Energy Resources, Economics and Environment
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Lecture - 20 P1
Primary Energy Analysis – Part 1

We have looked at different ways of calculating whether a project is viable and mostly we have been looking at the economics as the basis. We have also seen how to look at, the environment and environmental impacts and quantify that in economic terms. In this module and in the next module we will be looking at, how do we assess a project from an overall energy point of view. So, first we will look at primary energy analysis.

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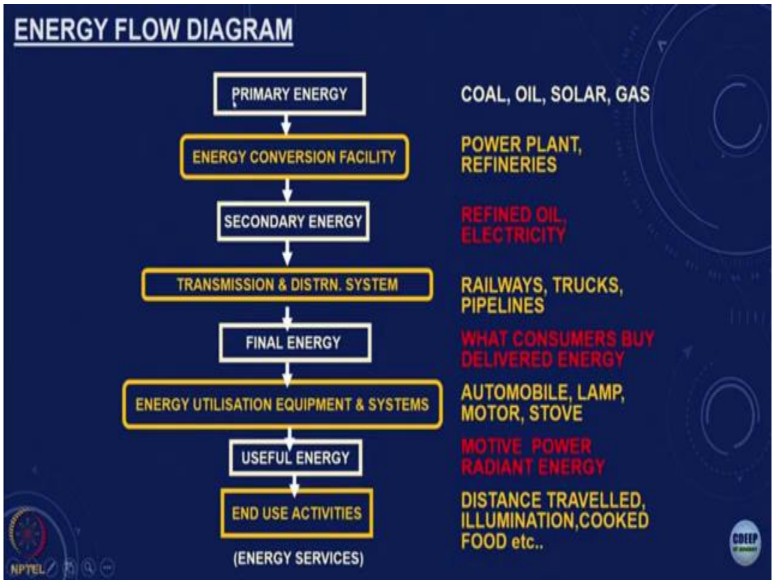

We have discussed this earlier, in passing initially we talked about the energy flow diagram that means we said that, when we look at finally the energy that is required, we need an end use or an energy service. So, for instance, if we are looking at illumination or the lighting that is being provided or if you are talking about going in a vehicle then we are looking at the distance travelled, we are looking at cooked food. That is the final energy service.

And so this has finally the end use. For that we need some useful energy, that useful energy is coming in the form of, we are getting some energy utilization equipment and systems, the energy that we are getting, the delivered energy the consumer is buying that is also called final energy. So, we looked at this final energy going to the useful energy.

In order to supply the consumer, energy is coming through a transmission and distribution network. For instance, if you are looking at electricity there is a large transmission distribution network, which is coming in, that electricity is a secondary energy source. There is a power plant, there are coal mines and finally, we from the energy service that we need and the useful energy that we use, we go backwards and we calculate the total primary energy or the energy that is available in nature.

So, we have already discussed this but I am just repeating we have this different terms, the primary energy, the energy that is available in nature that gets converted into a form like refined oil or electricity, secondary energy that is then distributed and is delivered to the consumer you get final energy, that final energy gives the useful energy which is used for the end use activity to provide the energy service.

So, whenever we talk in terms of primary energy analysis, we will look at two different options, in terms of, go draw the entire chain and calculate the primary energy which is required. And then, with each step of this chain we can look at what are the efficiencies, we can also look at what are the emissions. So, this is the primary energy analysis where everything we convert and compare on the basis of primary energy.

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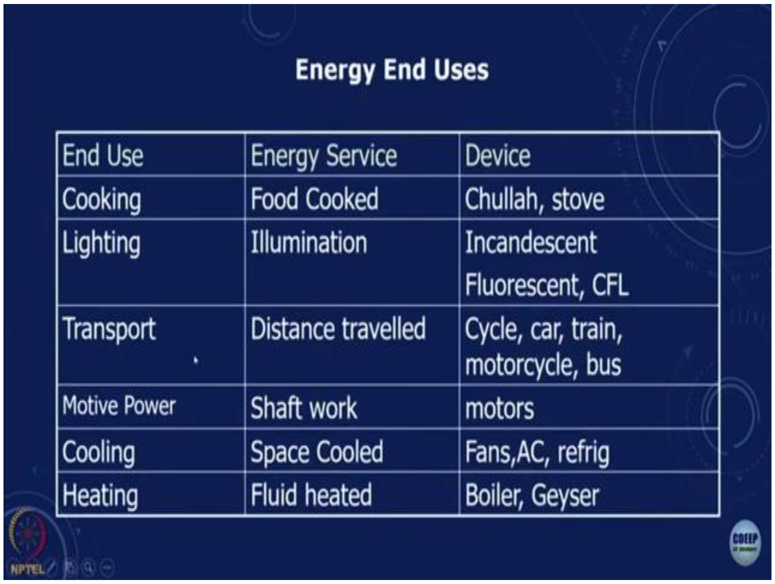

So, as we saw earlier the different end uses that we can list down is, for instance, food cooked is the energy service, illumination for lighting, distance travel for transport, shaft work for motive power, space cooled, fluid heated and each of these have different devices. Like the chullah, the stove for cooking, incandescent fluorescent, compact fluorescent lamps for lighting.

