Solar Energy Technology

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Lecture - 36
Economic Analysis

So far, we made several calculations obtained methods to calculate solar radiation transmittance (( )) product and another statistic utilizability. And we in detailed analyzed the performance of collector, which is the heart of the solar energy system different types flat plate collectors as well as concentrating collectors. Then subsequently we found that the long term performance is the need for the environmentally driven in systems in general, and for solar energy systems in particular. Considering that simulations is one alternative next to system scale experiments; system scale experiments though desire to find out the practical difficulties, the difficulty is they are time taking expensive and consequence easily the variation of the design parameters and their effect cannot be studied.

So, next alternative is the simulations; there are software packages which are available, which can simulate quite a few components that we want over hundreds, maybe three hundred or four hundred components are available and commercially available software packages like a transits. So, the system scale experiments however, are essential to find out the practical difficulties like for example, the control band width or leakages and the liket the material deterioration performance degradation etcetera, etcetera over a period of time.

So, ultimately having done this, we want to know the performance, so that the size of the system can be decided, if you have got 16 giga joules of load, how much of area you put? We have already given sufficient logic to say that the performance is not linearly proportional to the area of the collector, but it is monotonically increasing at a second derivative negative or a convex upwards curve of this particular form.

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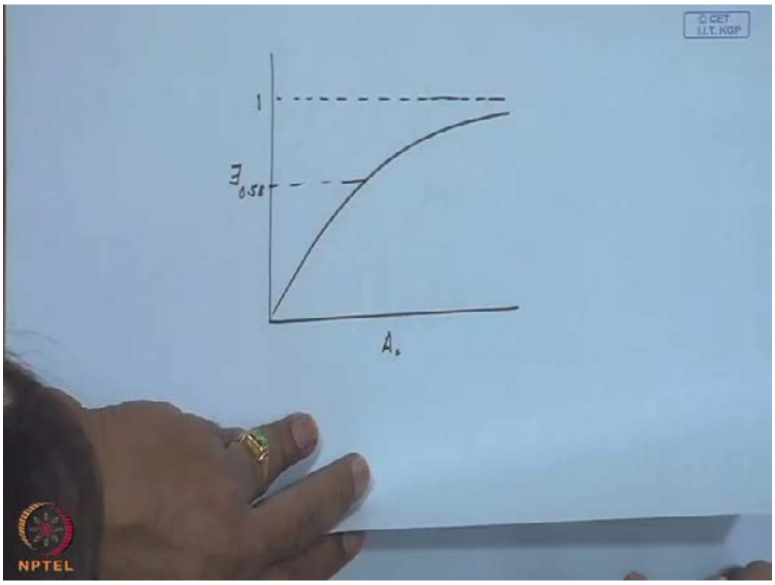

So, if I plot the solar load fraction f versus the area of the collector, the main variable of course, this curve depends upon the type of the collector, performance, location, then the parameter that you choose etcetera. I have given one set of curve one would wonder whether you will go for a 100 percent solar load fraction or may be something like 0.58. So, the reason is here it is increasing at a decreasing rate consequently the return from the solar energy as the area increases will be becoming marginal returns will be less and less. Consequently my economic viability will be effected if you choose a larger area of course, still it may be economically viable or even if you take a very small one it may not be viable that is a different issue which we are going to assess through this lecture. So, this is one objective.

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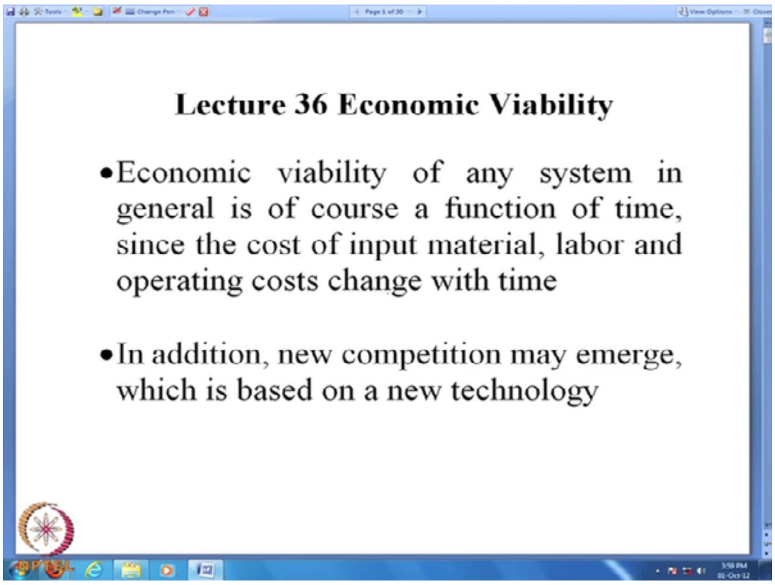

And economic viability of any system in general is of course, a function of time since the cost of input material, labor and operating costs change with time.

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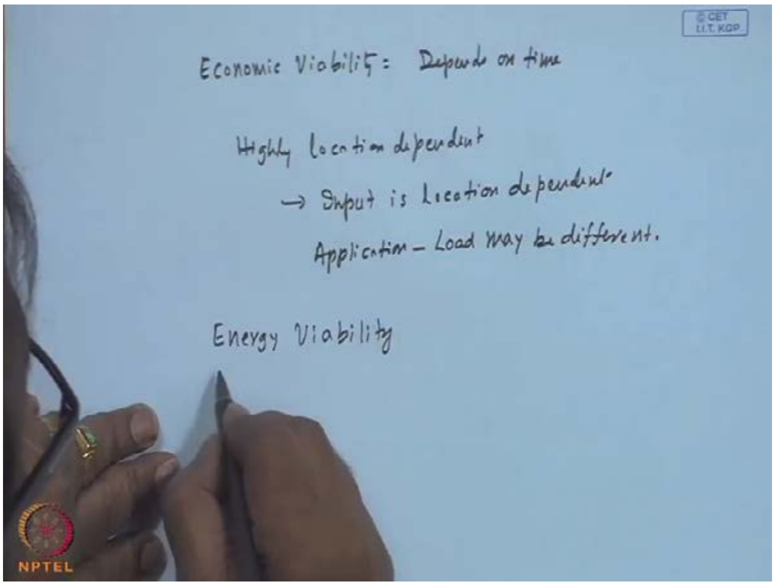

So, economic viability is depends on here we should not understand or rather miss understand this has some sort of an unsteady phenomena that is not the intention of saying the making the statement. In other words something may be viable in 1980, which may not be viable in 1990 again may be become viable in 2010 or so, it could depend upon the for example, in comparison solar energy things or it could depend upon the cost of production of the material with mass scale advantage coming, the prices of the components may come down, the prices of the fuel may go up the competitive fuel may be gone going up. So, my economic scenario may completely change; or new oil results should be found or fossil fuel results should be found and the prices will come down, then the attractiveness of the solar energy system may become less. So, this is the sense in which I said it is a function of time, not that it is a d by d t of of some sort of a unsteady phenomena.

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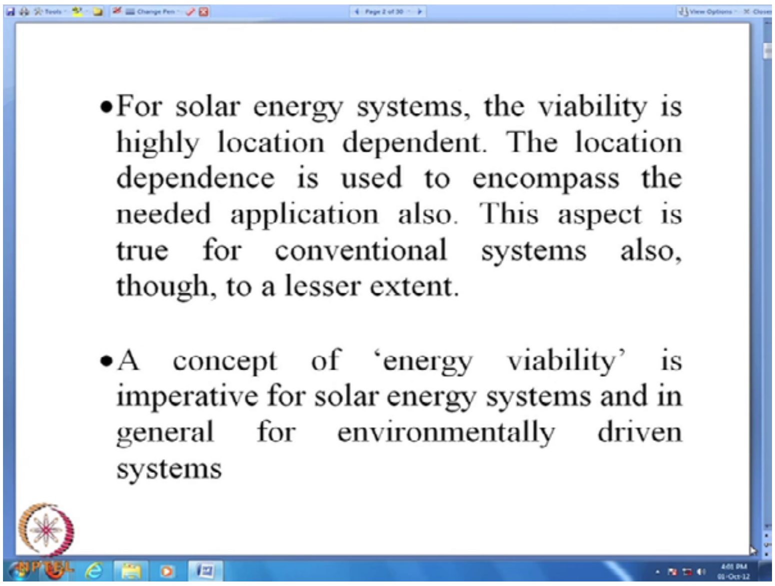

And then new competition may emerge, which is based on a new technology; this is one thing that one has to look into. So, for example, even if we take a decision today, solar thermal versus solar photo voltaic, with mass scale production if the photo voltaic cells are going to become cheaper, you may go to producing electricity with the solar voltaics even to heat water. Or if there is a mass production of the flat plate collectors or the evaluated tubular collectors or the concentrating collectors, which are cheaper and give you high pressure steam at 400 C or so, to run a super power plant like configuration with the solar. Then that may be an attractive option. So and there may be entirely a different thing that we may not be knowing as of today a new technology or new source may emerge.

And this solar energy viabilities highly location independent; this is because input is different, is location dependent right, solar radiation changes from location to location, ambient temperature changes. And then the application or the load may be different or to drive from the point in a place like Darjeeling, Shimla, Srinagar where the climate is cold, you design a space heating system, and if you put the same space heating system in southern part of India possibly there may not be not more than two or three days, where you may have to use a space heating in say Chennai or Vishakapatanam or Hyderabad. So, these are so that way this space heating system per say defined to be a space heating system shall not be of any utility in a place, where there is no heating requirement.

