Energy Conservation and Waste Heat Recovery
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Lecture – 67
Course Wrap-Up

Welcome back and today what we will do is, we will wrap up our discussion on Energy Economics as part of this course on Energy Conservation and Waste Heat Recovery. We were discussing the input-output method of Wassily Leontief and we discussed the overall how the input output matrices line up and how powerful that method is to calculate that for a certain demand of an economy, how much should be the production for each sector of the economy. So, that demand is met and in order to do that, we need to know the elements of a matrix called the transaction matrix which we denoted by e.

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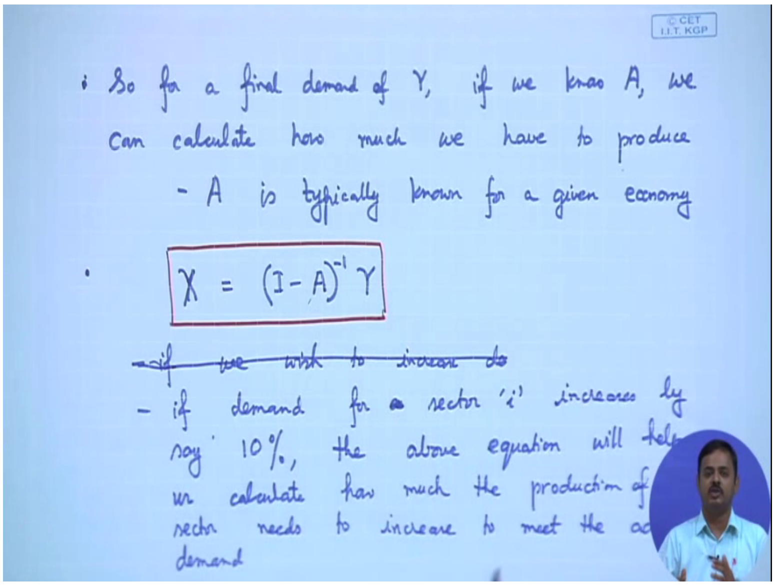

So, we need to know the final demand which of course we should know, we should plan and A is the interdependence. This is the transaction matrix which shows the interdependence of the outputs of different sectors. Recall the output of a sector first goes as inputs to all the other sectors including itself and is consumed for production from each of these sectors and after that what is left goes on to meet the demand of a certain economy or of the demand of the certain nation, the demand of the population, demand for export and so on, clear. So, this is a very powerful method. As we said that if the demand is known, if the transaction interdependence relations are known, then I can calculate the production that is required to meet that demand, clear.

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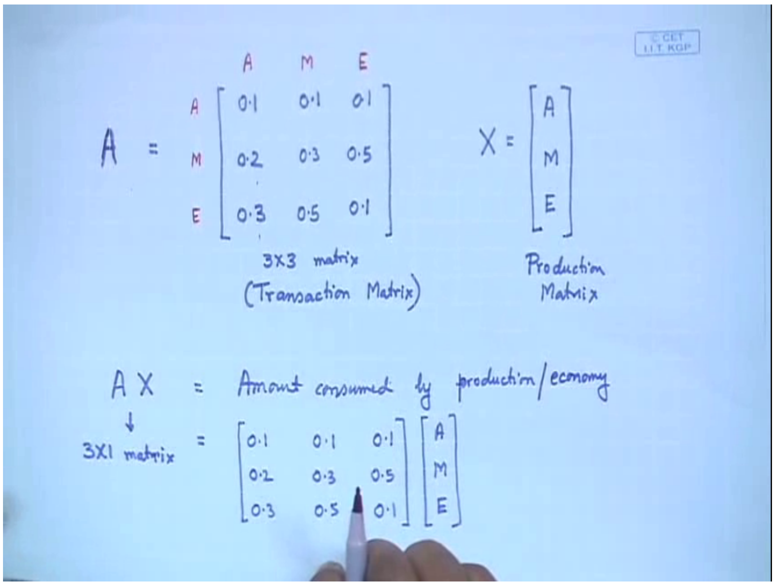

So, with that let us go back and solve the simple problem that we were talking about where we said that you know we are talking about a case where we considered three sectors; agriculture, manufacturing and energy and the e matrix turned out to be this because we said to produce one unit of agriculture. We need inputs as 0.1 unit of agriculture, 0.2 units of manufacturing and 0.3 units of energy.