And for travel, transport cycles, cars, trains, motors for shaft work, fans, air conditioning, refrigeration, space cooling, boilers and geezers for heating and in all of these there are many different possible devices, different sources so we can have actually a whole set of different diagrams, the energy flow diagrams.

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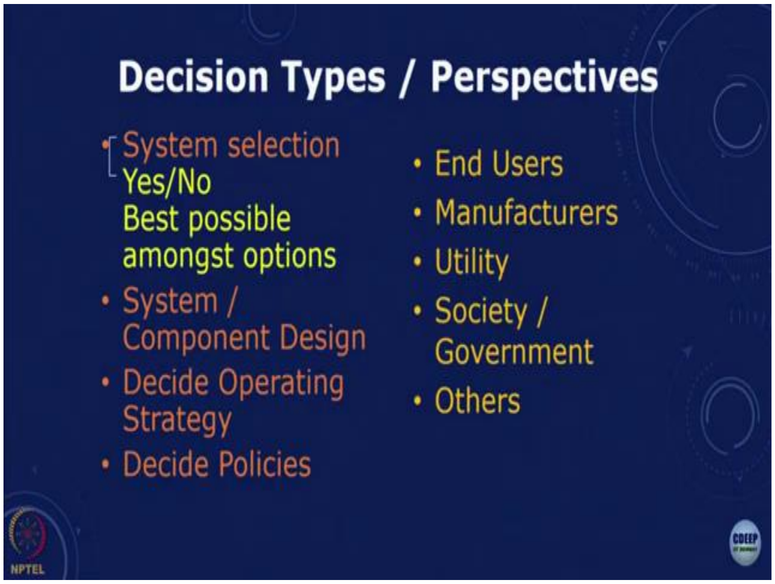

So, whenever we are looking at the types of decisions, we saw this earlier where we were looking at either a yes, no timed of decision or a best possible decision amongst options, that is for system selection. We may also be choosing, designing the system or the component. For an existing system we may decide an operating strategy and we may decide policies and these are the types of decisions.

And when we look at perspectives, you can look at it from the perspective of a end user, the manufacturer, utility, society government and others. When we are talking of primary energy analysis, we are looking at an option from the point of view of the entire chain and that means we are looking at it from the societal point of view, the overall efficiency, the overall cost.

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We can also look at it from a subsection of it that is from the point of view of the end user and we will take set of, for all of these decisions there could be different kinds of costs, criteria, the cost criteria we looked at initial operating life cycle cost, reliability, emissions, sustainability and equity. In primary energy, we will be looking at the total amount of energy and the issues related to sustainability and emissions.

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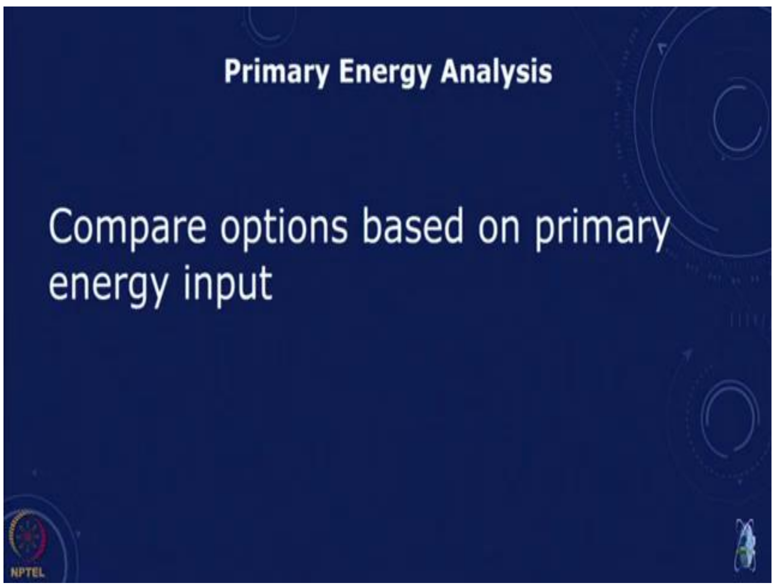

So, in primary energy analysis, what we are doing is we are going to compare different options based on the primary energy input for a given we will decide a certain amount of final energy service or final output which is required and for that we would compare these options and then we will compare them based on the primary energy.

We will draw the energy flow diagram or the energy chain for both or for each of these options then compare work backwards and compare the primary energy input. So, let me give you a set of different examples and then we will try and do a couple of them.