Now, this is you make how much you have invested, and how much you are going to save on the fuel, and then take a decision to decide the economic viability. But a larger issue and in fact, a primary issue is the energy viability. This is not addressed much, but lingering in the mind should occupy little more importance than what it did so for.

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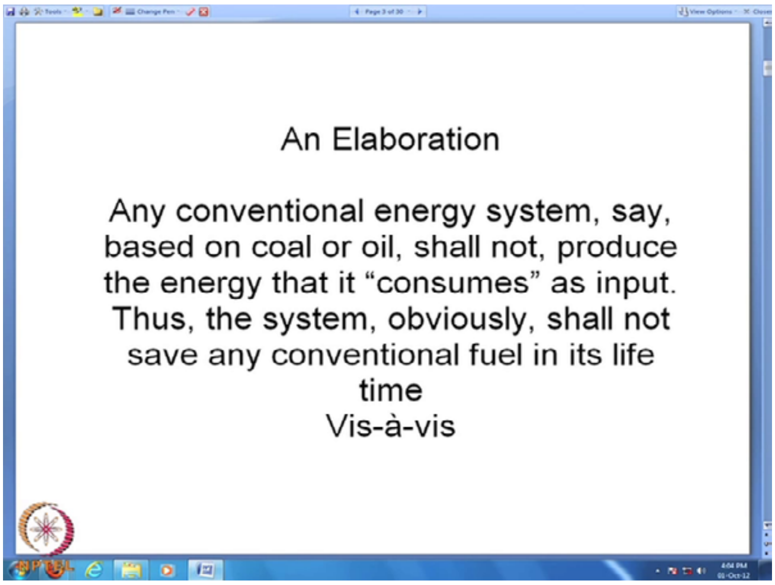

Any conventional energy system say based on coal or oil, shall not produce the energy that it consumes as input. You put the petrol or you put the fuel oil, then only the boiler or the water heater works. So, at the end of it, you have hot water or the work output whatever it is, but the conventional energy that has been put into the system will never be coming back, it is not saving that energy. Whereas if you have a solar energy system in its life time it is going to save certain amount of conventional fuel compared to whatever is the fuel that is under consideration.

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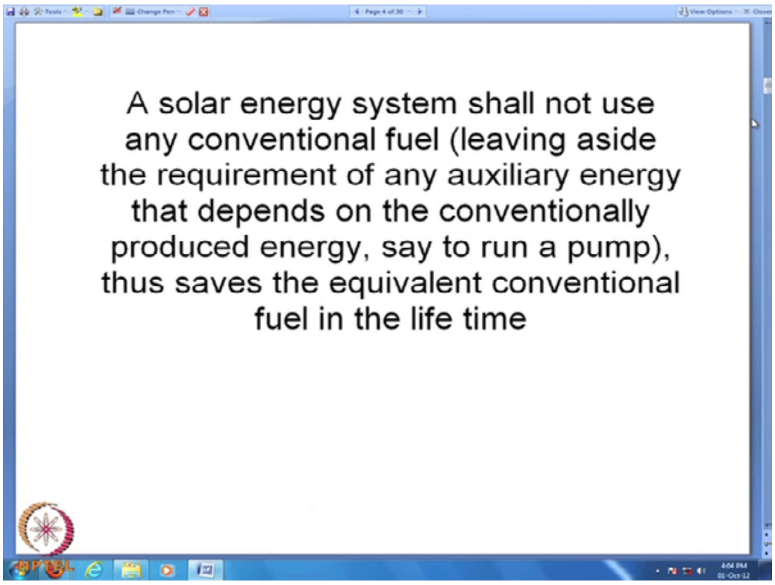

So, a solar energy system shall not use any conventional fuel for time being we will leave a side the requirement of any auxiliary energy that could depend upon the conventionally reproduced energy, say to run a pump. Thus saves the equivalent of conventional fuel in the life time. So, this is a 100 percent saving of the conventional fuel.

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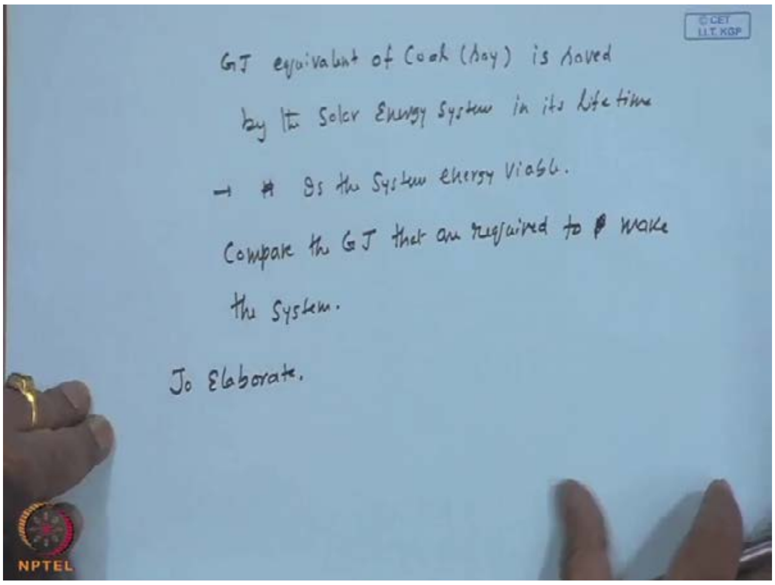

So now, if certain giga joule equivalent of coal say is saved by the solar energy system in its life time; one aspect is the money or whether it is economically worth it or viable or not that we will come little later. Now has what is the system energy viable rather let us compare giga joules that are required to produce the system, to make the system rather.

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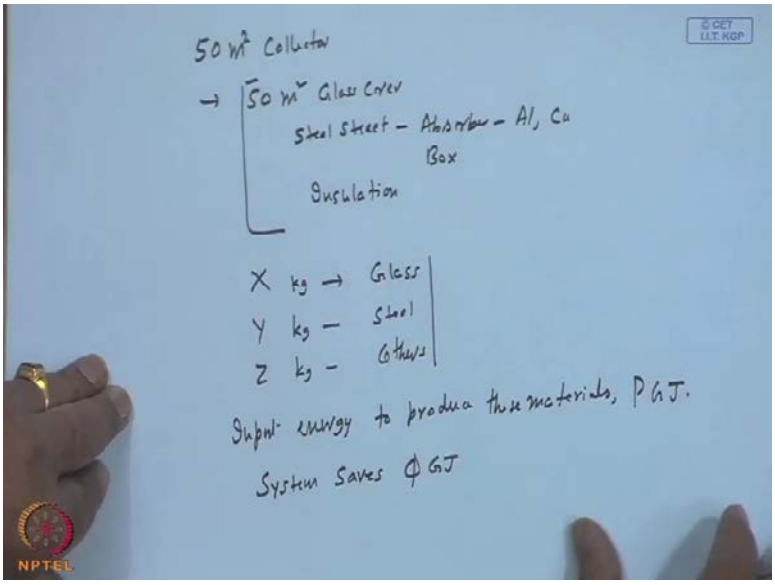

To elaborate - in the examples we considered 50 meter square of collector area. So, this may require 50 meter square glass cover at least, then steel sheet and for absorber or box of course, I may use aluminum or even copper never the less it is a material then some insulation. So, this all these things may come to some X k g of glass and Y k g of steel and some Z k g others. The input energy to produce this material in addition of course, the power required in making etcetera, etcetera, you can add is some p giga joules and the system saves say q giga joules.

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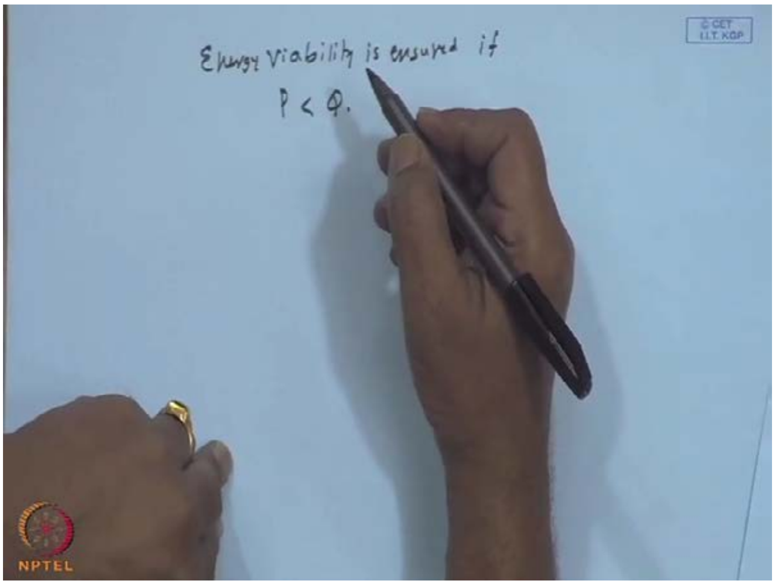

Energy viability is ensured if, if your p is less than q. The energy that has gone in to making the system should be less than the energy that it has saved during the life time. Now this is not a trivial issue, because if you take a conventional ic engine for example, the size of the i c engine is much smaller compared to the power output compared to a system like solar energy system right. Apart from the quality of the energy etcetera even if you consider let us say simple hot water producing system, and compare it with an electric heater, the material that has gone into a 1 kilo volt heater or 2 5 kilo volt heater is much less compare to the solar collectors usage.

