Energy Resources, Economics and Environment
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Lecture - 20 P2
Primary Energy Analysis - Part 2

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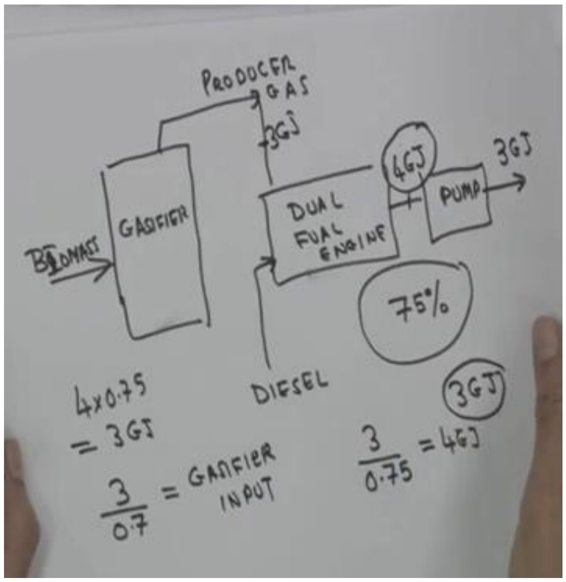

Let us quickly, look at the option C, which was, where we have the biomass gasifier. So, here what we do is, we have a gasifier, where we fire biomass and then we are getting producer gas. This producer gas goes to a dual fuel diesel engine or dual fuel engine. It could also go to a dedicated spark ignition engine so that it could be, but dual fuel engine is also consuming a certain amount of diesel and then this is converted over to the pump and this is the energy output. So, we have 3 GJ. Now, for this duel fuel engine, there is usually a certain limit in terms of what is the proportion of the producer gas in this.

So, at most what we are looking at is, we are looking at something like 75 % of the input can be provided from the producer gas and 25 % comes through diesel. When we look at this then what we will do is, we will say 3 GJ, which is in the pump, take the pump efficiency and get what is the input which is required here. So, that means 3 divided by 0.75. So, this will be 4 GJ here. Now, from the 4 GJ, let us say by energy terms 75 % will be provided from the biomass gasifier.

So, that means 4 into 0.75, it turns out to be 3 GJ as the output of this producer gas, 3 GJ. So, the efficiency of the gasifier is 0.7 so we can do 3 divided by 0.7, is the gasifier input. We can then divide this by the calorific value of the biomass and will get a certain amount of biomass which we get and you can cross check these numbers.

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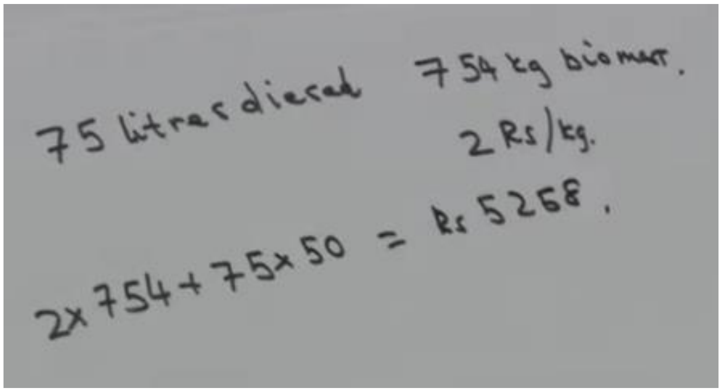

And then so basically, what we get is in this case, we have 75 litres of diesel. Remember we earlier had, 290 litres of diesel and this is 754 kgs of biomass. So, if the biomass price is 2 rupees, per kg then the total cost, operating cost will be, 2 into 754 plus 75 into 50. You can check this, this comes to about 5258.

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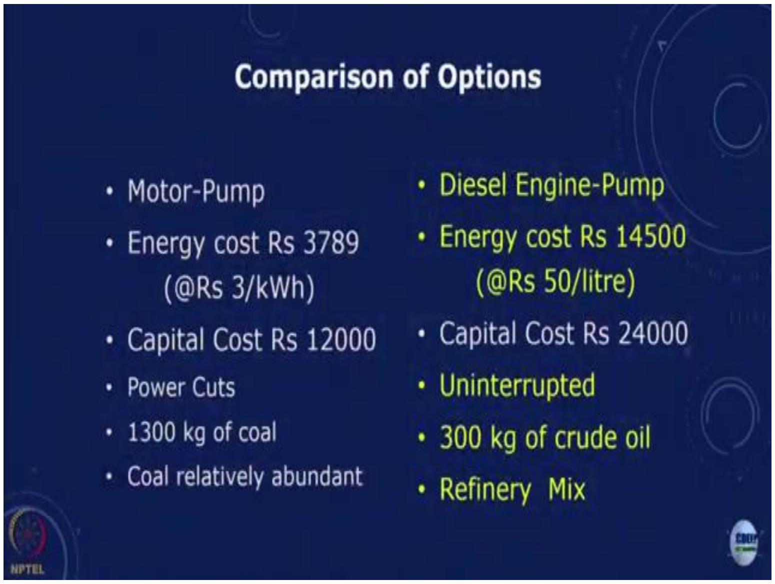