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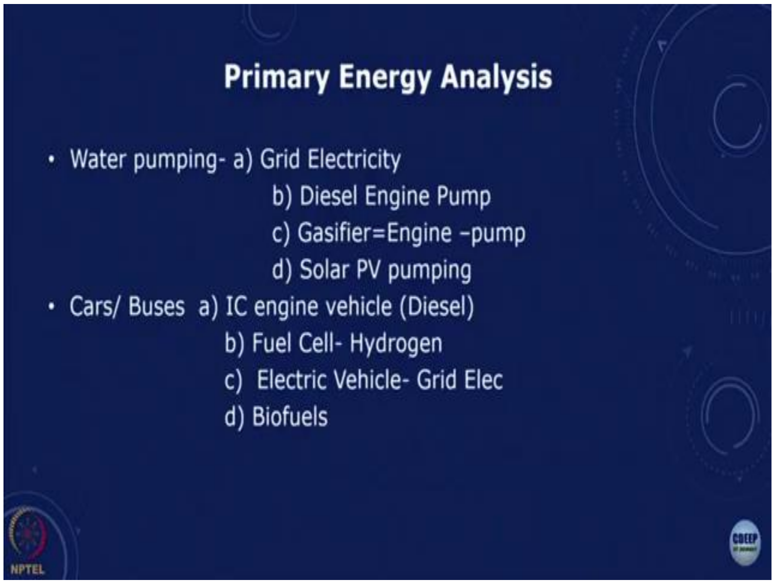

So, for instance if you look at agriculture, in all over the country where we have, in our agricultural fields, we need water and that water is pumped. So, there are different ways in which we can provide the energy for the water pumping. The first one is we can have essentially grid electricity, going, driving an electric motor.

And the second option is that we can have a diesel engine, running so grid electricity, driving a motor, driving the pump. Diesel engine, directly coupled with the pump and driving the pump. So, you do not need to actually generate electricity. We can have a gasifier, running an engine and then running the pump.

So, there you have biomass and then this could be a dual fuel engine so there could be some amount of diesel. We can have solar, PV during the pumping. These are four of the options, we can have a whole set of other options also, we can have combinations, we can have hybrid. So, we will look at this example.

In the case of vehicles let us look at, if you look at car or a bus and, we can compare an IC engine vehicle again, this could be petrol, it could be diesel, it could be CNG. We will look at an example where we are comparing diesel vehicle. We could have fuel cells in hydrogen.

So, that means hydrogen is the fuel, hydrogen can be generated, can be stored, hydrogen can come again from different sources. It could be from natural gas, it could be from renewable energy. We can have, an electric vehicle, running on grid electricity and then you have the electric transmission and then we can, so for all of these you will have a completely different chain and we can look at the different primary energy use and the different emissions.

We could also create, biofuels from different kinds of bio sources could be waste, could be, actually plantations and then we can use these bio fuels to run engines and then you can have, so it becomes a renewable source. So, this is in terms of cars and buses.

Similarly, you can think in terms of cooking, for cooking write down the different sets of options that we can have for cooking and then for each of these again, you can think in terms of making these calculations for primary energy.

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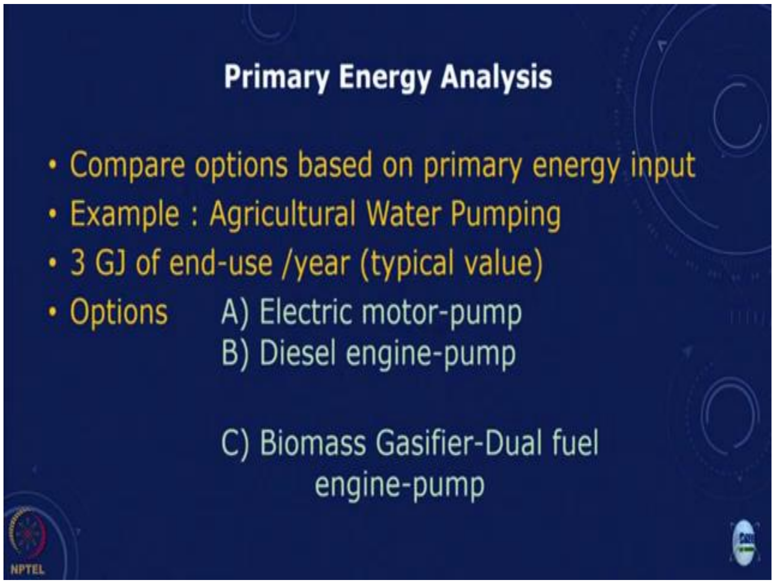

So, let us look at now, an option. We will look at the first option, that is water pumping and we want to compare the options based on primary energy input and so the example is agricultural water pumping. If you look at, typically there are a large number of pumps used all over the country and we have some measurements in terms of the kind of water use.

The final end use which is there for the pump is the flow rate of water into the head that is developed and that is the power output which is the end use and that in multiplied by time depending on the number of hours of use. So, based on the studies, which have been done in the country. Typically, the value of end use, which we require is given to us as 3 GJ. So, we need, this is given 3 GJ of final useful energy.

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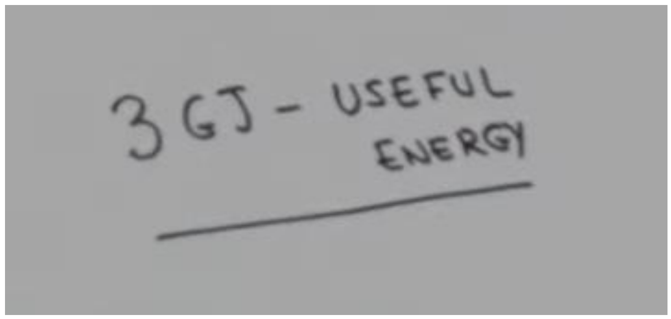

And we want to see, what will be the primary energy requirement in three cases? You could also do a similar thing for solar, we are not doing that in this. The first one is electric motor pump, the second B is diesel engine pump and C is the biomass gasifier dual fuel engine pump. So, if we look at the electric motor pump, just take a minute and sketch the diagram, schematic diagram of the energy chain.