So, economic viability which is more a function of time, certain times, government polices and the subsidies and the tax concessions and the interest rates and this inflation and the fuel and other materials depreciation so on and so forth energy viability or otherwise is a fundamental issue. And you can just make calculations by taking the amount of energy required per kg of steel per kg of copper, aluminum, glass etcetera, these are all energy intensive materials, and estimate the weight of a solar collector and find out what it is for 50 square meters. So, the first joule of energy is really saved, after the energy that was gone into making these systems has been met or replenished by the system. We are really not worried even now at this stage the quality of the energy that has gone into produced the material and the quality of energy that we are getting out of the solar energy system. If you do that another premium has to be given for example, if electricity is used or coal is used, it is high grade energy source compare it to hot water at

60 degree centigrade that you may be obtaining from a water heating system. This is not to discourage or being pessimistic, but this is an analysis that needs to be done when you are considering large systems.

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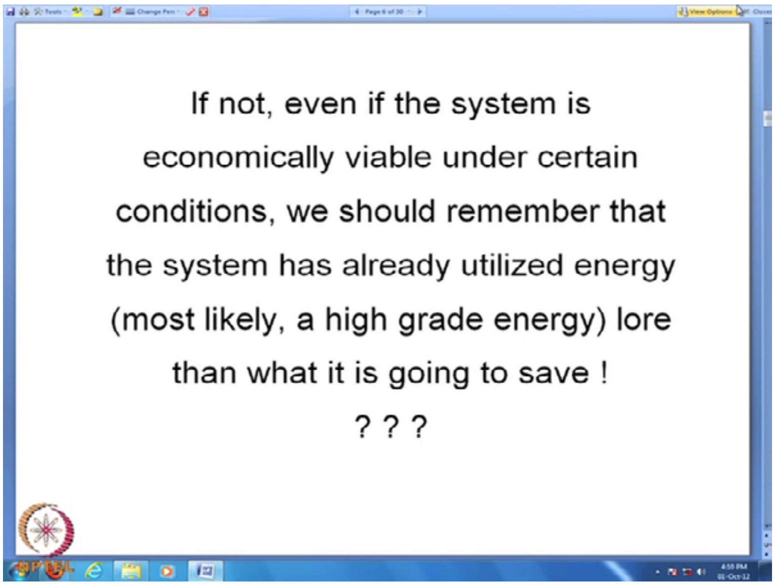

So, if not even if the system is economically viable under certain conditions, we should remember that the system has already utilized energy more than what it is going to save. If that is so, in other words we are spending more energy than what we are likely to save by this method, and it is not humor, it does happen in certain systems. So, certain calorific values, which we may require in calculations; this is available from a excellent web source that is India solar dot com.

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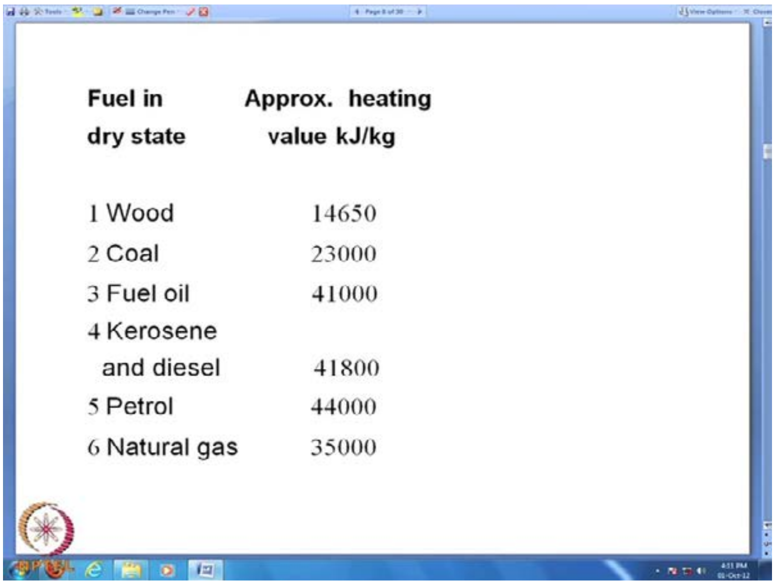

And I have extracted the relevant things wood; this is I have complied from other units kilo joules per kg 14650, coal is almost double, that fuel oil is almost double, again kerosene and diesel same petrol is higher natural gasses slightly lower.

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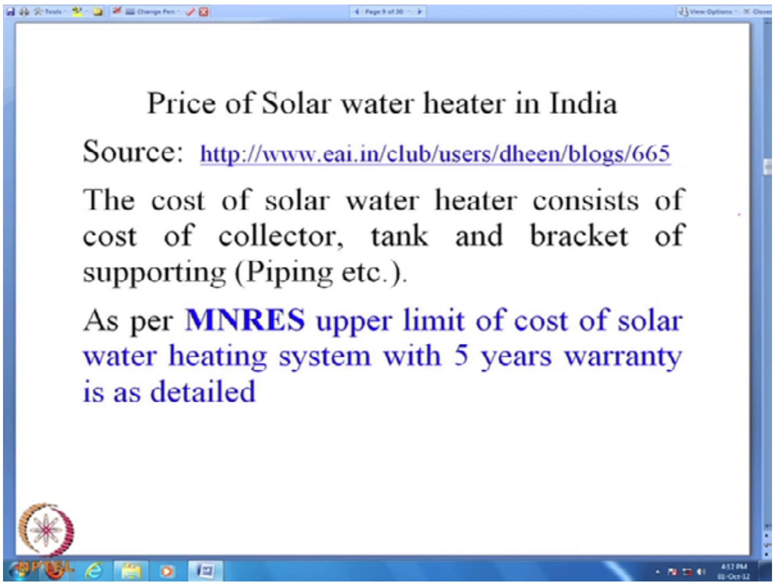

And now to have a idea for economic analysis, again a good website is available - www dot eai, which is the I think ministry of renewable energy sources. They have specified a sort of upper limit cost of solar water heating system with 5 year warranty. In other word the manufacturer should be able to supply the solar water heating systems, at this price for the capacities as indicated. And there is a bank upper limit also which I have seen though I cannot it is not relevant to give it in this course. Fortunately the banks are willing to finance a little higher than what the mnres has specified

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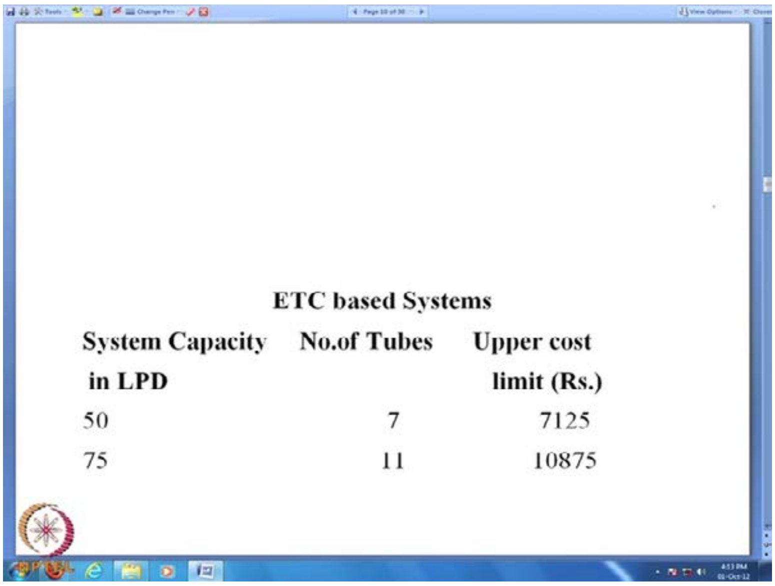

MNRES specification for example, if you have a system of 50 liters per day using evacuated tubular collectors or you can go to books or the website to know more about the manufacturing specifications for etc or the evacuated tubular collectors, they are slightly cheaper number of tubes are required 7 and their cost they have specified is 7125.

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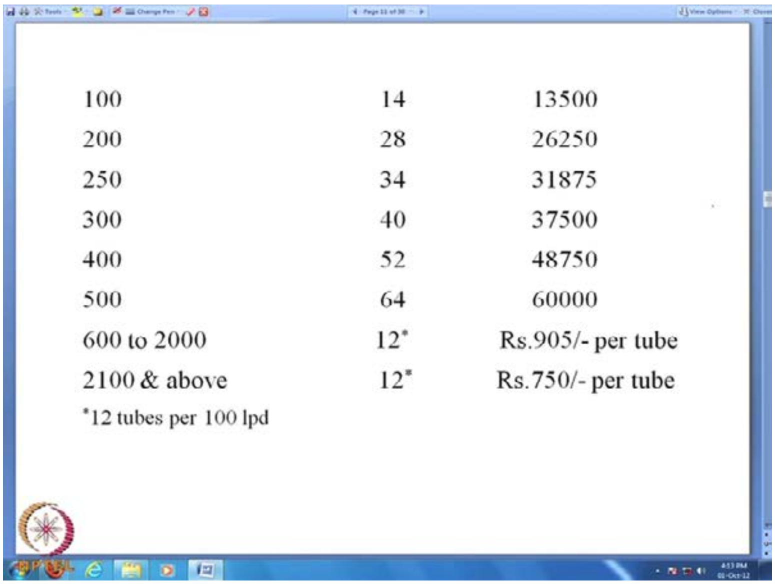

And that keeps on decreasing per liter basis as you go up for example, it comes to 750 per tube, if you have about 2100 liters and above.