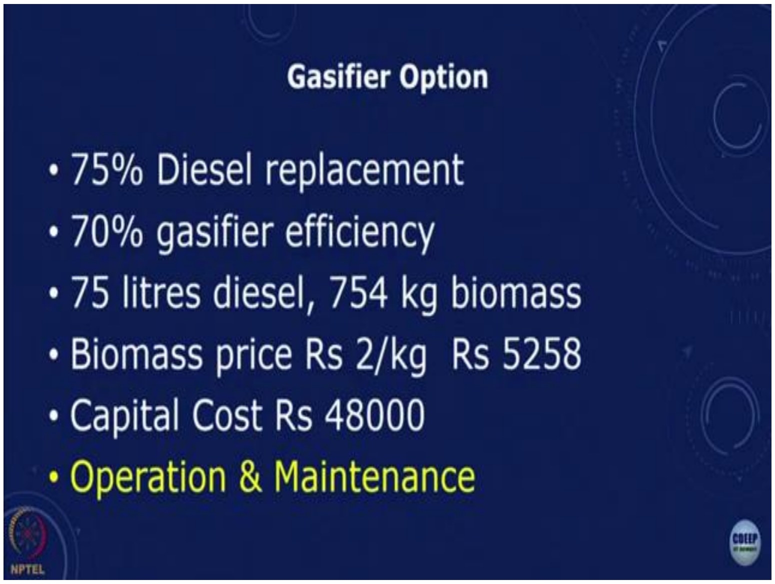

So, let us compare it with the, diesel engine pump instead of 14500, we are getting now 5258. So, of course the operating cost reduces. However, the capital cost increases because now you have the gasifier, there is, also it is more tricky in terms of operation and maintenance. We will see that in terms of CO_2 now. The CO_2 emissions will reduce because the biomass is considered as carbon neutral and we can then calculate.

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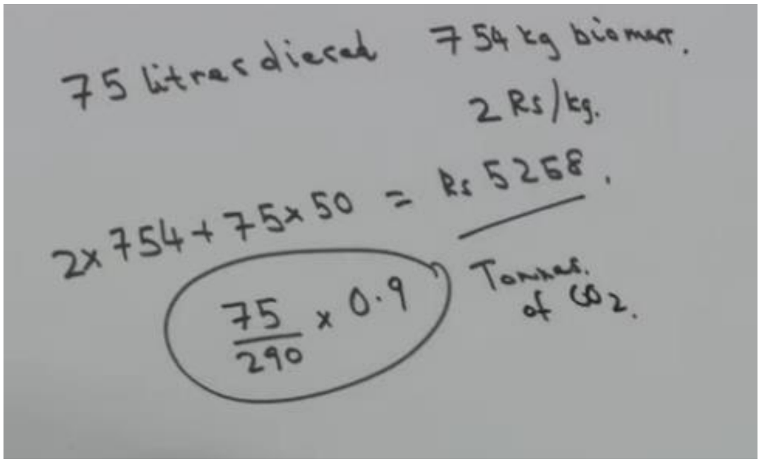

This is just going to be roughly what we calculated 75 by 290 into 0.9, is what we had calculated, tons. So, the amount of, CO_2 reduces significantly in this option and of course, but it is a costly option. There are other things that one can think of and then we have, there is now move to have solar photovoltaic based pumping.

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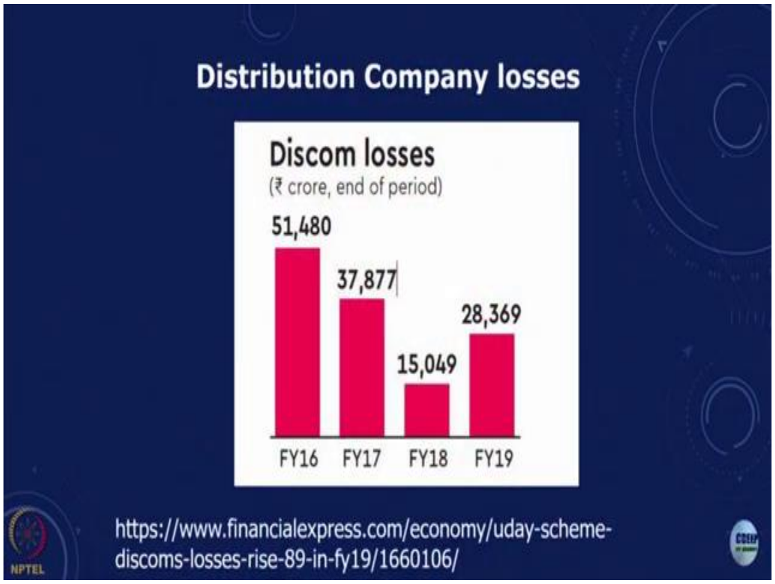

So, you can look at this. Now, one of the issues in all of this, is that, the distribution companies because of the agricultural pump sets and the theft which is there, agricultural pump sets many cases have been given, were given free electricity. So, with the result that typically distribution companies have been making significant losses and you can see these are the different years with this uday scheme, based on the government estimates, reasonably large lost components.

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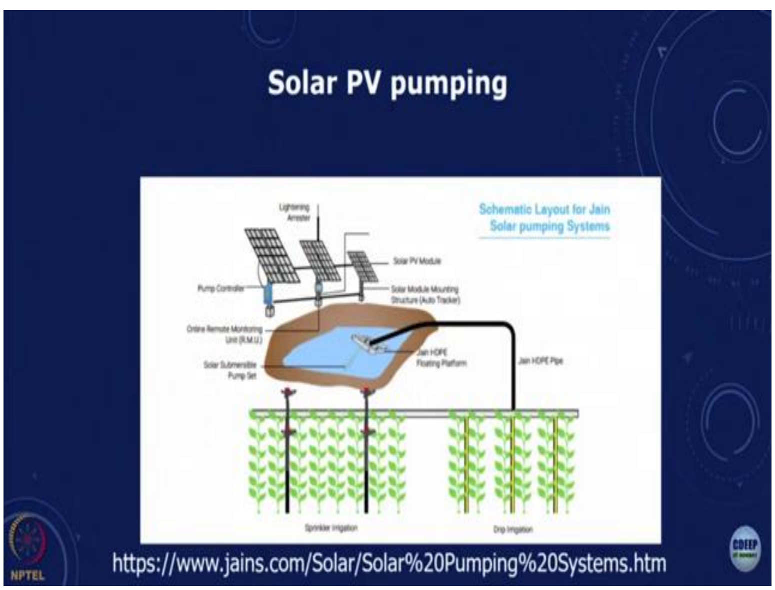