Similarly, for manufacturing and energy, all right and this is the transaction matrix A, this is my production matrix which is unknown. Therefore, the product of 2 A times X is the consumption matrix amount consumed by production or economy, right.

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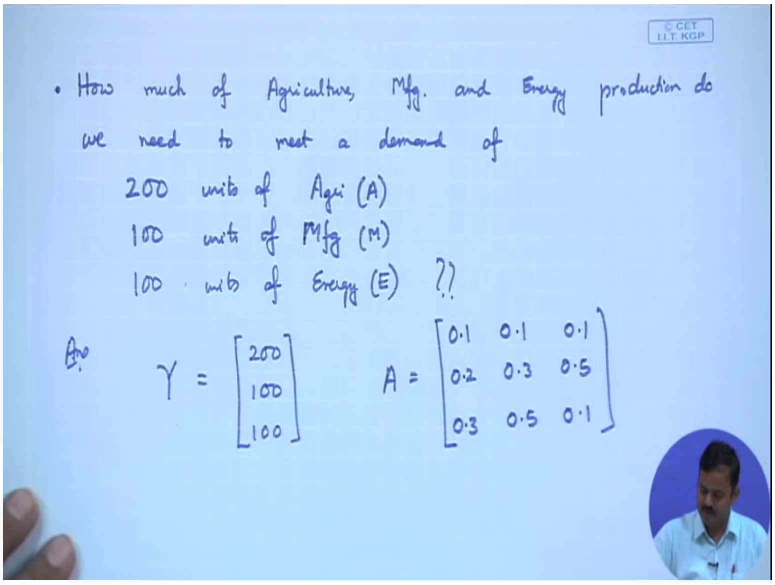

So, now, what i will say is from that I would say how much I am posing the question, how much of agriculture, manufacturing and energy production do we need to meet a demand of what 200 units of agriculture, 100 units of manufacturing and 100 units of energy. So, this is my question and this is what I want to answer. So, how do we do that?

Recall we said that what is given is answer. Y is given as 200, 100, 100. The A matrix we had got last time as 0.1 0.1 0.1 0.2 0.3 0.5 0.3 0.5 0.1. Recall this is the same matrix.

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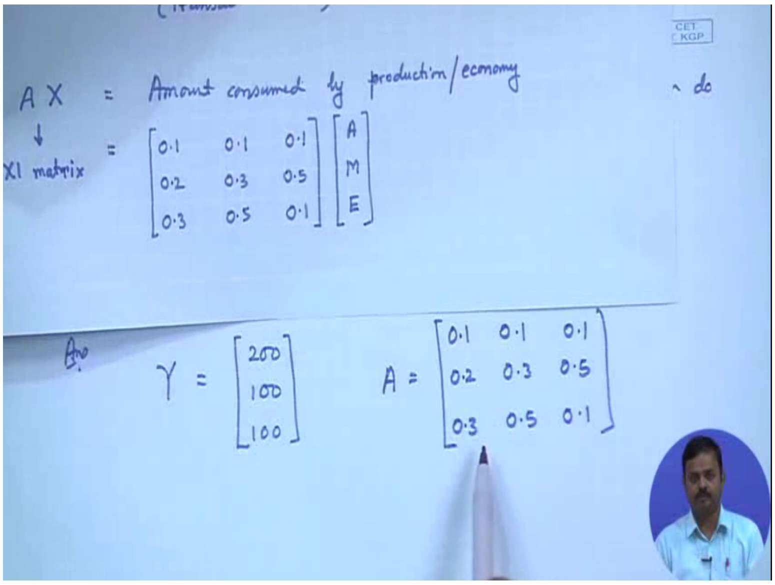

This is what we again wrote here. So, AX matrix is the product of these two.