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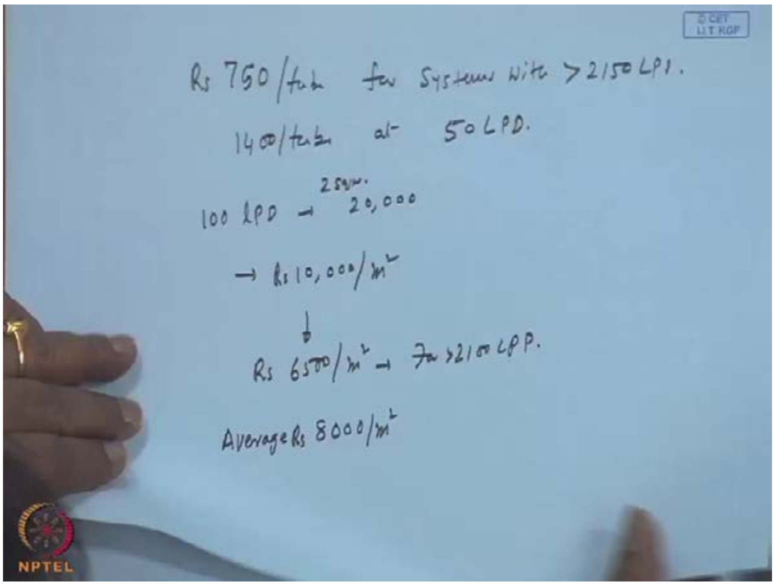

So, 750 per tube per systems with greater than 2150 LPD and if this is for 50 LPD if it is 7100, this is almost about how much? 1500 or 1400, compared to about 1400 tube at 50 LPD, almost it becomes half for larger systems. That may be because side preparation and auxiliary like pumps etcetera; they will be taken care more easily in the larger system. So, similarly for a flat plate based system, 100 liters per day capacity, 100 liters per day that upper limit specified is 20000, 2 square meters. So, per square meter I guess say about 10000, rupees 10000 per meter square; and this comes down to something like 6500, 6500per meter square, per 2100 greater than 2100 liters per day. So, I mean ballpark average value you may consider it has 8000 per square meter average; this is suppose to include installation, storage tank and pump. So, this is a quite a valuable information.

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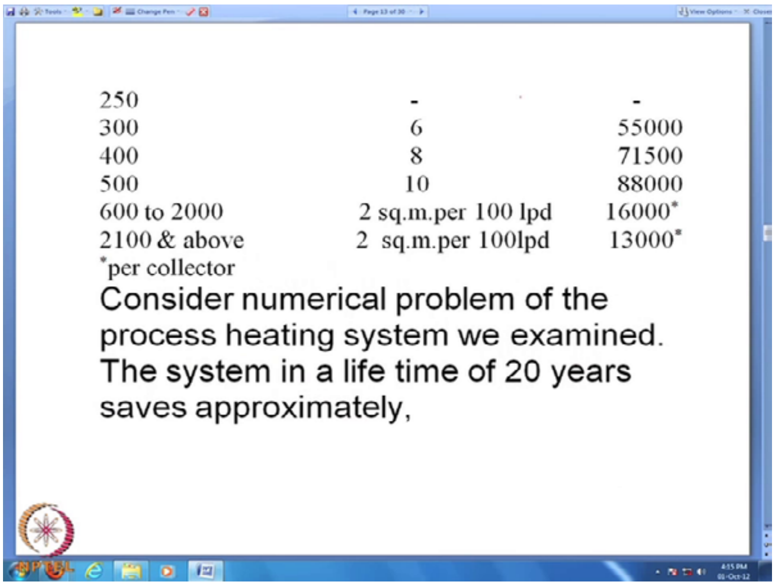

And you will have some understanding of the figures. So, let us consider the simple numerical problem of the process heating system we examined. The system a has a life time of 20 years, in a life time of 20 years saves approximately.

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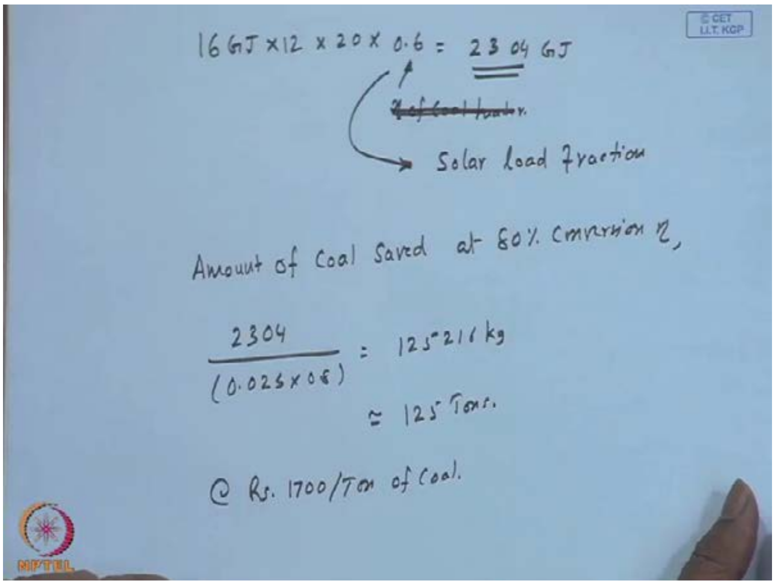

So, we are considering 16 giga joules of the load on the first or second problem that we solved; that will be for 12 months I am assuming it to be uniform, for 20 years multiplied by 0.6; this is the efficiency of coal heater, I use a boiler using coal at 60 percent efficiency reasonable that comes to 2304 giga joules. So, the amount of giga joules required that the solar energy system produces at a solar load sorry this is not, this is the solar load fraction, because we calculated at about 0.5, over all if I assume the solar load fraction to be 0.6, you will have about 2304 giga joules saved in 20 years.

Now, the amount of coal saved at 80 percent conversion efficiency, which is this 2304 giga joules dived by the calorific value into 0.8 in giga joules we can just check up. Coal - 2300 kilo joules, so that will be 0. 0 to 3 giga joules; so that comes to 125216 k g that is roughly 125 tons. So, and again I have to depend upon the news paper announcements in the website coal India price seems to be at Rs 1700 per ton of coal. If it is more my economics looks better; if it is less it looks... So, this may be there may be still some inflation over that actually the issue was about increase in the price by the ten percent or so. So this I have taken and the grade of the coal required for water heating may be lower than the grade that they are talking about. So, consequently these 2 may nullify each other, but I am taking about two rupees per kg right that comes to 1700 per ton of coal.

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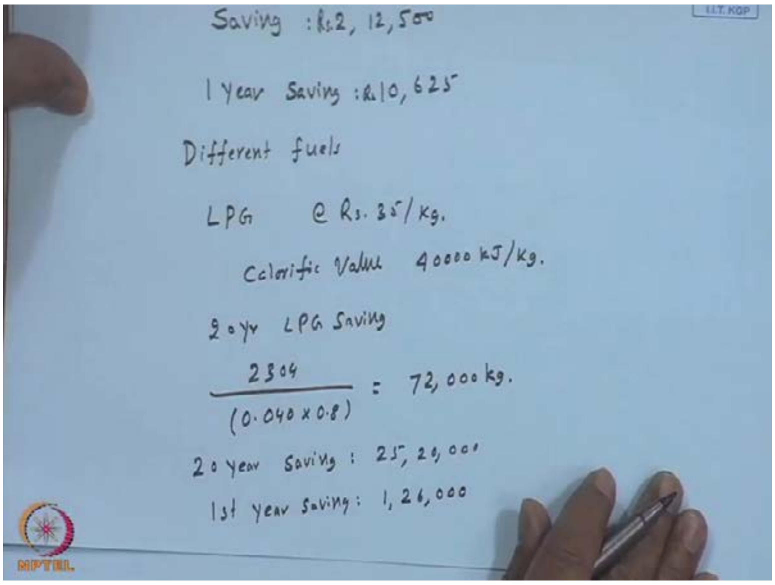

So, saving will be one 25 tonnes two lakhs 12500 r s. So, this of course, is a very, very simple minded simplistic calculation that you are assuming the fuel price remains the same for 20 years, and the solar energy system performance there is no deterioration etcetera, etcetera; of course, it has nothing to do with the deterioration, but we have taken the number of 2304 giga joules as if it is producing that much every year; consequently that assumption inherent. So, but if one year saving is calculated, where you can expect the performance to be stable, and where you can expect the price to also to remain the same. First year saving will be just proportionate 10625 and a note is in order if the fuel is different this figure may differ drastically, so different fuels. If you take LPG, this is at I have considered Rs 35e per kg, I am not really sure whether it comes under the recent hike or not I took it about 450 rupees a fourteen kg cylinder that comes to 35 rupees a kg and has got a higher calorific value of 40000 kilo joules per kg.