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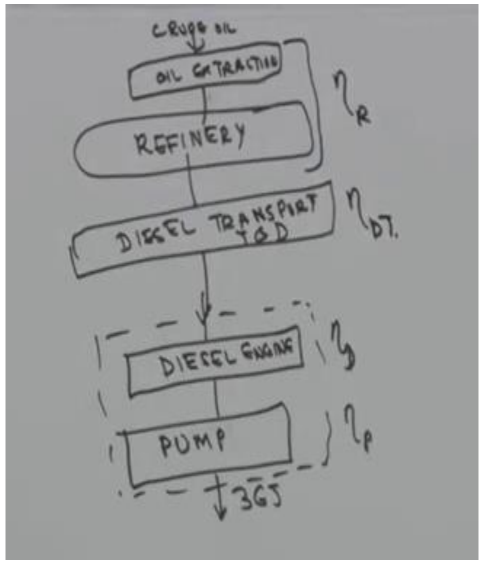

So, we will start with basically, we will have the pump. Then before that will be the electric motor. This is the useful energy output, which we are given as 3 GJ/year. Now, this is the electricity that is purchased by the farmer and if you look at this boundary, this system boundary is what the farmer sees.

So, here if you look at this as eta motor and eta pump. The overall efficiency, which the farmer sees is, eta motor into eta pump and so the energy input required in terms of electricity input is 3 into 10 raise to 9 joules divided by eta motor into eta pump. Now, here before this, you would have that electricity that we are getting is coming through a transmission and distribution network.

So, you have a transmission and distribution network and this will also have another efficiency eta T and D. This is the secondary energy that we are getting and before this we have, you would have the power plant, eta power plant. Before the power plant would be the, if we think in terms of coal, you will have the coal mining and transport and then this is your primary energy source, which is coal.

Of course, you could have the similar thing from hydro or from any other source, and so here again, you will have eta CM. So, if we look at this overall efficiency, this is going to be eta CM into eta PP into eta T and D into eta M into eta P. That is the overall efficiency.

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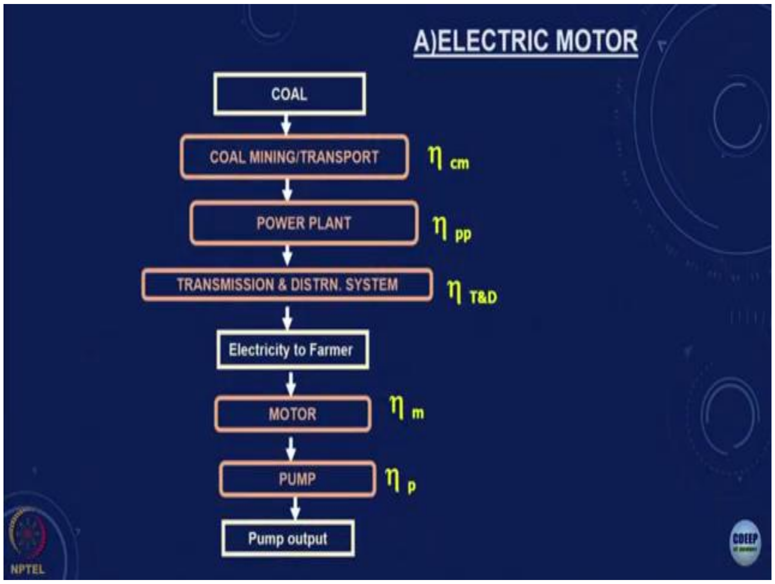

So, this is what we have just now seen, if you see it now in the, you know better fashion, which we have seen, this is the values. Now, we can put down typical values of this even if we look at the best values that we have for motors and pumps. You can put down these values and you can calculate these. Now, just to give you an idea, you may want to think about how you would calculate these.

For instance, if we want to see how to get the efficiency for coal mining. We would look at a particular mine and see that in that mine how much energy is being used, electricity as well as diesel, convert that in terms of energy terms, convert that in terms of the kgs of coal, which is being mined and then see what is the output and what is the input and based on that we can get an efficiency.

In the case of transport if we see, if the coal is being transported by train, we would look at the distance which is being transported, for that distance then we would see how much is the, if let us say it is an electric train or it is a diesel, how much energy is being used and see the total carrying capacity divide by that and we can get what is the energy use per kg of coal and then convert it all in terms of percentages and get an efficiency. These are not very low.

There is not, not too much of energy is used in the transport and in the mining. So, the efficiencies are relatively high. However, in the power plant, that is the point where we have the loss of the efficiency because we have basically the understanding that when you are talking of transfer of heat to power, we have the thermodynamic limitation and that is why you will find that power plants typically with have slightly lower efficiencies and that is the power plant and T and D.