So, one of the things that the distribution companies are thinking of, is to try and look at supporting agriculture pump sets moving to solar and of course there is a capital cost involved. So, typically what happens is you will have the solar PV modules and then you will have the, pipeline for the, there is a schematic, for a particular company with a solar pumping system.

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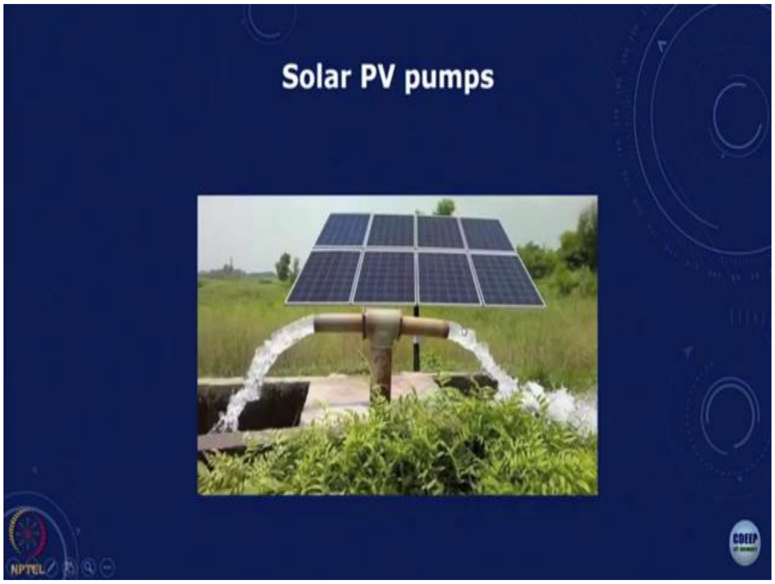

And when we look at this, this is typically how it will look in the field and the, the advantage also is that in many of these cases if you have some storage, it is possible to then pump whenever you have the solar and then you can use it in the pump, use this in the field, if you have the water storage and that may be a.

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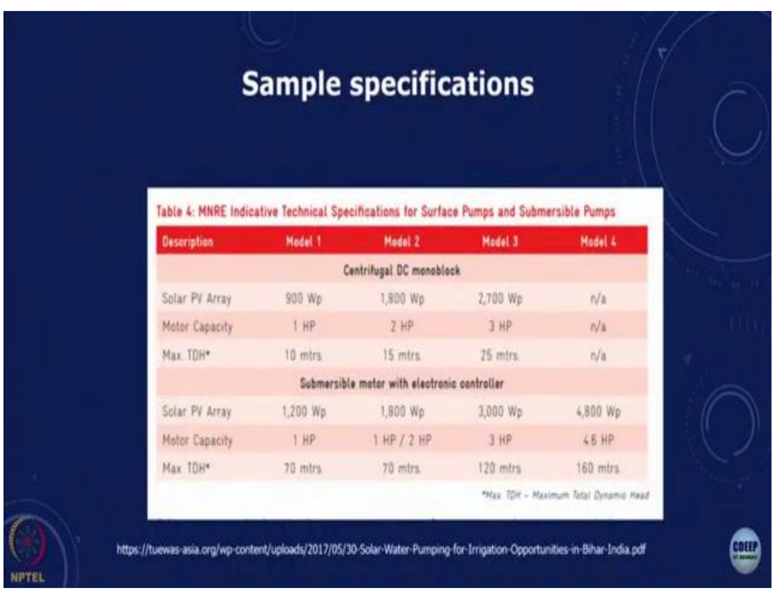

Table 4: MNRE Indicative Technical Specifications for Surface Pumps and Submersible Pumps

Description	Model 1	Model 2	Model 3	Model 4
Centrifugal DC monoblock				
Solar PV Array	900 Wp	1,800 Wp	2,700 Wp	n/a
Motor Capacity	1 HP	2 HP	3 HP	n/a
Max. TDH*	10 mtrs	15 mtrs	25 mtrs	n/a
Submersible motor with electronic controller				
Solar PV Array	1,200 Wp	1,800 Wp	3,000 Wp	4,800 Wp
Motor Capacity	1 HP	1 HP / 2 HP	3 HP	4.6 HP
Max. TDH*	70 mtrs	70 mtrs	120 mtrs	160 mtrs

*Max. TDH – Maximum Total Dynamic Head

There are many different types of configurations, which we can do and you can see that you have different modules of arrays going from 900 watt p to about 2.7 kilowatt. Different kinds of centrifugal pumps or submersible pumps and their large number of possible configurations. So, this is another option which we can see.

