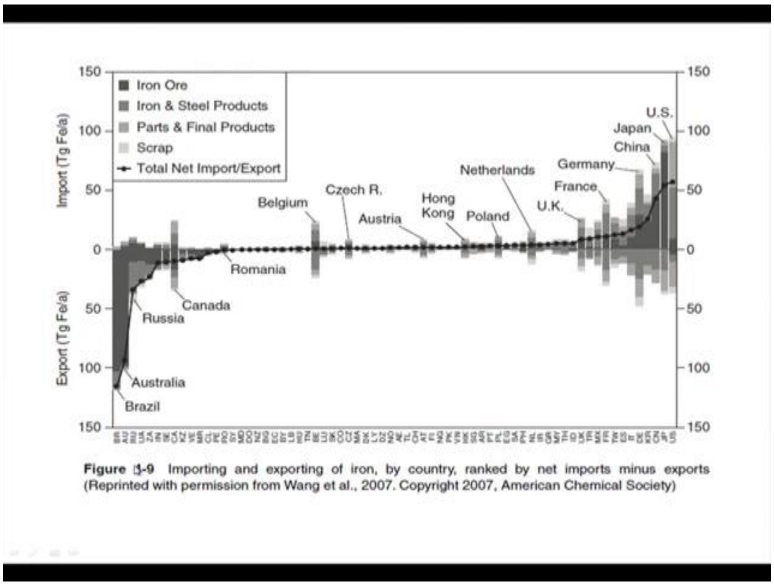

Figure 4-9 Importing and exporting of iron, by country, ranked by net imports minus exports (Reprinted with permission from Wang et al., 2007. Copyright 2007, American Chemical Society)

So, this graph is more interesting, if you look at that is those 2 kind of just those 3 outside just looking at the iron flow for different countries, first you starting with the global then china, then in adjutancy US then china this one this figure kind of you tells that what is import and export of this iron is going on for different countries several countries have been listed here.

If you look at India which is right here which is 2 bars below before china. So, we are looking as sorry Canada. So, it is 2 bar before Canada is what we are looking at for India Indian scenario, and you see over here dot down here IN that is the India. So, 2 bars before Canada so, but here the in the middle we have a 0 line. At the bottom we have export. So, if some countries show up too much on the bottom; that means, they are exporting a lot they are not importing that much you see some more on this side does not see much here; that means, they are importing a lot and lot exporting you see many countries kind of in the middle. So, they are importing as well as exporting you might be wondering why they do that because we are looking at iron that does not mean we are looking at just the raw iron seeds we are looking at products made of iron.

So, for a particular country you might be exporting certain products made of a iron which has iron as one of the component. And you might at the same time be importing certain products which are made out of iron. So, and here on that on the top left you see that iron ore iron, so different colors different sets of basically gray or black makes tells you what kind of products or material we are looking at. And then the line with the dot you see that is a total net import and export. So, that kind of you see over here as well on top side is import on the bottom side is on export; so some of this which is the highest exporting country Brazil. So, we start from Brazil then Australia Russia Canada as we go over here we kind of go towards the middle of path partly it is below partly it is above. So, that then it becomes kind of it is exporting as well as importing, but predominantly exporting until I would say all the way to Romania.

And then it kind of gets in kind of the balance then you see things being exported a lot, but here some are kind of in the balance and, but later on you see kind of increase in more and more and more import for example, US is actually is the highest importer of a steel US is a importing lots of products is like if you go to any big shopping area in US you see the products mostly made outside US. So, that is. So, those products are coming in and many of them contains heavy amount of iron and other material.