So, 20 year LPG saving will be by and 0.040 giga joules times 0.8 I am assuming the same efficiency; that is coming to 72000 kg. So, if this comes to a 20 year saving, it will be 25 lakhs 20000. This seems to be little unbelievable, but it is true, you can also check the calculation, this is because 35 rupees a kg is almost 20, the compare it 17 times the 2 rupees a kg of the coal, consequently this should be also 20 times the saving, which is 2.5 lakhs this is similar to that; so, that is alright. So, first year saving will be again two offset the inflation depreciation degradation of the performance etcetera. So, if I worry only about the first year saving; this is Rs, I am forgetting Rs…

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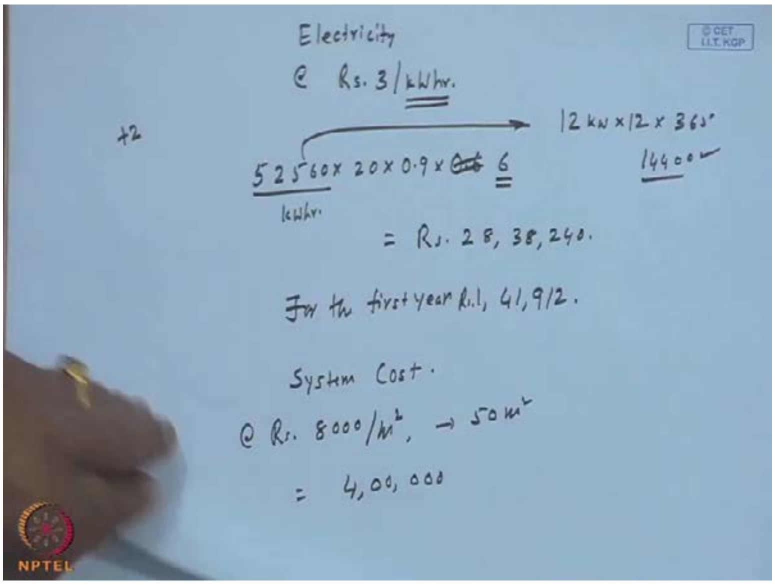

Now, electricity at Rs 3 kilo watt hours; so this may be lower, but then there are various laps, so I really do not know how to take care of it, but if one somebody wants to change the number he can make it 6 and make it more attractive or less attractive whatever so but this is about the first level of price. So, that comes to twentieth 52360 times 20 into efficiency of 0.9 into I think this should be 0.6 this is your, because it is per kilo watt hour I have calculated it is 12 kilo watt this number 12 kilo watts for 12 hours a day multiplied by 365 right. This is 144 14400 into 3 is right. So, this is directly my kilo watt hours of the load earlier we were calculating based upon the giga joules, now I have got the rate per kilo watt hour.

So, and the system was supplying 12 kilo watt at the rate of 12 kilo watts for 12 hours a day. So, this comes to, so many kilo watt hours for the 20 years multiplied by efficiency of 0.9 and load fraction of 0.6. So, this should be equal to this is equal to Rs 28, 38,240. Wait this I will just check it, whether it is a this may be at the rate of 6 rupees, this money should be there right, I will clarify in the next class now. So, this comes to a saving of 28 lakhs and for the first year saving 20 into 0.9 into 6, I think 1 lakh 41912 system cost at Rs 8000 per meter square and 50 meter square that comes to 4 lakhs.

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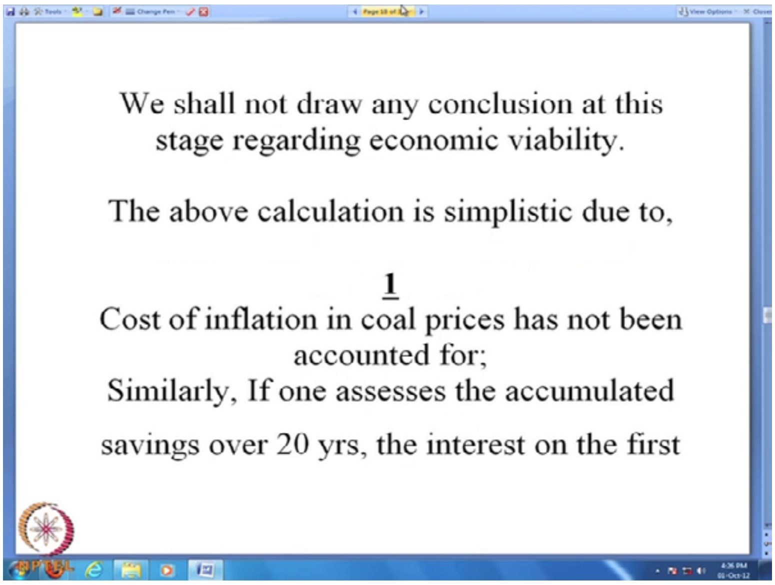

Right now, we do not draw any conclusions at this stage regarding economic viability. The above calculation is in one sense simplistic.

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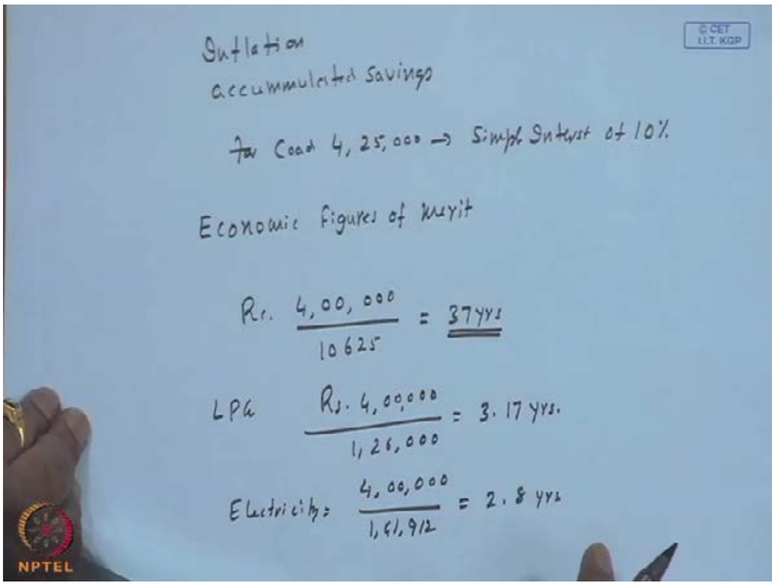

Because inflation in coal prices has not been taken into account; and accumulated savings based upon whatever is the fuel; first year savings are alright, but if you are putting it in the bank, first year savings will be for 19 years, second year savings will be 20 years, then that amount turns out to be for coal, not that 1 lakh something, but 4 lakhs 25000 with a simple interest of 10 percent; you can make a the whatever is the total amount which we have obtained in the case of a coal or assume that it is there with the bank at the rate of 10 percent simple interest for a period of half the total period 10 years that will give you a pretty accurate estimate. So, this is little better than the previous cost, if you consider the cost of the system to be 4 lakhs.

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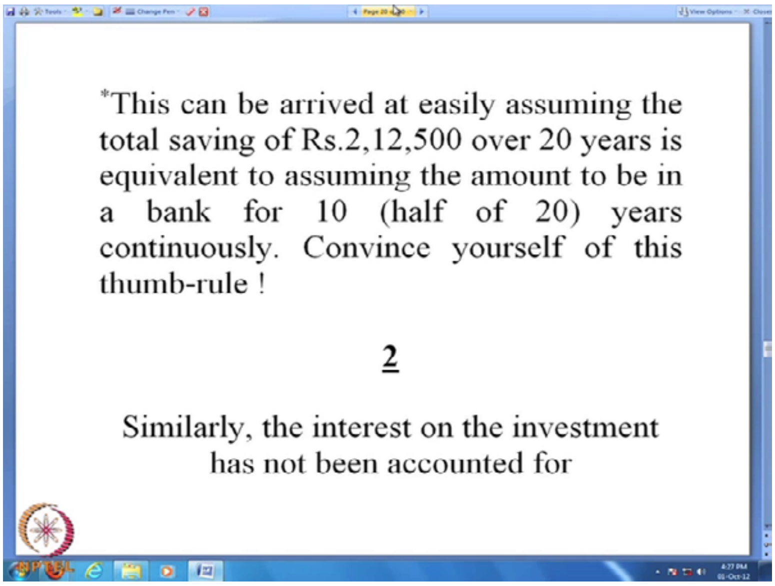

So, this can be arrived at easily assuming the total saving of two lakhs twelve thousand five hundred or 20 years is equivalent to assuming the amount to be in a bank for 10 half of 20 years continuously. Convince yourself of this thumb rule, you can do this and we will find out.

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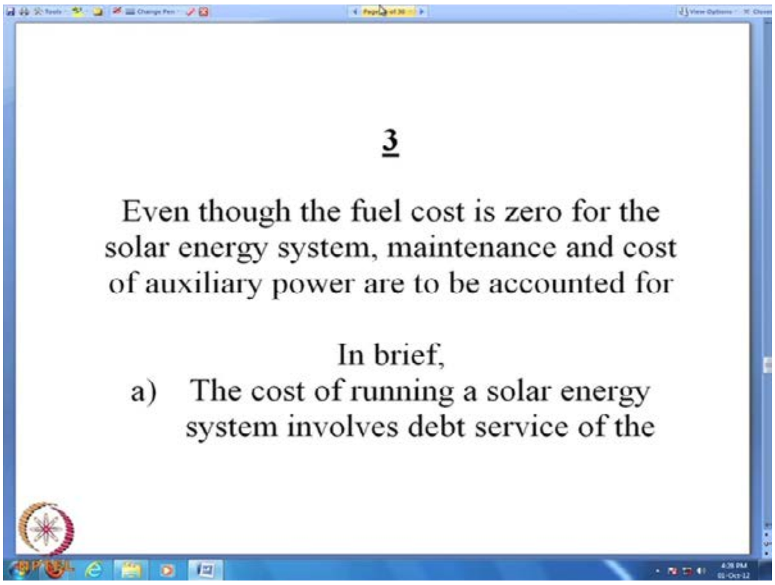

Similarly the interest on the investment has not been accounted for. Now if you spend f4our lakhs something on the system, you are straight away loosing if it is your own money 40000 at least at ten percent rate; and if you have taken a bank loan you may have to pay more than ten percent or twelve percent. So, that money has not been taken into account. So, the saving from fuel first of all should take care of that interest also. Even though the fuel cost is 0 for the solar energy system, maintenance and cost of auxiliary power are also to be accounted for. So, this we have also not done.