So, if we look at these are the typical values, you can crosscheck these but these are the typical values that we see. Motors, the good efficient motors will have 88 percent and pumps if rated as it is best efficiency point maybe 75 %. In actual practice pump may be operating at part load and the motor may also be operating at part load. So, you may find that instead of 88 and 75, we may be looking at something like 50 % for the pump and maybe 60 %. So, then that becomes the overall thing becomes, much lower.

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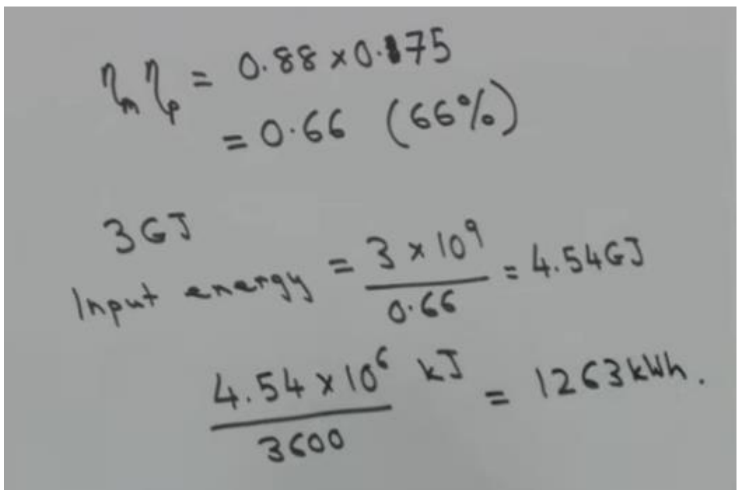

So, let us look at what is the efficiency that the farmer sees. The, in the farmers side we are looking at an efficiency of eta motor into eta pump, which is 0.88 into 0.75. 3 by 4, so 0.22 this is, comes to 0.66, 66 % efficiency. And we also said that let us say 3 GJ of electricity which is being used.

So, that means this is 3 GJ, the input energy will be 3 into 10 raise to 9 divided by 0.66. So, if you look at this, we will get this is as the, total amount of energy which is being used, you can just check this 3 divided by 0.66, it will be approximately, we can just check this 3 divided by 0.66 it is 4.54.

Now, if we want to convert this into the amount of electricity, you will find that this is 4.54 into 10 raise to 6 kilojoules, 1 kWh is 3600 kilojoules. So, if you do this, you will find that this is, this comes out to be something like 1263 kWh. So, we found how much is the energy which is being used at the side.

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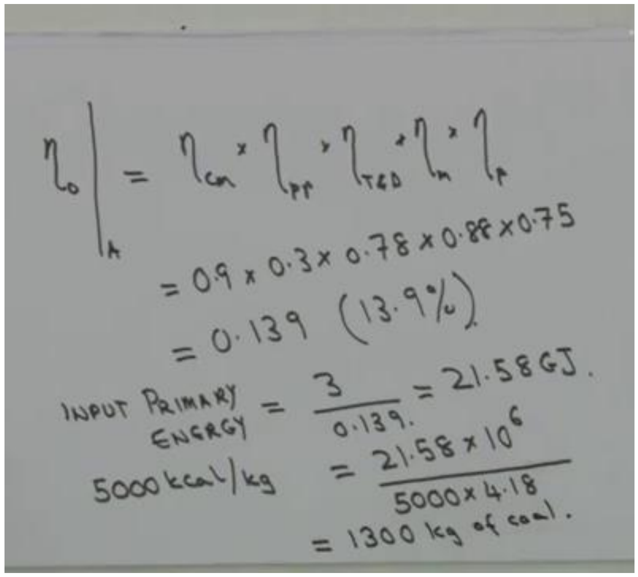

We can also calculate the overall efficiency and the overall efficiency will be eta overall for case A, is eta CM into eta PP into eta T and D into eta M into eta P. And this is 0.9 into 0.3 into 0.78 into 0.88 into 0.75. And if you check this, this comes out to be 13.9 %. So, we saw that from the point of view of the end user. We are looking at this as 66 % is the overall efficiency at the farmer side. The, but if you look in terms of primary energy, this is going to be 0.139 and we can also then see how much is the input primary energy required.

Primary energy, primary energy input, this is going to be 3 GJ divided by 0.139 and you can calculate this as 21.58 GJ. We can also convert this into the amount of coal that is being used. So, suppose we are looking at this as, let us say coal has a calorific value of 5000 kilocalories per kg then this will be 21.58 into 10 raise to 6 kilojoules by 5000 into 4.18. This is kilojoules per kg, this was in kilojoules. So, this will be in kgs and you can calculate, it will give you approximately 1300 kgs of coal. You have calculated now, what is the primary energy that is required.