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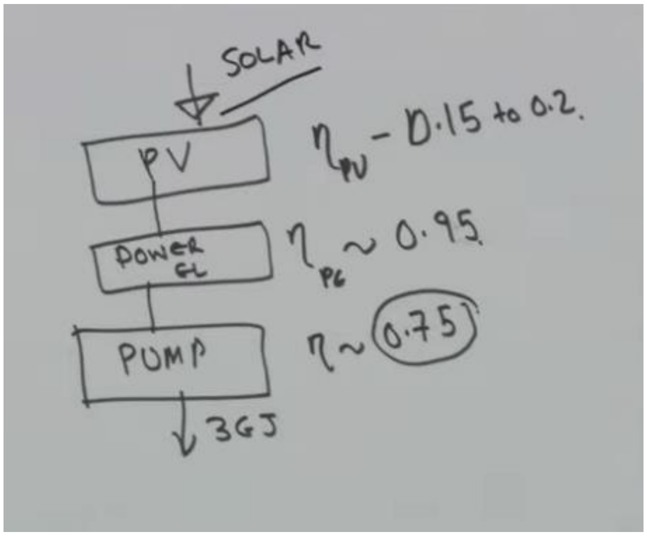

And in this if you look at the efficiency when we talk in terms of this, it is going to be only the pump and then we have some kind of a power electronics and then you have the PV, incoming solar radiation. Power electronics is a fairly efficient, will be of the order of, let say 0.95 or even more. Pump we had set, pump efficiency we had set 0.75. Some of these submersible pumps, etc. might have slightly lower efficiencies. The PV modules in the field may have efficiencies ranging from 15 to 20 %.

So, from an overall efficiency point of view, this is the, you may find that the efficiency is lower than the efficiency which we had from the oil. But please remember efficiency is important provided the resources constraint. Since this solar insulation is relatively free. We do not have to pay for it and it is not constrained then the efficiency may not be the criteria when we think in terms of solar. So, with this we complete the part, on the we, the example that we saw.

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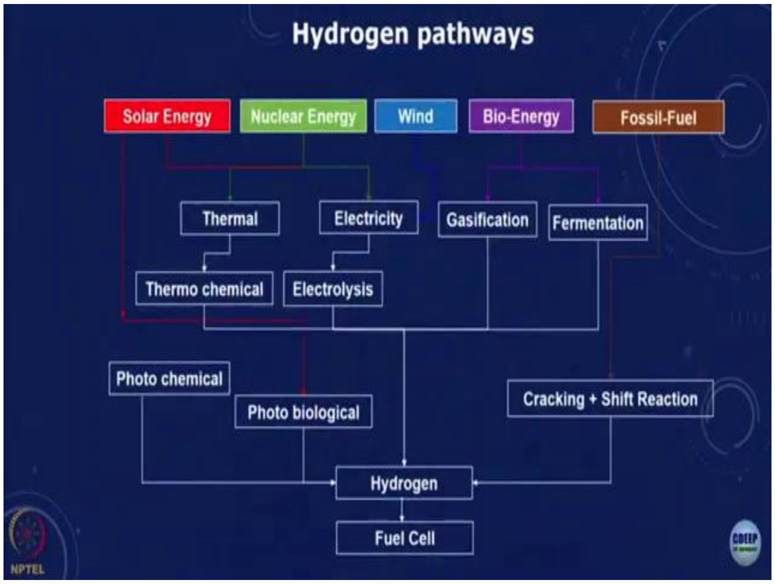

Now, we would like to look at another example and that is for a car. We would like to see, is it possible to think in terms of a fuel cell based car, and how would that compare with the IC engine based car. So, in this example, we are going to just, I will just show you some of the numbers and you can calculate it yourself. We are not going to, do the detailed calculations like we did in the earlier example so that you have already got that.

Now, when we think in terms of hydrogen, there are several, several researchers and several energy professionals believe that hydrogen is going to be the future and hydrogen is in general, it is a secondary fuel. So, when we think in terms of a pathway to have hydrogen, we can have hydrogen from a variety of different sources. We can start with fossil and then we can do cracking and shift reaction and then get hydrogen and that is the largest this steam methane you reforming is the largest chunk of hydrogen production. It is, today it constitutes more than 90 % of the hydrogen produced in the world.

We can look at hydrogen from nuclear, we can look at hydrogen from solar, both and when we can look at, photochemical, photo biological, hydrogen from biomass, gasification, fermentation. So, there are a whole set of possible ways in which we can get hydrogen. After we get hydrogen, we can use that hydrogen in a fuel cell, to give us electricity. And this is compact, it has no emissions with it and no moving parts. So, it is, an it is high efficiencies. Unfortunately, it is still very costly and the life is relatively low. So, this is why fuel cells and hydrogen has not become as common as one expected it to be.

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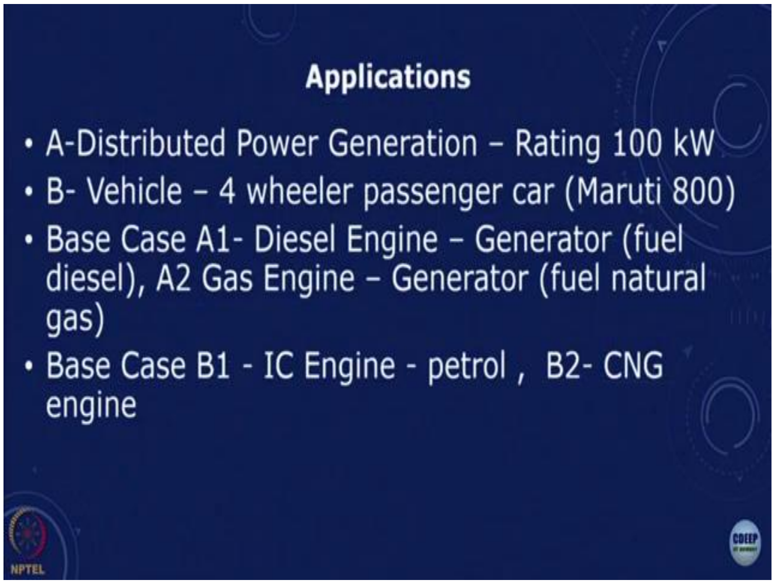

So, we will look at two applications for hydrogen, one is an application where we are looking at distributed power generation. So, we want to generate power and in the case of distributed power generation, we have many different options. Let us look at an option where you have, so here we are looking at not the grid, but it is an isolated system.