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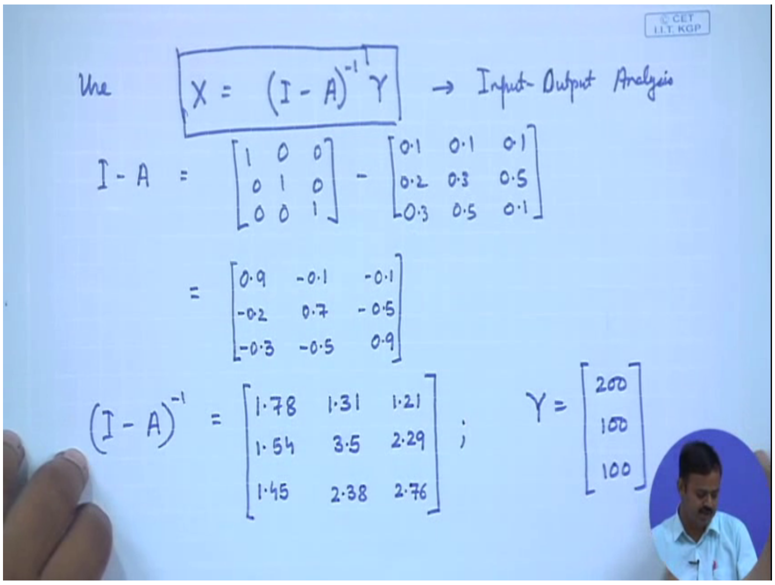

So, therefore, what I can write is the fact that we will use X is I minus A inverse times Y. We are going to use this. This is our input-output method.

So, if you use this what do I have let us calculate each of them. Y is known to 100 100 100. We know that I minus A what is that going to be I is 1 1 1 0 0 0 0. We know this minus and what is A, right. Again this we got it which means I minus A is to be turn out to be 0.9 minus 0.1 minus 0.1, then minus 0.2 0.7 minus 0.5. We all know how to do matrix additions and subtractions, right. So, each of the element correspondingly 1 minus 0.1 0 minus 0.1 similarly, this is how we get I minus A.

Now, we have to invert this matrix to get this. So, therefore I minus A and this is where you have to trust me. I have calculated it for you. There are lots of tools today online which you can use at least for small matrices. So, this turns out to be I minus A inverse turns out to be 1.78 1.31 1.21 1.54 3.5 2.29 1.45 2.38 2.76. So, this is what I minus A inverse turns out to be and we also know that Y is 200 100 100. So, are we in a position to calculate X? Yes we are because we know I minus A inverse and we also know Y matrix. So, let us do that.

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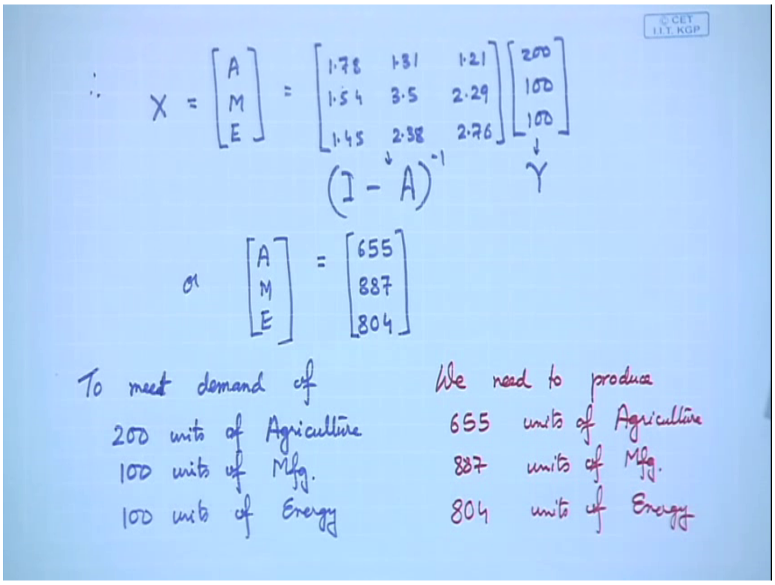

Therefore, X is going to be which is equal to by the way the production matrix A M and E is going to be 1.78 1.31 1.21 1.54 3.5 2.29 1.45 2.38 2.76. So, this is my A, sorry I minus A inverse and this is my Y, clear. So, this turns out to be, finally turns out to be 655 887 and 804. So, we know 1.78 times 200 plus 1.31 times 100 plus 1.21 times 100. It comes to 655 and similarly for manufacturing for energy.