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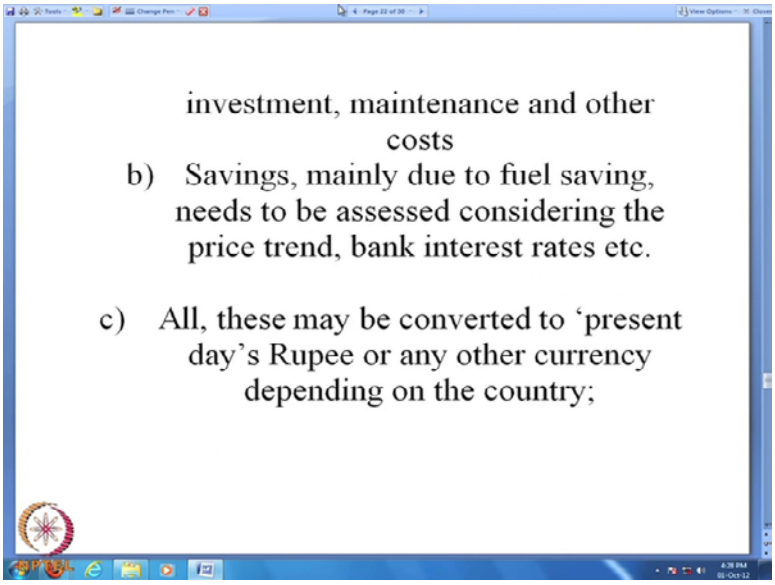

In brief, the cost of running a solar energy system involves debt service of investment, maintenance and other costs. That means, there are certain costs associated with running of the solar energy system; and savings mainly due to fuel savings needs to be assessed considering the price trend, bank interest rates etcetera. All these may be converted to present day rupees or any other currency depending on the country.

In other words, if you are going to save 10000 rupees in the tenth year, 22000 rupees in the eleventh year etcetera; what is the equivalence of today? So, one can make an economic scenario depending on inflation etcetera, and come out with the system is worth 22 lakhs 3200 today or the amount of fuel that you are going to save is going to cost so much in today's terms. Then you make a balanced judgment whether the cost whether the system is viable or not; of course, this goes into too much detail of economic analysis, which is not exactly the objective of this course; and as a matter of fact you require at least half a demister if you really want to go into in details.

But nevertheless, remember it is not so simplistic that you calculate the investment and divide by the saving per year and come out with a payback period and say that it is attractive or un attractive, but that could be an indicator. And one can depending upon the size of the system and the economic scenario of the country or location or the system; you can modify or go to more and more sophisticated methods. If you are considering a domestic water heating system that simple calculation may be alright, but if it involves crores of rupees, then somebody has to do a better analysis.

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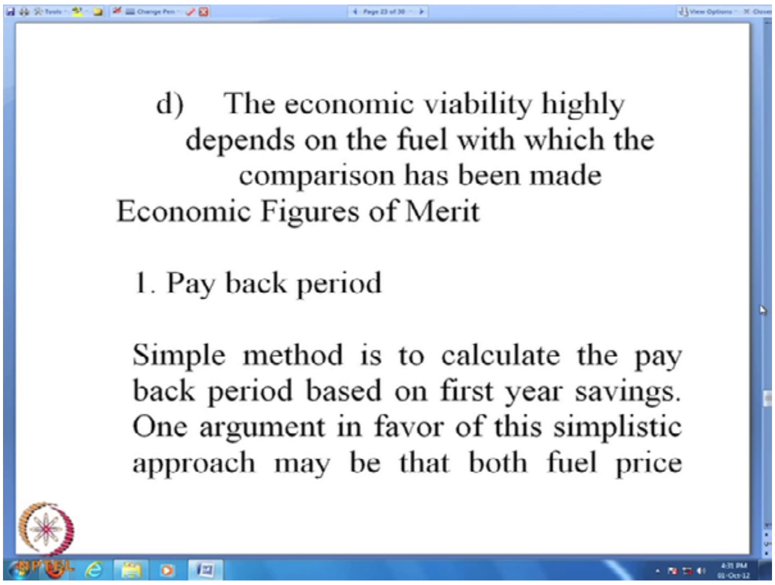

The economic viability highly depends on the fuel with which the comparison has been made right. So, as we have seen, though even if there are I do not know even if there are mistakes, but still if the rates are reasonable, which of reasonable ratios at least that is what I believe. The if you compare with the wood or coal, the solar appears to be poorer, and compare with LPG it is fine; compare with electricity it is fine; in other words it appears to be attractive option.

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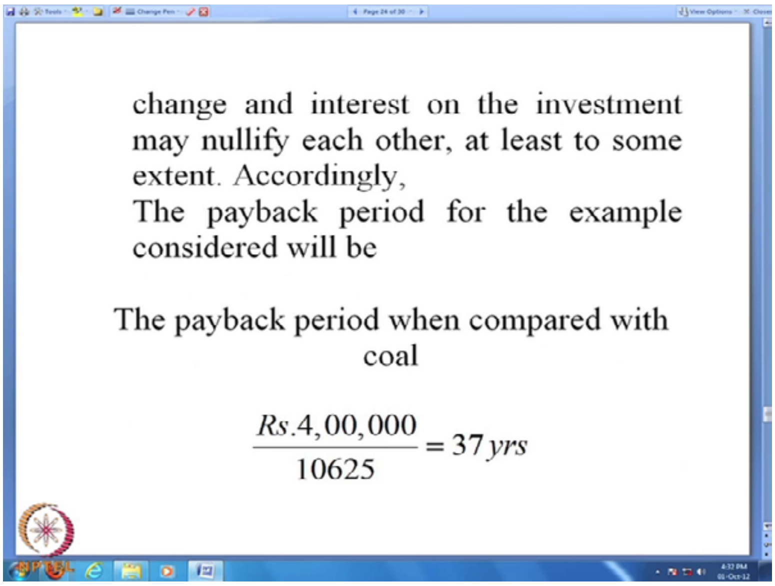

Now there are what we define the economic figures of merit. So, as I said that simple method is to calculate the payback period based on first year savings. One argument in favor of this simplistic approach may be that both fuel price change and the interest on the investment may nullify each other at least to some extent. Accordingly the payback period when compared with coal will be Rs. 4 lakhs the system cost by 10625 which comes to 37 years which is more than on the expected savings 20 years of lifetime or whatever we have assumed.

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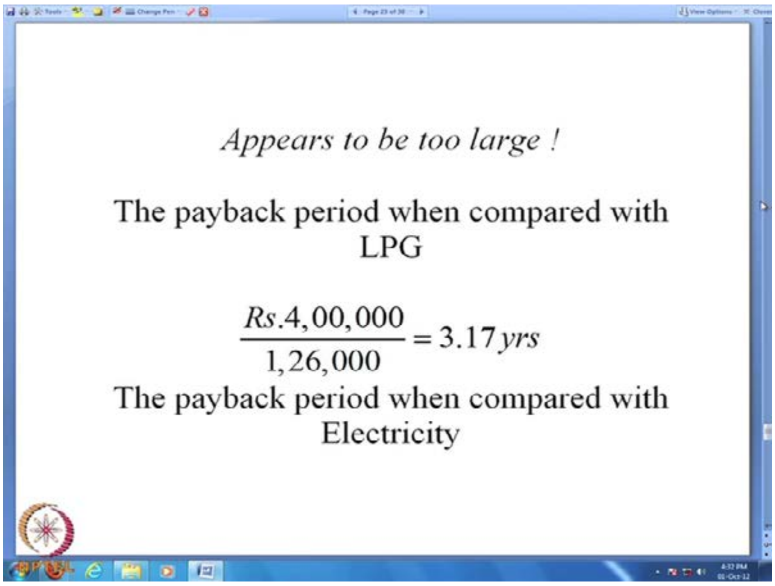

These are the orders of magnitude, and if the price is very high, it will come down. Appears to be too large it is surprising, I will check myself once again you can also do the same thing and including the prices. Then if it is LPG this is Rs 4 lakhs by 1 lakh twenty six thousand. The ratio seem to be correct, because the price of 1 kg is 35 and the fuel price, the calorific value is higher. So, this comes down to drastically low 3.17 years and compare it to electricity 4,00,000 by 1,41,912, let me just check this number once.