We can, I have the diesel engine, generator or we can have a gas engine fired by natural gas, gas engine generator and in the third case we can have essentially a hydrogen based option. So, these are the base cases, we can, I have compared it with a fuel cell hydrogen option. In the second case for the vehicle, the base case can be IC engine for petrol or diesel and at second base case could be CNG engine.

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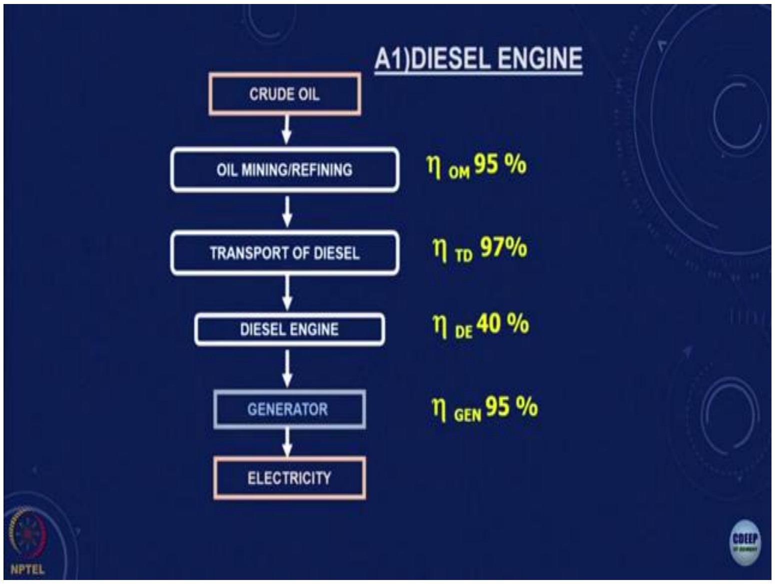

So, if we look at the option for power generation, from diesel we can see the generator, the diesel engine, transport of diesel, oil mining and refining and this is very similar to the system that we saw for the pump. We have put down typical efficiencies, you can multiply it.

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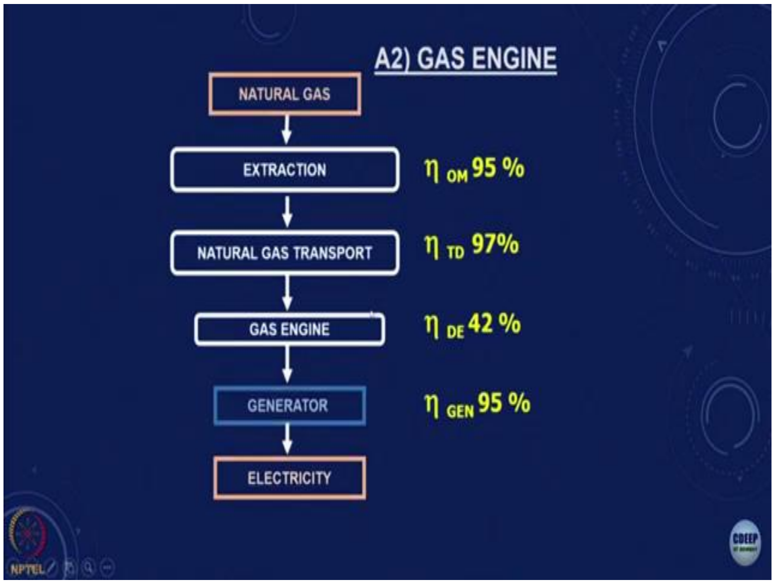

And the second option is when you look at natural gas, natural gas the same thing generator, you have a gas engine, then natural gas transport, natural gas extraction. Again, you can see the efficiencies are pretty good.

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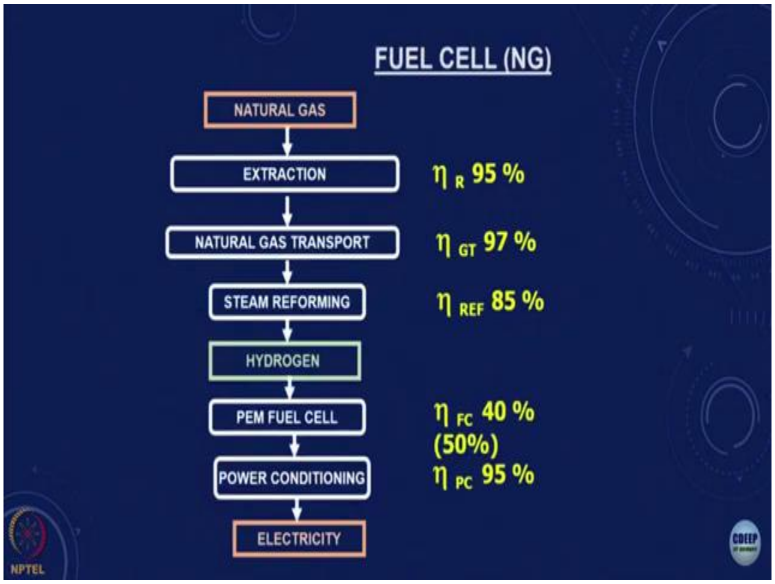

In the case of fuel cell, we now, let us look at natural gas giving us, the natural gas having the extraction then we have natural gas transport and then we are using that natural gas in steam methane reforming to get hydrogen, that hydrogen is used in a PEM fuel cell. Which can have efficiencies from 40 to 50 % and then you get electricity.