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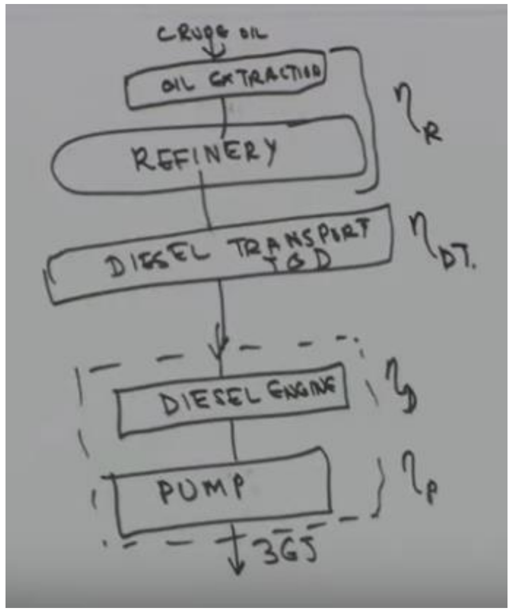

So, in a similar fashion, let us look at now the second option. Second option is where we are using a diesel engine. So, even a diesel engine if you see, we start with, if you look at this again, you will have the pump. And then before the pump instead of an electric motor you just have the diesel engine. Then the diesel which is coming to the farmer, then we have this is the final energy. This is 3 GJ and this is the diesel which is being bought.

This is mark farmers boundary. We will look at this as eta pump, eta diesel engine and then they will be the diesel which is being transported, there is something similar to what, diesel transport, T and D. This is like the T and D. And then we have the refinery and then we have the, maybe the, the oil well, oil extraction and then this is the primary energy which is crude oil.

We have taken this together as one term with eta R, as the efficiency, this we are talking of is eta DT. So, if you see it now here, the same thing which we have drawn crude oil and we have merged the oil extraction and the refinery into eta R, diesel transport, eta DT, diesel to the farmer, diesel engine and then the pump.

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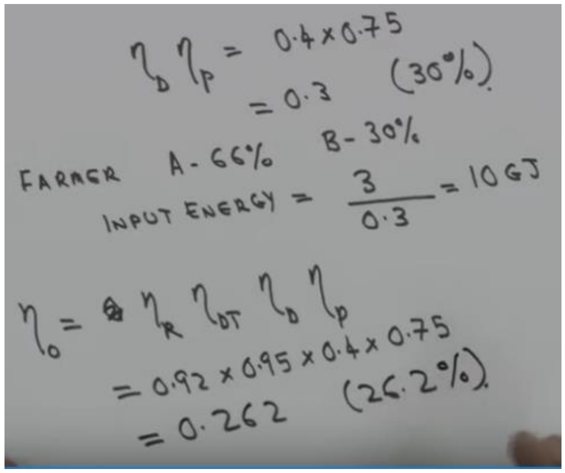

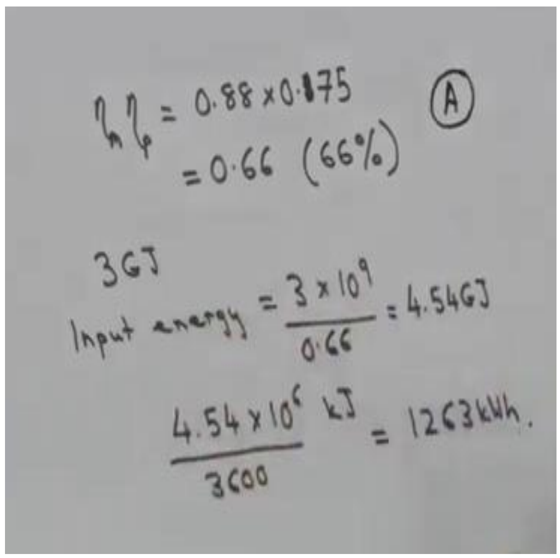

So, now let us calculate, for the farmer's side now, the efficiency that the farmer sees is eta D into eta P, which is 0.4, 40 %, 0.75. So, the farmer, at the farmer side the efficiency is 30 % and if you look back at what we calculated earlier for the farmer in case A, the farmer's efficiency was 66 %.

So, from the point of view of, at the farmer side the farmer sees in case A, efficiency is 66 %. In the case of B, it is 30 %. So, it looks like the diesel engine pump efficiency is half the efficiency of the electric motor pump. So, that is an interesting thing to see. So, it looks like it is, it is less efficient.

Let us look at it in terms of, so that means the input energy that we now need, input energy will be 3 GJ divided by 0.3, which is 10 GJ of input energy. Let us look at now the overall efficiency, overall efficiency if you see refinery is 0.92, diesel transport is 0.95. So, the overall efficiency is, going to be eta R into eta DT into eta D into eta P. 0.92 into 0.95 into 0.4 into 0.75. So, that comes out to be 0.262, 26.2 %.

So, now if we compare that with what we had calculated for case A, you will find that in the case of A, for case A we had calculated this as let us say 13.9 %.