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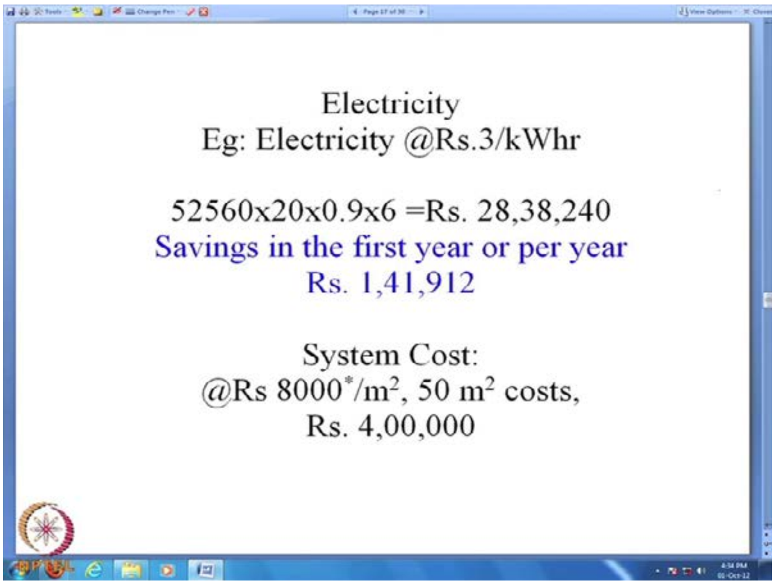

This is 1,41,912 only I think the issue is whether it is a 3 rupees per kilo watt hour or finally, I thought it is higher and took it as 6 does not matter. So, this comes to two point eight years or it will be I think it is alright because compared to LPG this should be lower, because the cost is higher I suppose. So, these are pretty good indicators and the seems to be reasonably ordered and the prices are slightly different that collector prices are reasonable LPG price is reasonable electricity really varies from 3 to 10 rupees or so and consequently that number can change from 2 years to 5 years

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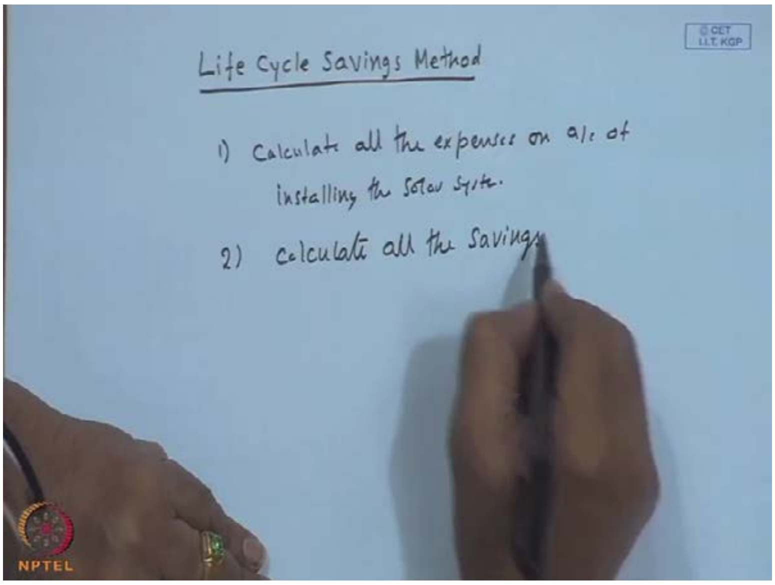

Now there is a method that we call the life cycle savings method, because if you use the simplistic thing so many assumptions are made or your fuel prices the saving performance being uniform etcetera. And if you want to include all those things, the calculation becomes intricate, but nevertheless you have to assume a scenario that is of course, inherent in any method, because you exactly you do not know, what is going to be the inflation over a period of 20 years; and you do not know the depreciation. Particularly now of course, the solar energy systems are in operation, but last let us say actively 2 decades; if not more and, but still not sufficient experience is there to tell that the system life is going to be 20 years 30 years or 15 years without or what is the typical degradation over a period of 1 year 2 years, and what are the maintenance costs like for example, how many times you may have paint a flat plate collector or how many glasses may be broken, it may be either thermal expansion or may be hailstorm, these are I have witnessed. So, this is quite a possibility of course, then you use a toughen glass and a certain things.

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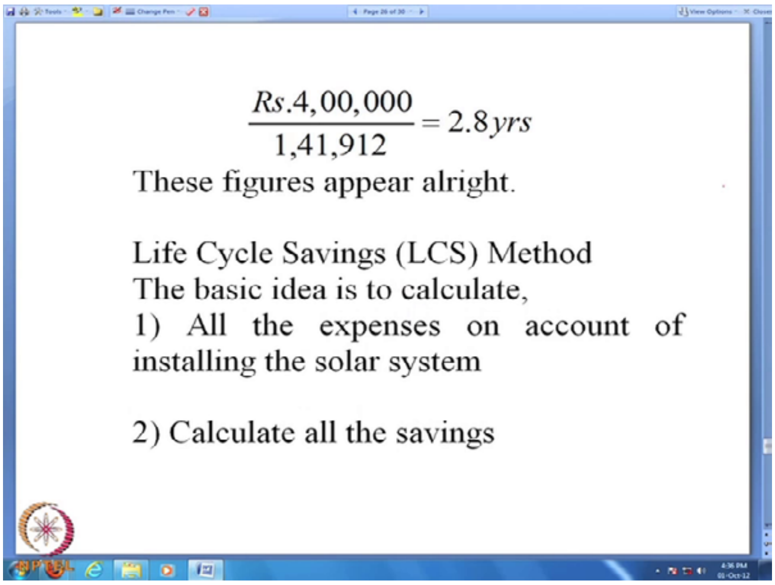

Like that nevertheless I mean, we do not have the information like we have on a cycle or a motor cycle or a car, not yet. So, this is the basic idea is to calculate all the expenses on account of installing, the solar system. Calculate all the expenses on account of installing the solar system; similarly calculate all the savings.

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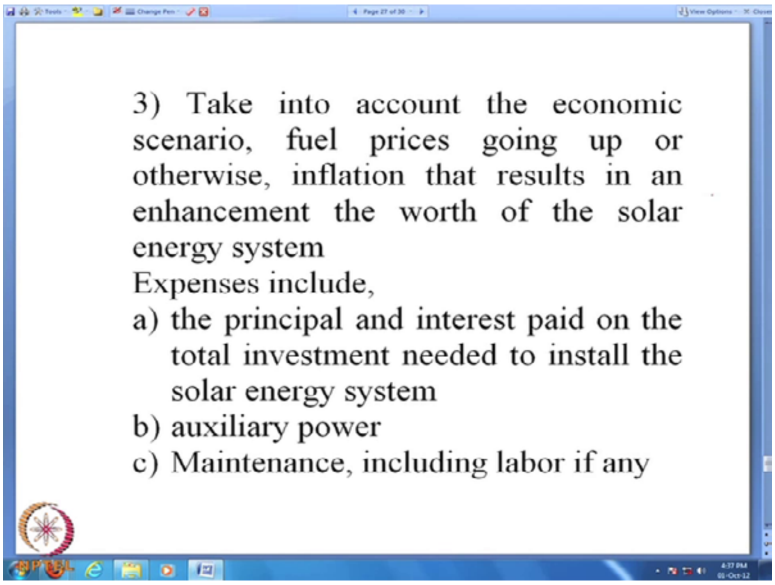

Now, take into account the economic scenario, fuel price is going up or otherwise inflation that results in an enhancement, the worth of the solar energy system. And expenses include you can go through this thing. So, I will read it out instead of writing, the principal and interest paid to the total investment needed to install the solar energy system, auxiliary power, maintenance including labor if any.

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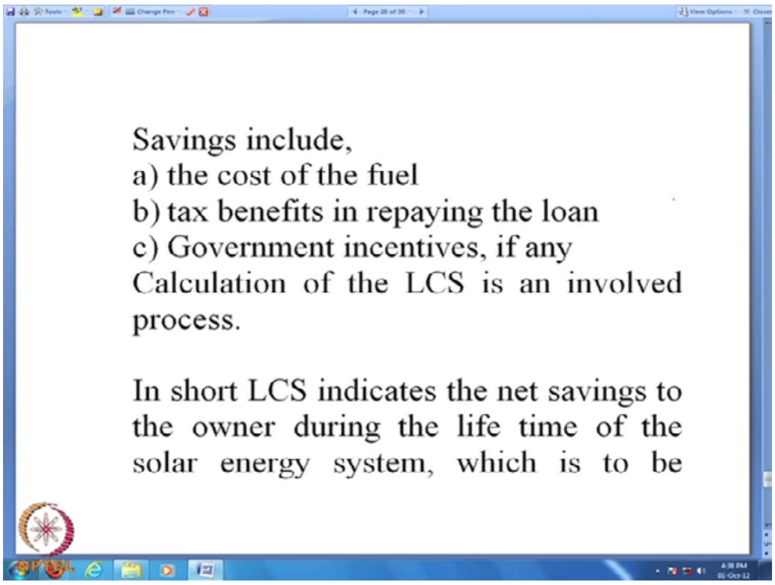

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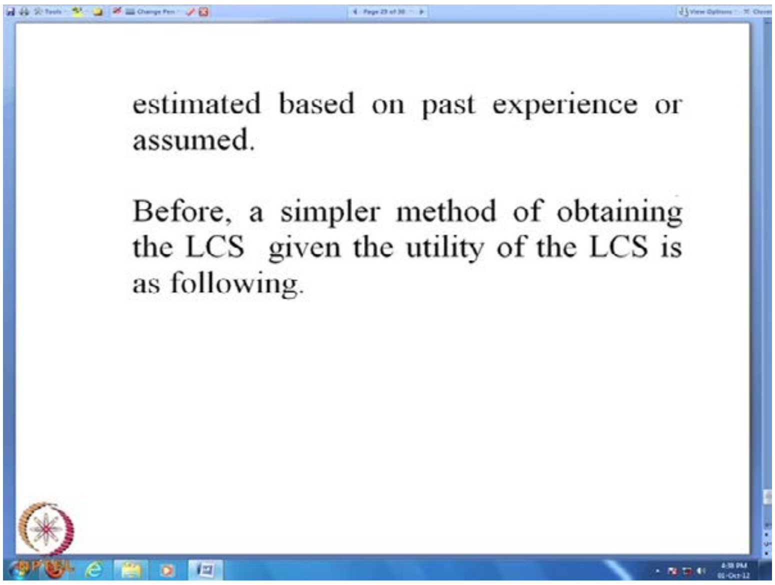

And savings include mainly the cost of the fuel tax benefits and repaying the loan government incentives if any and calculation of the LCS in involved process. So, in addition you have to bring it what is called the present cost factor. What is the value of 100 rupees 10 years later today? In short, LCS indicates the net savings to the owner during the life time of the solar energy system, which is to be estimated based on past experience or assumed; that is the not the LCS, the let us say time period 10 years 20 years 15 years that has to assumed before a simpler method of obtaining LCS is given let us examine what is the utility of this life cycle savings right. Suppose we have got the method to calculate the total, net savings over a period of twenty years assuming that the life of the solar energy system is 20 years, I have taken care of a possible scenario for the fuel prices, a possible scenario for the depreciation a possible scenario for the degradation the performance etcetera, etcetera and obtain the life cycle savings.