So, what does it mean? It means to meet demand of 200 units of agriculture, 100 units of manufacturing and 100 units of energy. This is the final demand by the way. We need to produce what? 655 units of agriculture, 887 units of manufacturing and 804 units of energy, you can see that out of 655, 455 is consumed by the different sectors themselves and after that 200 units is left to meet the demand of the population for manufacturing. Out of 887, 787 is consumed by the different sectors of the economy just to produce, just to satisfy their own productions and finally, what is left is 100 units and similarly, the other case right . So, now let us say I tell you that my energy demand is going to go up by 10 percent next year, not let us say sorry let us not take energy.

We would like to show energy as the input. Let us say why I want to manufacture more? I want to increase my manufacturing by 50 percent. The final demand of manufacturing instead of 100 is 150. So, what will we do? We will take the same thing except that Y matrix now becomes 200 150 and 100 and then, what will happen is all these numbers are going to change. So, it is going to show that to satisfy that desired increase of 50 percent of manufacturing, demand to satisfy the increase of 50 percent in demand in the manufacturing sector, the output of each of these other sectors have to go up by some amounts and will therefore be different from what we have got here, right and this method allows you to do that, clear.

So, this is a very popular method. Input-output method is used by most companies today to forecast their, I mean to calculate their production that is required to meet the demand, economic demand to forecast that if we have to increase our GDP by so and so much over the next 10 years. Then, what all do we need to do in terms of production from each of these sectors, so that I can satisfy that goal? So, the power of this method as you can see both in the generic form as well as the small example of a three sector problem that we solved. You can see it is so simple. It is simple n by n inter relation or transaction matrix that we need to know and the final demand of course we have to know I mean if you are projecting something, if you are doing planning, then we need to know what the demand of the population is.

So, that is given and if we know that then it is so easy to calculate how much we need to produce. Not only that it gives you a sensitivity, it allows you to do a sensitivity study also. As we said increase the production of a sector I by a certain amount, how does it now increase or the demand of a certain sector increases by 10 percent, how does it impact the production of all the other sectors? How much do I have to increase the production of every other sector on which that sector I is dependent on, so that increase in 10 percent demand is met. So, that is the beauty of input-output method.

So, that kind of wraps-up our discussion on energy economics.

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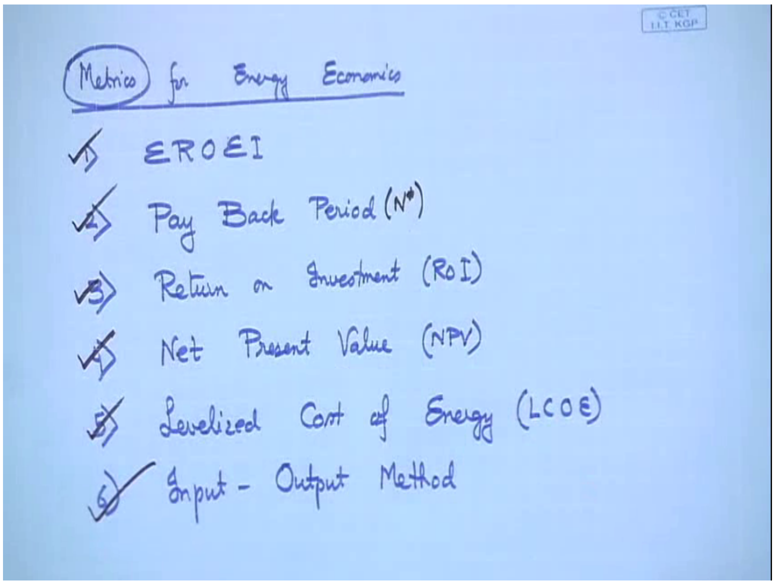