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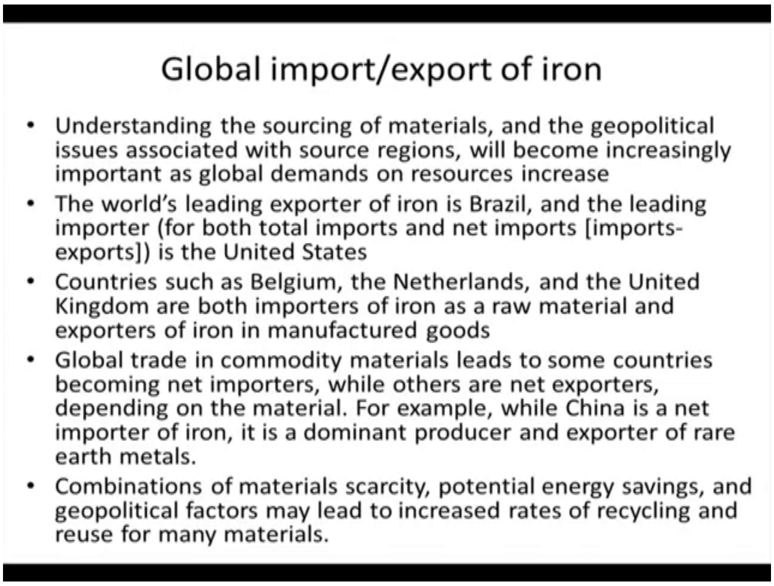

So, what we saw in those pictures it is the understanding the sourcing of materials and the geopolitical issues associated with some resource region. We know what some of these critical materials we will talk about. So, while leading exporter of iron is Brazil which we saw in the picture and the leading importer for both total exports and net imports is US which we saw as well countries like Belgium, Netherlands, United Kingdom's are both importers as well as exporter. So, the import the iron is a raw material, export iron in the manufactured goods, global trend global trade in community material it is some countries becoming net importers while the other becoming net exporters, we saw that for example, while china is a net importer of iron it is also a dominant producer and exporter of rare earth metals.

So, combinations of materials scarcity potential energy savings geopolitical factors they lead increase in this rate of recycling and reuse of many materials.

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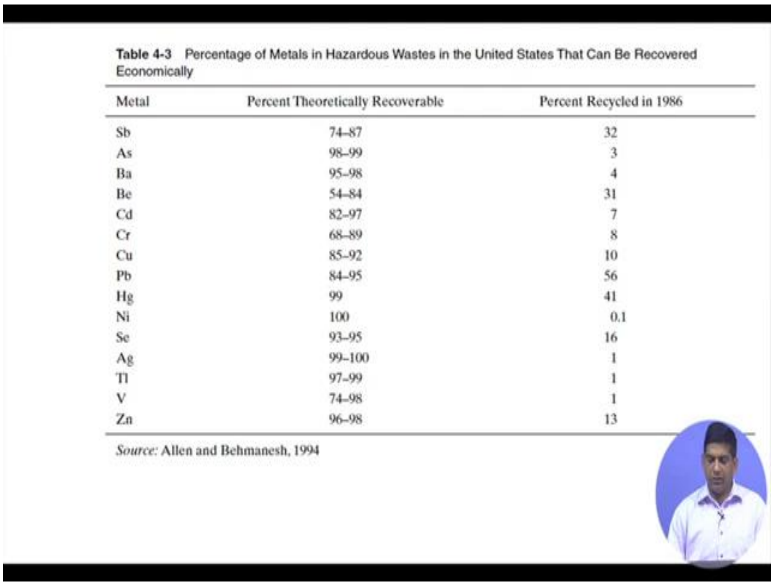

Table 4-3 Percentage of Metals in Hazardous Wastes in the United States That Can Be Recovered Economically

Metal	Percent Theoretically Recoverable	Percent Recycled in 1986
Sb	74–87	32
As	98–99	3
Ba	95–98	4
Be	54–84	31
Cd	82–97	7
Cr	68–89	8
Cu	85–92	10
Pb	84–95	56
Hg	99	41
Ni	100	0.1
Se	93–95	16
Ag	99–100	1
Tl	97–99	1
V	74–98	1
Zn	96–98	13

Source: Allen and Behmanesh, 1994

So, someone some of the; so like one example here percentage of this study was done several years back actually almost 20 years back where they look at the percentage of metals in hazardous wastes in the united states that cannot be recovered. So, these are the different metals present this is the percent theoretically recoverable rate. So, that percentage recycled in 1986. So, although it can be recovered it can be recycled especially say for example, if you look at the nickel almost 100 percent can be theoretically recoverable, but only 2.1 percent was being recycled.

So, many of them silver for example, or vanadium or even zinc very low recycling cadmium chromium copper if it is better little bit better it can be, but it could go much better lead was nearly 56 percent recycle or mercury was 41 percent recycle.