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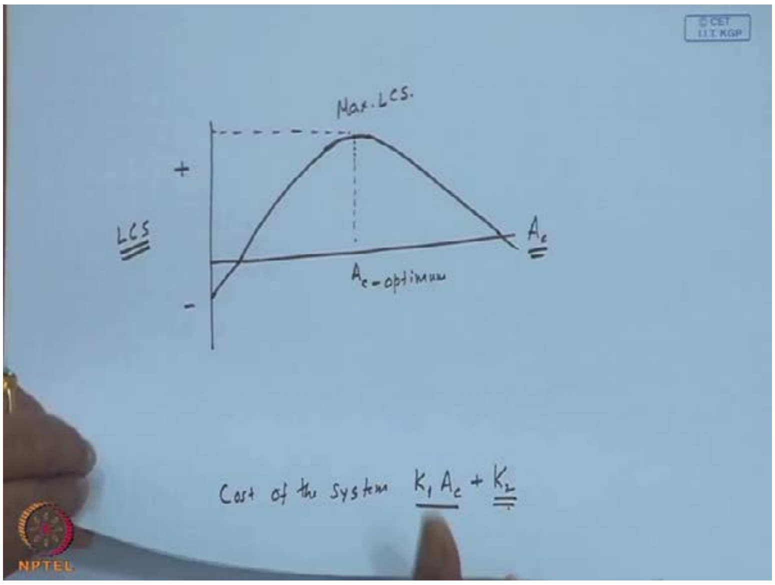

If I plot, in general we may think that A of the collector is the main parameter, the other things are fixed, we are examining a given system; that means the location is fixe, application is fixed, the load is fixed everything, and operating parameters. Somebody through simulations came out with the, this is the best orientation, slow flow rate, etcetera, etcetera.

We can always divide the total cost of the system, A constant k 1 times area of the collector plus k 2; that means, it is a area dependent cost if you increase the area the cost will linearly increase. So, a portion of the piping portion of the platform preparation everything can be associated with each square meter area. The other one is a fixed cost, for example that of a pump right, it may not directly unless the changes range a lot, the pump cost is independent, similarly the heat exchanger, consequently you can by enlarge divide the area as a area independent cost, and a area dependent cost. What are the component that will go in as a matter of detail, but for the purpose of explaining this, you can say that the total cost of the system is something like m x plus c. So, this c will depend upon independent of this area that you have put in.

So, if I take the x axis as collector area, and the y axis as the life cycle savings at area tends to 0; obviously, life cycle savings will be negative. Because in other words you have forgot to put the collector in a way, and you bought all the other components. So, there is no energy delivered consequently there is no savings, but you have paid some money for the heat exchanger or whatever, the other component that do not depend upon the area of the collector.

So, my initial life cycle savings will be negative. So, this goes up as the area keeps on increasing, because I am getting more and more savings, and this will go because my solar load fraction is increasing as the area is increasing, but then since it is at a decreasing rate, this starts decreasing after certain area. So, something like this, again it may become 0 or it may not become o. Now, this is a point I can call it optimum, because this is where my maximum life cycle savings, whatever may be we are finding out the life cycle savings, because as area increases my life cycle savings do not linearly increase there will be a maximum and there will be a minimum. And this negative thing is it is a mathematical way of saying as A c tends to 0, this area independent cost still costs the owner something. So, his life cycle savings is negative.

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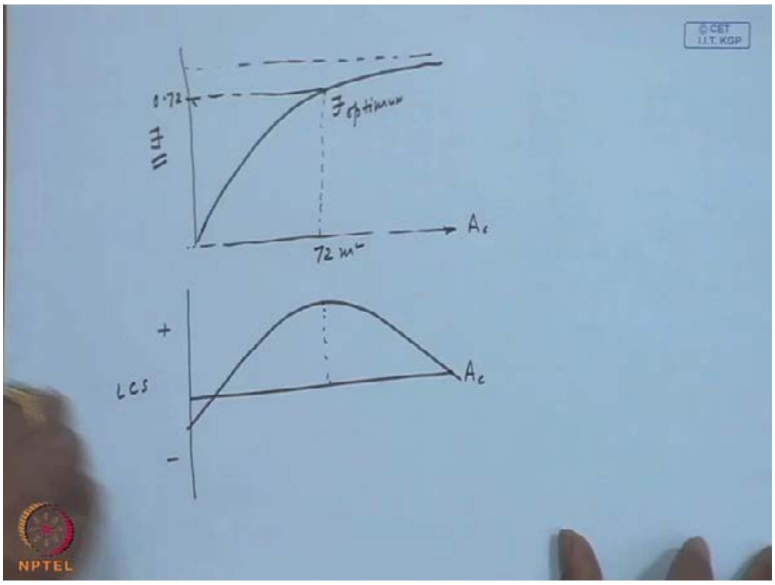

So, this we keep it over here, and superpose with the load fraction curve, this is the area A c – positive, negative LCS, and this curve like this, and again AC versus solar load fraction, this is what it means the slow increase at larger area will lead to decrease in the… In other words, it is not giving sufficient saving in the energy, though the cost is increasing linearly with the collector area. So, this is the maximum savings, and I go up here and this will be my f optimum either this point which may be 0.72, and this may be 72 meter square.

One thing this is propagating is you do not need to aim for a 100 percent solar load fraction, but you aim to maximize life cycle savings, because initially some subconscious feeling is to show that solar can do everything, but I think wisdom prevails, and the objective will be to… It is a not a substitute you do not want to replace one energy source with the another energy source, you would like to utilize where it is best, solar may be best in certain application, auxiliary heating using cold may be better at some other place.

So, the ultimate objective being the load or the demand on the conventional fuels use less. This spirit one has to there is no let me put it this way ego issues in the sense that you wanted to do it everything by solar, that is not the objective you want to do best with the solar. So, this is how your life cycle savings are useful, and if you want to say I will give you formula to decide this particular point depending upon the method of calculation of the life cycle savings, but the whole exercise we have done right from defining the solar radiation under extra terrestrial conditions to terrestrial components and processing to long term, and short term periods then the optical properties a collector performance, and the simulations to get the long term performance along with the design methods to get this curve.

If I combine this f versus A c curve with the life cycle savings curve, it will tell me that what is the best thing, because till when we made the v bar f chart calculations though we made it only for one month, one can in principle make it for all the twelve months and find out a capital F is sigma f i L i over sigma L i 1 to 12 and obtain this curve. And we have already established sufficiently strongly, that this f versus A c curve will be non-linear with a second derivative being negative.

So, this was our performance solar energy system study academic plus practical point of view objective, and then once you combine with economic economics it will tell you the best system is this, otherwise it becomes arbitrary whether it is point 7.8.2 right; of course, smaller the life cycle savings the minimum thing one can have is life cycle savings to be 0, it cannot be negative.

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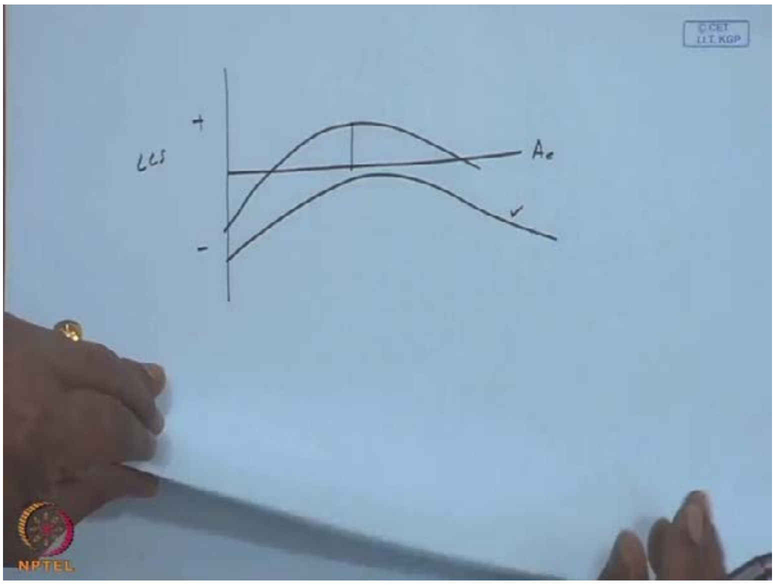

And in fact, if sometimes this is not unlikely area LCS plus it looks humorous, but it is not true, it is it is true I am sorry it may never become positive, yes there is a maximum, but not positive. In case you go to a very a cold place where the solar radiation is less, and you are trying to generate a high temperature a possibly the system life cycle savings may behave like this.

Now, you can see in the examples that we considered a comparative the location at 40 degrees though it is still a higher latitude, and Srinagar that having a lot of diffused fraction your R bar factor is considerably reduced, because your R b is multiplied by one minus diffuse fraction in calculating the total tilted radiation on the collector surface. So, the examples we picked up they illustrate various aspects how the climate influences etcetera. So, give little thought to those things. So, this A possibility and but then at least we want it something like this right, then you pick up this point. So, the minimum one can do is a 0 life cycle savings thought negative, and if it is positive we will pick up the maximum. I shall in the next class tell you how to calculate this life cycle savings, and find out this optimum point by a certain method.

Thank you very much.