So, this is what we have discussed. So, let us just do a quick recap. We started by discussing the dependence or how energy is so important. We said energy is the master resource and we say that no economy can prosper, no nation can prosper, economy cannot grow unless we have adequate quantities of affordable energy. Then, we went on to the discussion on energy out over energy in also called EROEI, that is Energy Recovered on Over Energy Invested and what we said was if we have to let say if we take the example of an oil field and if we have to extract 100 barrels of oil, how many energy equivalent to how many barrels of oil do we have to spend in order to extract that energy, right?

So, that ratio of the energy that we extract versus energy that we spend is EROEI and the higher that number, the more attractive is that form of energy and we are just talking about energy cost at this point and we are not even talking about the cost in terms of monetary value of energy which is a different part. This is how much energy is required to produce one unit of energy, all right. Next when we went to actually the monetary economics of energy. If we take an energy product or energy installation, we talked about payback period.

So, payback period is a number of years that is required to recover the initial investment cost, but we said that the payback period does not take into account the time value of money is which means the cash flow that I get the net cash flow that I get 5 years from now is worth much less today, right. So, therefore is worth much less than today. So, therefore, we have to discount that. We have to say that if 100 rupees 5 years down the road is worth, how much today because there is inflation. So, that is something we do not do in part of as part of payback period. So, that is a drawback of the method, but it is still an useful tool and most of the investors do look at this term before they decide to invest on a certain project. Return on investment is also similar. It is a ratio of the net cash flow that we get over the initial investment cost, but this also unfortunately does not take into account the time value of money.

So, that led us to net present value where the cash flows are discounted to take care of the time value. It is discounted by a certain parameter called discount rate and therefore, the cash flows during over the lifetime of a plant is discounted to find out what is its current value or the present value. So, that is the total money inflow at today's price and total money outflow at today's price is going to be the installation cost, the difference of which gives, difference of these two gives the net present value and when I say the cash inflow is at net cash inflow because as you operate the plant, there are also some operating costs.

So, revenues minus the annual operating cost, that is the net cash inflow that when discounted over the years and added up should be more or higher than the installation cost or the net present value should be greater than 0. Only then is a plant economically viable, otherwise it is a losing proposition to even start with. Then, we talked about levelized cost of energy. So, it is the cost or it is the price that one has to pay to produce 1 unit let say 1 kilowatt hour of energy, but what it takes into account is the various factors that go into that cost, both inflow outflow everything and also the energy production which goes into the denominator in the levelized cost of energy.

We also said that the levelized cost of energy gives a sort of fair comparison between two energy installations, using maybe two different installations, maybe even using different forms of energy, however, it is also very important to ensure before we compare two installations. We must ensure that the levelized cost of energy has been calculated using the same method. The same factors have been incorporated the same assumptions. Let say with respect to discount rate for example has been made and finally, the last parameter that we, last method that we discussed is the Leontief's input-output method and it is extremely powerful method. This is a method that is used by many countries for the economic forecast to forecast their GDP growth.

This tells you that if you have a certain demand of the population, how much do we have to produce across every sector of the economy, so that we can meet their demand. It also tells you that they if demand goes up by a certain fraction in the next 5 years, how much does the production of each of the other sectors, not just that sector, but each of the other sectors on which that sector depends on must go up to meet that increase demand. It is an extremely powerful tool and the power actually lies in its simplicity. It is a very simple matrix method. So, this kind of wraps up our energy economics discussion.

So, friends with energy economics we have also come to the end of our course on Energy Conservation and Waste Heat Recovery. So, I hope it was a good learning experience and a good journey for you as it was for us. So, what we are going to do in the next 5 minutes is, I have with me Professor PK Das who taught you the first part of this course. So, we will spend the next few minutes to wrap up and sort of recap on the different topics that were taught as the course progressed. So, we start with Professor PK Das. So, I would hand it over to him now to recap his part.