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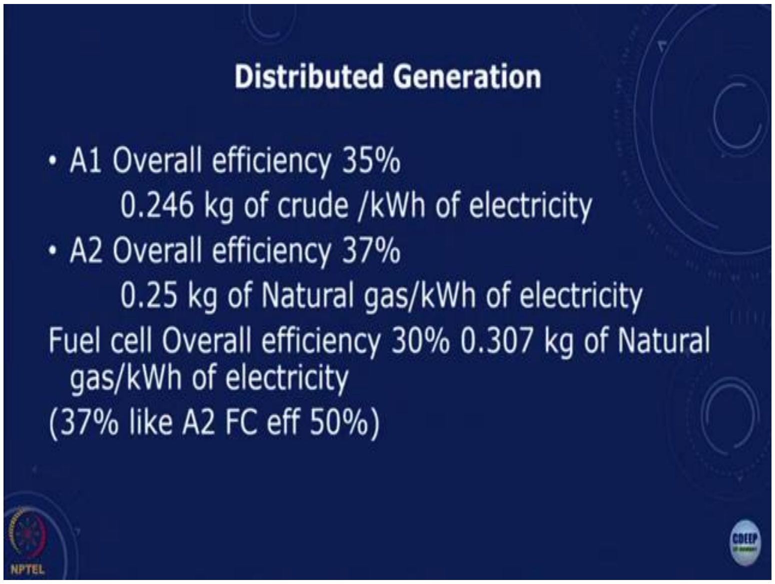

And we look at this, if you look at the distributed generation you find, that you can do these numbers, now convert it into primary energy. And you find that in the overall case, for the A1, which is based on oil, we are getting point, about 0.25 kgs of crude per kilo watt hour. Similar kinds of things for natural gas.

In the case of fuel cells, the overall efficiency is slightly lower and it is similar to the fuel cell. If you take an higher efficiency of fuel cell, of 50 % then it goes up to 37 %. So, it is very similar to the natural gas cycle, if we can go up to higher efficiencies. From an efficiency point of view, it is almost similar from a, when we are taking it from natural gas.

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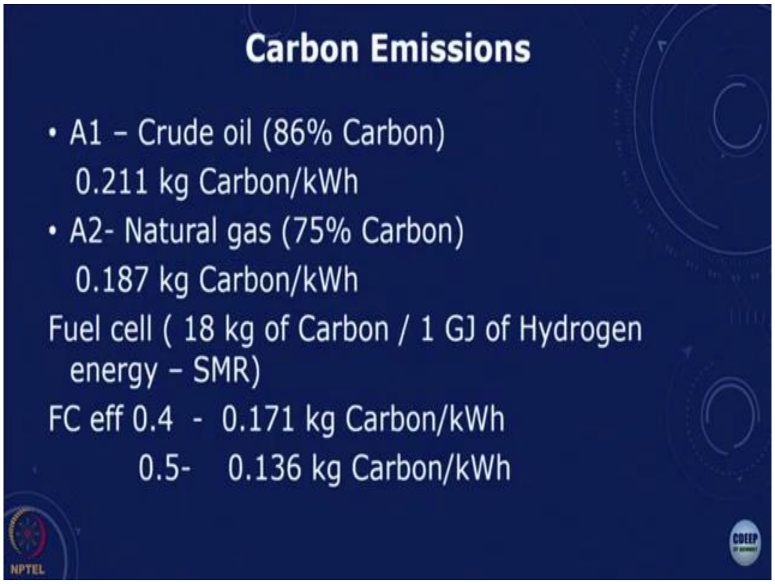

But the interesting thing is, from a carbon dioxide point of view, this turns out to be better and we can see that in the case of, with an efficiency of, 0.5, we are getting now 0.136 kg of carbon per kilo watt hour, as compared to 0.187 or 0.211 kgs of carbon, for crude oil or natural gas. So, from there is an incentive to go for, fuel cell hydrogen from a CO_2 point of view. And of course, if we get the hydrogen from renewable sources or from biomass, that would be even better incentive.

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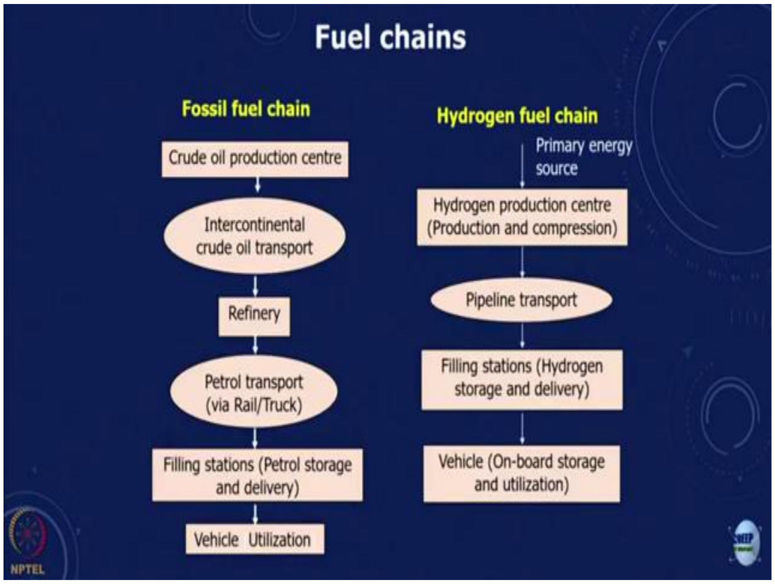

So, this is in terms of the distributed generation option. Now, let us look at the option for, hydrogen vehicles as compared to IC engine vehicle. So, if we look at the chain that we had, we have the vehicle, you have the petrol filling station, the petrol transport, the refinery, transport and crude oil production and that is the fossil fuel chain. Hydrogen chain will be vehicle, filling station hydrogen storage and delivery, the pipeline transport, hydrogen production centre and the primary energy source that we have.