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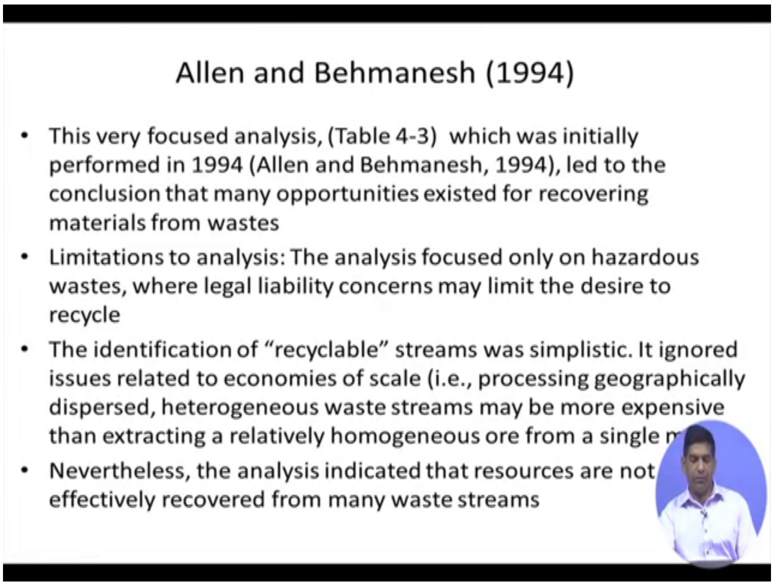

So, but these are mostly related to the hazardous waste. So, there could be there are other types of materials out there. This as I said this was a very focused analysis this was one-point paper done if it is it has a certain objective of that paper. So, but it just found that many opportunities existed for recovery of materials from waste which even exists today that, there are lot of we can if we can come up with a good technology for recovery of heavy metal as like most of us carry at least one electronics every with us and that the electronics, as I was said like a phone like this sometimes have 35 to 40 elements in there.

So, if we can if we can extract these elements. So, basically where we lack is the technology, if we can come up with a better technology which we can help extracts some of these heavy metals that will increase the recycling rate. So, we have to make it economically profitable to recycle and so, identify it is analysis focused only on this particular analysis that we just suitable that I showed you that focused only on hazardous waste.

So, not on other stream, but recycle stream was simplistic ignore the economy of scale. So, those things would be looked into nevertheless analysis does indicate the resource are recovery it effectively recovered from many waste which is even today is true.

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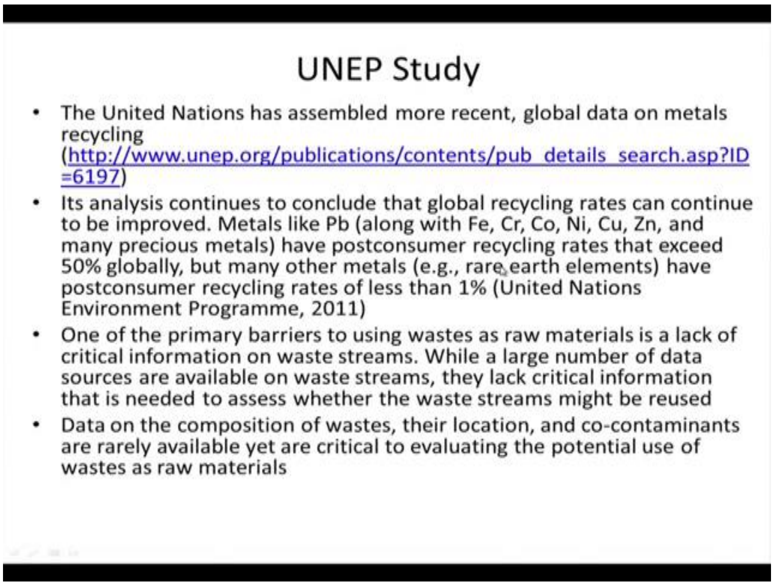

Some of the other that information was very old, but the some of the one recent report and I have put given you the link over here. So, you can try to go and look that particular report. So, UNEP has come up with a recent global data on metals recycling. And it is that was done in 2011, so outside on 5 years back so not too bad. So, it analysis does complete it does conclude that global recycling rates can continue to be improved metals like lead along with iron and copper chromium nickel zinc and all those have postconsumer recycling rates that are exceed 50 percent globally.