Hello everyone. We have gone through several lectures on Energy Conservation and Waste Recovery. In fact, in total there are 36 lectures. It was started initially by me and then, it was taken over by Professor Anandaroop Bhattacharya as we decided that we will have a quick wrap up of what we have covered.

Let me start with my part and then, again I will hand it over to Professor Anandaroop Bhattacharya. So, I have started with wasted recovery and energy conservation. What is the relevance of these topics in the total energy scenario and in this regard, I like to remind you a few things that I have told that the total energy security or sustainable development which is the buzzword which is very important for today’s development, future development that cannot be achieved without energy conservation and in energy conservation, waste heat recovery is a subset. Now, it could be again reminded which I have told may be number of times that there could be many aspects of energy conservation and waste heat recovery and within this span of let say 60 lectures, we have taken 66 probably.

So, in the span of 60 lectures, it is very difficult to cover and then, there are many aspects. One aspect is the academic aspect and mainly the course has been designed like that, but we were happy to see that quite a few person from industry have joined us. It is very good to see that and again we have got time to time interactions from the persons who are from industry. Unfortunately, we could not design it totally for industry people so many of the case studies which could have been taken from industry that we could not do because we had to cover the basic course and one of the purpose of this course is that it can replace any elective course of this student which I mean what they are taking in their respective institutions.

So, we have designed it as some academic course and in that respect we have started from the basics and in any energy system which is our prime importance is that an appreciation and understanding of thermodynamics. So, we have started with thermodynamics, then thermodynamics has got different aspects, but energy conversion aspect of thermodynamics is very important as far as energy is concerned and then, we have devoted on different cycles particularly those cycles which are now extensively exploited commercially. Then, their variations combined cycles and then, different aspects or other different possibilities of topping cycles and bottoming cycles because they are important for energy conservation and waste heat recovery.

So, from there we have I mean that gave us some opportunity to discuss unique thermodynamic cycles which are generally not covered like your Kalenna cycle, Organic Rankine cycle etcetera and from there we have gone to heat exchanger. Heat exchanger is the single most important equipment for waste heat recovery in particular and energy conservation in general. So, heat exchanger also we have started from the basics because we believed that probably there will be students who are not having adequate background of heat exchanger and things should not be very unfamiliar to them.

So, we have covered heat exchanger, basic design methodology etcetera and then, we have spent some time on spatial heat exchangers which are used for waste heat recovery and energy conservation and then, ultimately we have gone to a new topic which we can say that it is in principle method for energy conservation. It may not be directly one can relate it to waste heat recovery that is heat exchanger network analysis. So, in a big industry there will be many heat exchangers and we have to conserve the energy, so that minimum amount of heating and cooling requirement will be there, minimum amount of heat exchanger will be there, minimum number of heat exchangers will be there.

So, we have gone for heat exchanger network analysis which is again a very unique topic for energy conservation and then, of course Professor Anandaroop Bhattacharya has taken it up and he has discussed different other aspects which are very special for energy conservation and waste heat recovery and ultimately, all the industrial world is run by the economics. So, he has spent some time on economics so on those topic probably he will like to say a few things, but I like to say a few other things which are related to the course whatever we have dealt in the course that is just the basic minimum time to time. I have mentioned that additional reading is needed.

Unfortunately, there is no structured text book on this topic and I believe it is very difficult to have a structured textbook on this topic, but relevant material I have mentioned number of times at the beginning also. I have given some relevant material which are mainly from internet and of course, the course will act as a guideline. Again I have followed the forum where you have interacted. It is good to see that initially some 5000 plus participants were there of course when we got started. Getting the solution of the weekly assignment, we have seen a drop in the number, but even then a sizeable number of participants are submitting the solution.

So, I hope that it is important you are finding it important and relevant a sizeable number of person you are finding it important and relevant. A few more points I could see from the forum that number of persons from industry are also very enthusiastically following this course. They have several question even one of them has shared a software with us. Thanks to him and it would be good if sometimes we can get who are the persons from industry and from which industry, they are coming from or which industry they are representing. So, if necessary we can have even a small session addressed to those persons again for this course.