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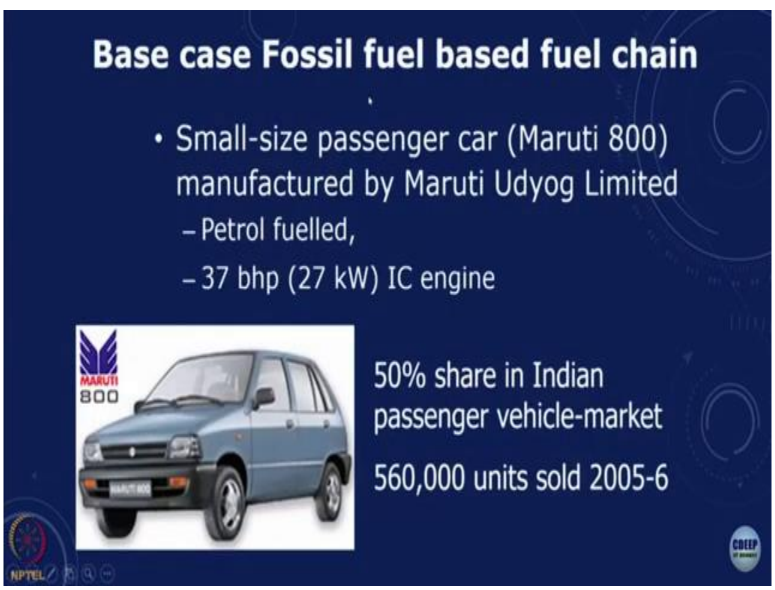

We will take an example, with a small vehicle, a small size passenger car, Maruti 800. Petrol fuelled 37 bhp – Break Horse Power, which is comes out to 27 kilowatt. This was the largest chunk of Indian passenger market in 2005, 2006. Today, that share would be lower because you have the other models. But just to give you for the example, this is an example, we had done some time back, you can make this as a basis.

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Now, when we calculate this, we have to calculate all on the same common basis. So, what we have to do is, we have to see how, what is the weight that we put on the vehicle because based on the weight that is there on the vehicle the power requirement will change and hence the fuel requirement will also change. So, the, we take the weight of the empty vehicle, the body excluding the engine and the tank and that for the 800 Maruti, 800 was five 550 kgs. Assume a certain number of weight of the passengers, that is 350, so that this becomes 900.

We have the coefficient of drag and the coefficient of rolling resistance, the frontal area and then we have to presume a certain amount of travel. We have done this calculation for a 100 kilometres of travel per day. Now, look at based on the amount of range or the amount of time that you have to, you can use before you refuel, we can decide what is the capacity of the tank. And I will give you a, I will upload a paper where you can see the details.

So, basically the petrol tank is, least in terms of weight because of the, it is 40 kg, CNG tank is 140 kgs and fuel cell turns out to be 130 kgs. And the engine 60 kg, 60 kgs and then this is 15, for the motors and 15, so that is 30. So, total if you see this is 160 kgs and CNG is about 200, here it is 100. So, that is the difference in weight.

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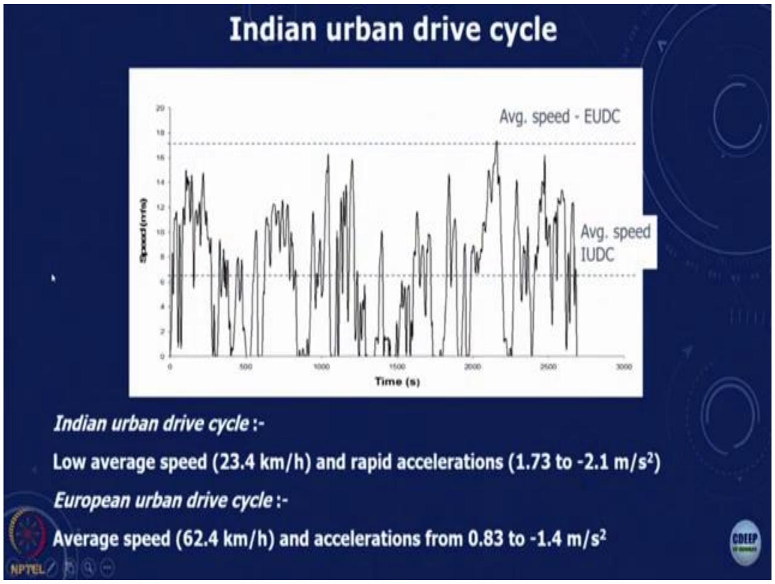

That difference in weight. So, what we do is, if you look at, different kinds of drive cycle and you can look at there is the, automobile research association of India, which does work on different kinds of automobiles. Drive cycle basically shows you the speed versus time trace typically.

And then there is, there are different drive cycles for highways and for urban. In the case of urban driving, mainly it is the road conditions and the traffic that limits and then so you have certain amounts of acceleration, deceleration. So, if you see as compared to the European drive cycle, Indian urban drive cycle has a lower average speed. Rapid accelerations as compared to 23.4 kilometres per hour, instead of 62.4.