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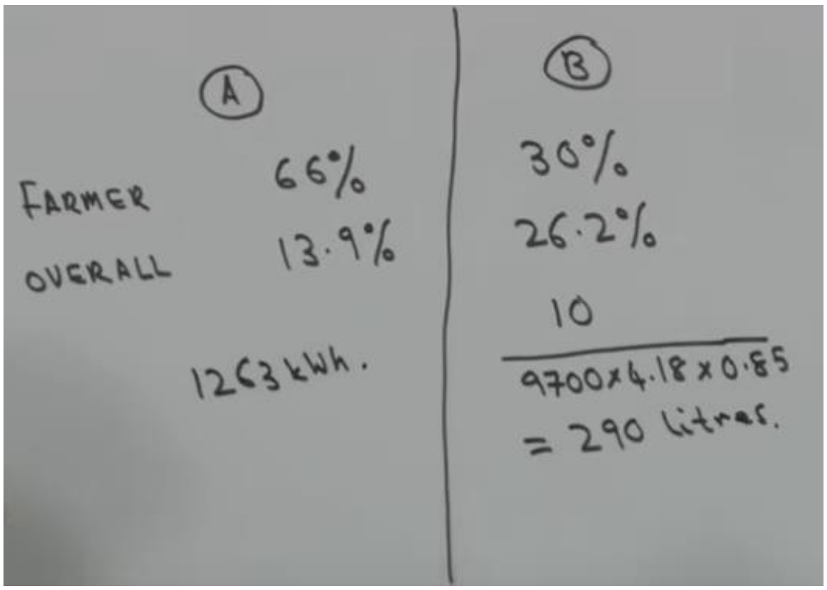

So, we see that case A, case B from the farmers side, at the farmer end if you see the efficiency for case A it was 66 %, case B is 30 % and overall this is 13.9 %, 26.2 %. Interestingly, what you find is that, the, it gets almost reversed. So, the here it is in the case of B this, in the case of the farmer for A it is double that of B and that means the electric motor pump seems to be more efficient than the diesel engine pump, but from an overall, when you see the entire chain, this is 13.9, which is almost it is a little more than half of the case B.

So, B looks more efficient from an overall point of view, but at the farmer end does not look so efficient. And so that is an interesting point. We can also now calculate, like we calculated the amount of coal which is being used, we can also calculate the amount of oil, crude oil which is being used, the amount of diesel input. So, the amount of diesel input which is there will be just 10 GJ divided by let us say 9700 kilocalories per kg into 4.18 and we wanted in litters, because that is how we, that is the unit which we see, so it is 290 litters of diesel.

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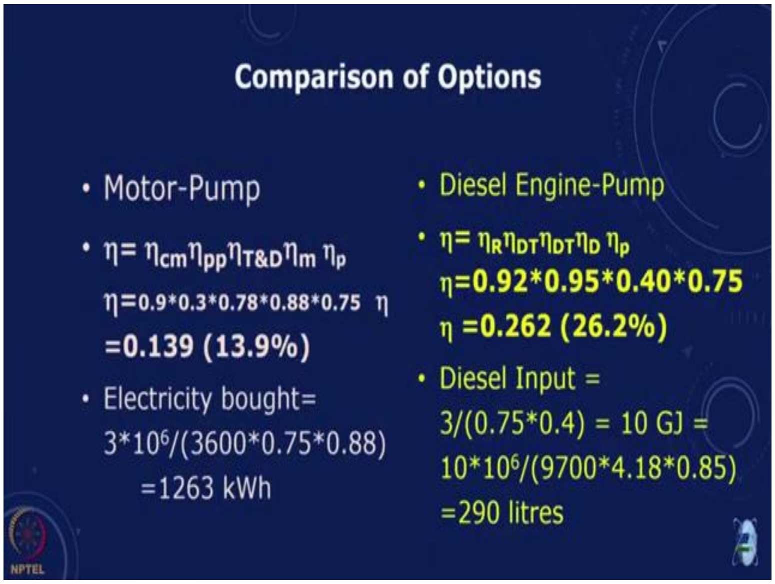

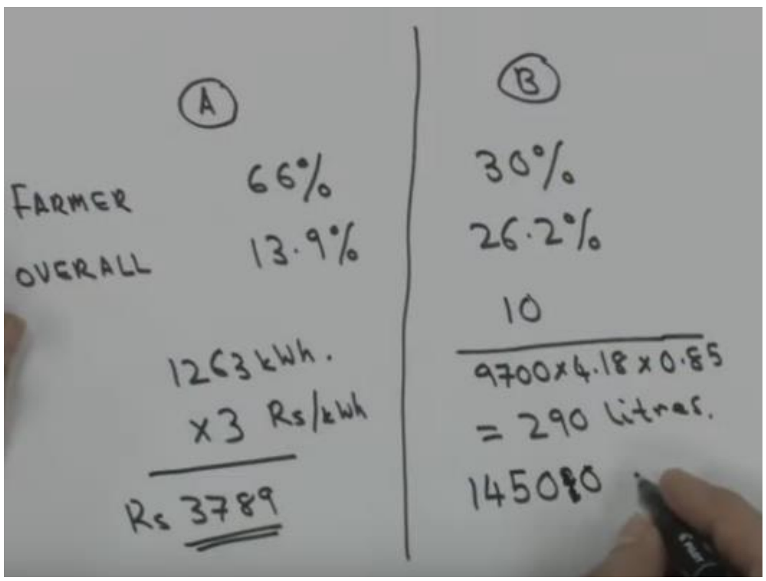

So, now we can see we can calculate how much here, we have by 1263 kWh, from the farmer point of view. What is the difference in the operating cost? If you look at that we can just take let us say of course earlier people used to have subsidized electricity and now let us say we are paying 3 Rs/kWh, then this will come to about Rs. 3789 is the annual cost of operation. Motor pump relatively, the capital cost is only you are only paying for the motor pump. So, capital cost is of the order of 12000 rupees. In this case the, the operating cost is 50 into the 290 and this comes out to be 14500 rupees.