I like to say that this is challenging because usually we take classes where there will be number of students. From the facial expression of the students, from the body language of the student, from the questions directly the student ask, we can know what is going on in the class whether they are accepting it well or not, whether what we are explaining to them they are really understanding it or not. So, that is lacking. So, it is really challenging for us to deliver these lectures in an empty class assuming or guessing what could be important for this student where the student will face difficulty. So, that way you have taken the challenge and of course, through the forum we can do some sort of redressal of the issues which you did not understand properly, but in that also you can see that at least for my case wherever there were some sort of slip of pen etcetera, so people have pointed it out. It is good to know that people are following it with a lot of care. So, I am thankful to you. At the same time, I would like to say that still we have to go a long way. In between also if you have some queries even from my part, you can post it in the forum.

We will try our best to address it at the end. I like to thank all of you, I like to thank those persons who are coming with questions and giving us again one opportunity to discuss these issues. I also like to thank the teaching assistants who are taking pain for posting these problems, getting the solution, discussing with us and posting the answers out of their own and sometimes of course after a discussion with us. So, I think this should continue and I strongly hope that some of you will benefit from this course. Thank you.

So, I think that was a very nice wrap up by Professor PK Das. He is also my teacher. So, it was again a very fulfilling experience for me to teach a course along with him. So, in my part coming to the contents when I took over from Professor PK Das in this course, we continued, we started with a continuation on discussion on heat exchange device and we started with heat pipes which I said you can think of it as a very specialized or a different special kind of a heat exchange device in the context of waste heat recovery where it helps to conduct or basically transfer heat from one location, where it is wasted or which otherwise will be wasted to a location where it is required in a most efficient manner.

So, from there onwards we went over to a discussion on direct energy conversion devices. So, these are devices which directly convert the energy in whatever form it is to electricity unlike a power plant where it is first converted to mechanical work by means of rotating a shaft of a turbine and then, converting it in a generator to electricity. So, as part of direct conversion we started with thermoelectric generators which we studied in more details, but we also discussed about Thermo Ionic Device, Tbermo Photovoltaic Conversion as well as MHD or Magneto Hydro Dynamic Conversion. We then moved on to discuss about heat pumps and then, waste heat utilization from incinerators.

So, there after we switched gears and went to energy storage device because it is important to store the energy that is generated when the demand is low and then, use that excess energy later when the demand is high. So, as part of energy storage devices, we definitely discuss batteries which comes to our mind first, but we also learnt about different mechanical storage devices like these are big energy or these are means of storing large amounts of energy like pumped hydro compressed air energy storage.

We also talked about flywheels, we talked about superconducting magnetic energy storage and then, of course electrochemical and chemical energy storage and finally, we discussed about energy economics. So, you have come up with an energy installation and energy plant from economics point of view. Does it make sense? So, we covered various metrics and we as part of that we learnt that definitely the cost in terms of dollars or rupees is important, but also there is an another economic, another important economic parameter which is energy recovery or energy, sorry EROEI which is you know how much energy you spend to extract an unit amount of energy. So, that also is a very important metric to determine whether it is worth going for extraction of energy from a particular source.

So, that kind of wraps up our course and as Professor Das already mentioned, I also really enjoyed. This was an unique experience for us you know giving instruction through the audiovisual mode instead of in a physical classroom. So, it was a unique experience for us. We also learnt a lot during these both while preparation of the courses as well as while delivering it and more importantly through the various discussions in the forum, the questions that you posted, the information that you shared. So, that was a learning experience for us and I hope it was a good learning experience for you as well and some of the things that you learned will be useful as you in your careers whether it is in the industry or in academia. I believe after this, you have a final exam. This being the last lecture, you also have to take a final exam. I would say do not worry too much about it.

So, definitely you have to take the exam, but if you have followed and understood the course contents, the exam should not be too much of a challenge, but definitely both of us wish you all the best on that exam, but I also sincerely hope that this is not just the end of our interaction. Please keep in touch with us, share with us your experiences, your questions and so on and let the interactions continue even when the course is over. Once again from both of us thank you very much and wish you all the best in your future careers ahead.

Thank you.