But many other metals especially the rare earth metals supposed to be recycling rate of less than 1 percent and that is it is a rare earth metals. So, it we it is a rare. So, we should these are try to recover it recovery of them. So, we if somebody wants to develop some technology that is the area where we should look at how to look at how to recover this rare earth metals from electronic in this electronics for other waste products.

So, the primary barrier is lack of critical information. How much lack of say any industry you would like to know how much is out there how much rare, say for examples if I tell you that you start a business of trying to recover this rare earth metals from the waste stream of India, number one question will come what is the wasting we are looking at how much rare earth metal potentially, we can recover. Because you will start looking at your business model and you will start looking at the economics of scale, that whether you have enough material to process and whether you will make enough money to selfsustain and make profit because as a business you have to make profit so that you can diversify.

So, data on the waste quality waste quantity as well as quality is very important, but unfortunately we do not have much and the data on the composition of waste and where what is the composition and where they are located if there is a co contaminants. So, these data are rarely available that kind of that creates problem in terms of potential use of raw material.

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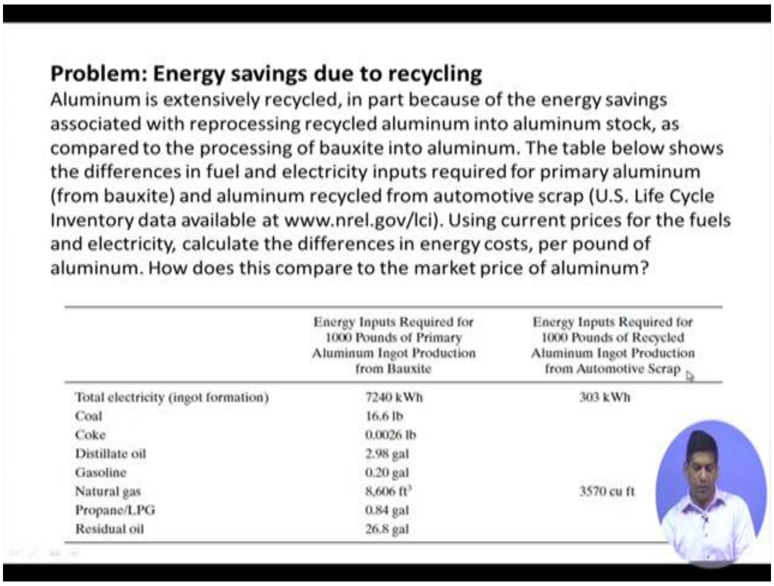

Many materials are still being recycled a lot aluminum is one good example aluminum cans are mostly recycled. And aluminum anything with aluminum gets recycled a lot and the reason for aluminum getting recycled as you can see and here. Energy inputs required for000 pounds of primary aluminum ingot production from bauxite energy inputs required for 1000 pounds of recycled aluminum from automotive scrap, you see that it kind of goes down to almost it is say what it is 24 times.

So, it is 24 times less 23 times less energy is needed for recycle then from like raw material. So, that really saves lot of energy and it saves energy and then of course, energy that saving of energy leads to more money being more profit margin better environmental performance. So, those all these things can help with that.

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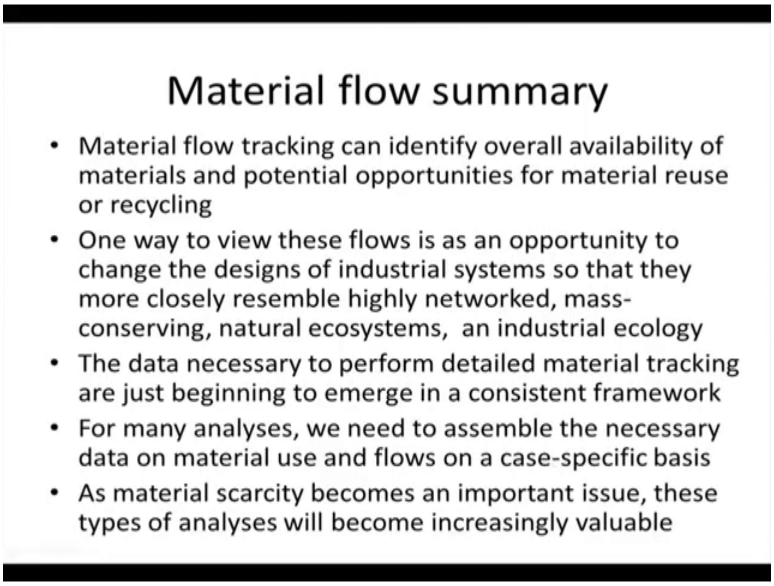