So, obviously the diesel engine pump, the operating cost is higher than the electricity cost. The capital cost is also higher because for the diesel engine the cost is there. So, from a cost point of view, this is the diesel engine pump set looks to be a costlier option. From the farmer point of view, it looks like this is a cheaper option, also this is a more efficient option from a farmer point of view, capital cost is also lower operating costs is also lower.

The disadvantage is that, in most of the country, of course the situation is improving now, but a large amount of, for the agricultural pump sets there are a number of power cuts and so, at the time when we want to use it, we may not be able to get the.

So, then and in this case, this is the, this is uninterrupted, you can use it as per requirement. We calculated 1300 kgs of coal and similarly, we can take the oil and then divide by the calorific value of the crude and you will get this as 300 kgs of crude oil you can crosscheck this. Now, the question is how do we compare 1300 kgs of coal with 300 kgs of crude oil?

From an energy viewpoint, this 300 kgs of crude oil is less energy. However, we have from a national viewpoint coal is relatively abundant. And also, in this case we can change the mix, as the mix changes there is flexibility. So, it need not necessarily be on coal, it could be on oil, it could be on gas, it could be from renewables. While here it is definitely on oil and then there is an issue in terms of the refinery mix.

So, in, as we have seen earlier in India, we have the largest chunk of our requirement for oil is coming through imports, but we have a lot of refining capacity. So, there is a lot, mostly we are refining crude and when we refine crude, we get the heavy fractions, the middle fractions and the light fractions.

In the middle fractions, we have kerosene and diesels and what happens is that the requirement for diesel is high. So, when we have a particular refinery mix, you will get for a particular amount of crude, you will get a fraction, some percentage which will come in the middle distillate.

Now, that percentage is not sufficient for the requirement that we have and we are also importing the diesel and kerosene and with the result that we have what is known as the middle distillate bulge and so, from a refinery mixed point of view you would like to see, if we can reduce the amount of diesel consumption. So, this shows us from different perspectives how primary energy analysis can be used to make the calculations. We will also the one last thing that we would like to see on this example is that what about the CO_2?

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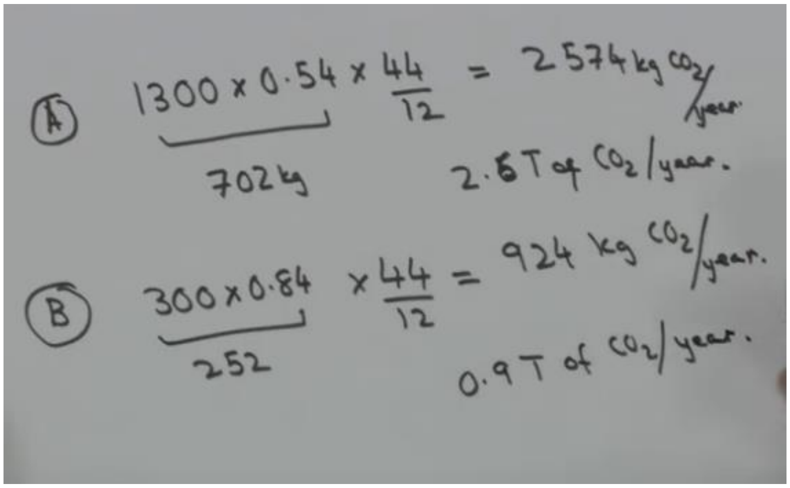

So, we can take the suppose we saying 1300 kg of coal, which we are using. We can take this as let us say 54 % carbon into 44 by 12. This will give us annually the total amount of CO_2 in option A. So, these are simple calculations which we should be able to do and this will result in this number comes to 702 kgs of carbon multiply by 44 by 12. This will be 2574 kgs of CO_2 per year, that means one agricultural pump has 2.5 tons or 2.57, 2.6 you can say, 2.6 tons of CO_2 per year is the emission.

If we look at this now from the point of view of the, option B, which is the diesel engine we can then now, see that this is going to be 300 kgs of crude oil let us say approximately 0.84, this comes to 252 into 44 by 12, 924 kgs of CO_2 per year. So, this is also something that helps, that the primary energy analysis helps you do, it tells you about the overall thing and so, this comes out to be 0.9 tons of CO_2 per year.

So, from a CO_2 viewpoint it is better to go in for diesel and then you see the trade-offs. Diesel is costlier, from a societal viewpoint there are issues in terms of imports and energy security. From the option of CO_2, the oil option is better. From a security option, the coal option is better. So, these are the kind of trade-offs which are actually there are in many of the cases.