So, to summarize material flow tracking can identify overall availability of the material, and what is the potential opportunities. One way of looking at this is to change the design of industrial systems. So, that they are more closely resemble highly network mass conserving natural system, like we have naturally eco system works in industrial ecology, the data necessary to perform detailed material tracking are just beginning are to happen India.

As I said earlier also we have an Indian resource panel now which they will be trying to generate these kinds of data either by themselves or they will try to have people do it for them. So, for many analyses we need to assemble necessary data for use and flow as on a separate case specific basis as material scarcity becomes an important issue which is this part of analysis will become increasingly valuable.

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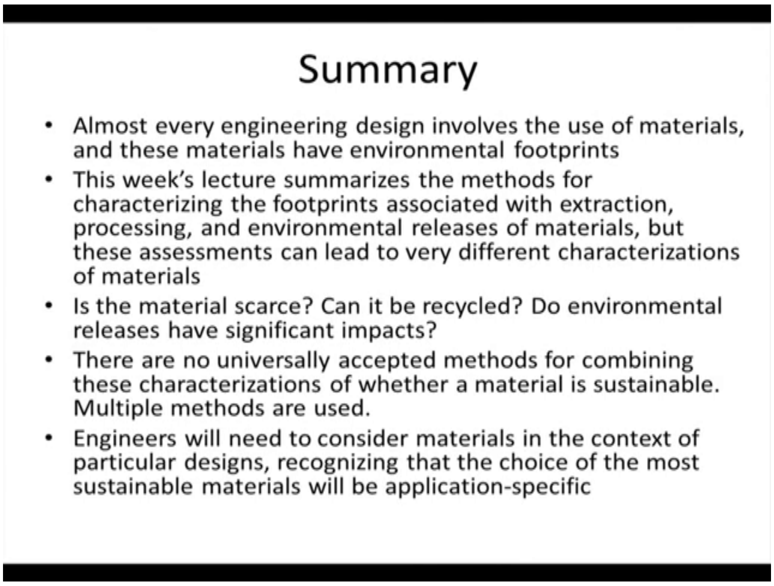

So, to summarize this week we have this is the last module for week 6. So, for all almost every engineering design it involves use of materials. And the materials have environmental footprints. So, in this week's lecture we were trying to methods for characterizing the footprint, we started with doing what are the good steps of doing LCA kind of given overview when you started looking at the metals where environmental fate and transport. So, footprints associated with extraction processing and environmental release of materials, but these assessments can lead to very different characterizations of material. And then also is the material is scarce can it be recycled do environmental releases have significant impact this. So, this those are things we can try to try to answer in this particular week's lecture material, then is the material is scarce can be we talked about that there are no universally accepted for combining these characterizations whether a material is sustainable multiple methods could be multiple methods are used.

So, those things can be done engineers will need to consider material in context of particular design recognizing the choice of most sustainable material will be application specific. So, most sustainable material will be depending on what applications we are trying to use it for. So, that kind of brings it to the end of week 6 material. So, as I have been telling you for a last few modules that are if the course is as you know the course is already up and running this is the 6 week.

You have I assume that you are doing the weekly quiz I is strongly encourage you to finish all the weekly quizzes as you make progress, that will help you understand the concept that kind of force you to do some reading. And then of course, those of you who want to take the final exam we will take that and then questions will be kind of similar is starting similar to format will be similar to kind of mixed, but there will be some math problems and other things as well which will be which will talk about.

So, with this let us close this particular module and then again I will see you in next module with the first one for week 7.

Thank you.