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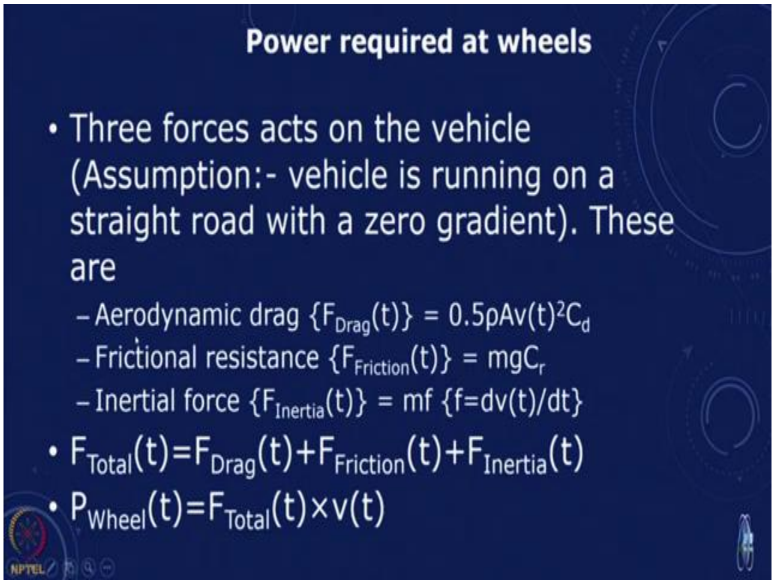

So, with this drive cycle, we then calculate. You can look at there is a freely downloadable software called advisor. You can put in the values over there, for choose your vehicle, vehicle characteristic and then we can, you can also just calculate it up front. By calculating the power required to overcome the drag, the frictional resistance and the inertial force and then this gives you the total and then you have the power at the wheel.

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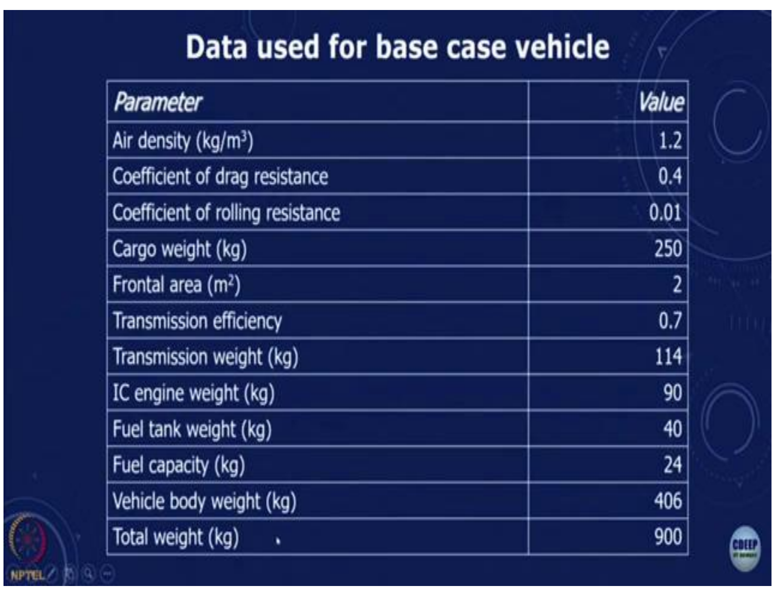

Parameter	Value
Air density (kg/m^3)	1.2
Coefficient of drag resistance	0.4
Coefficient of rolling resistance	0.01
Cargo weight (kg)	250
Frontal area (m^2)	2
Transmission efficiency	0.7
Transmission weight (kg)	114
IC engine weight (kg)	90
Fuel tank weight (kg)	40
Fuel capacity (kg)	24
Vehicle body weight (kg)	406
Total weight (kg)	900

And then these are the data that we use for the base case and we can, you can take a look at all of this.

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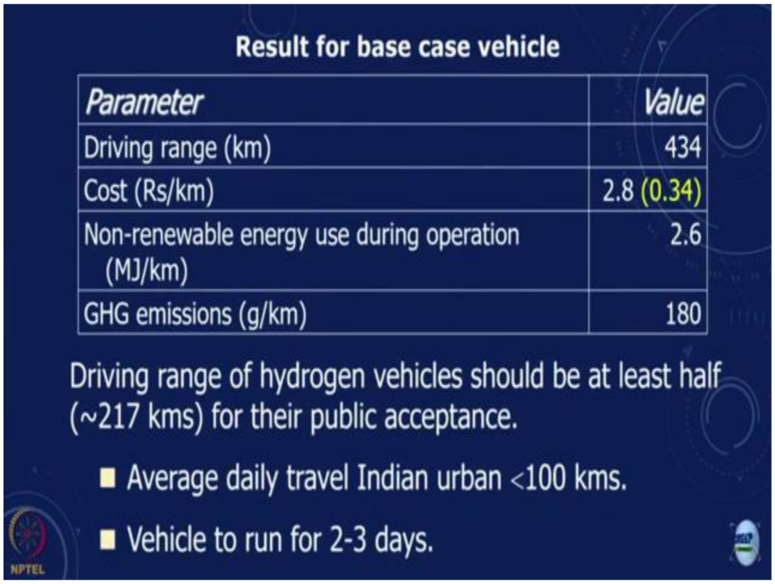

And then with we said, we have a driving range and then we got a cost in terms of rupees per kilometre.

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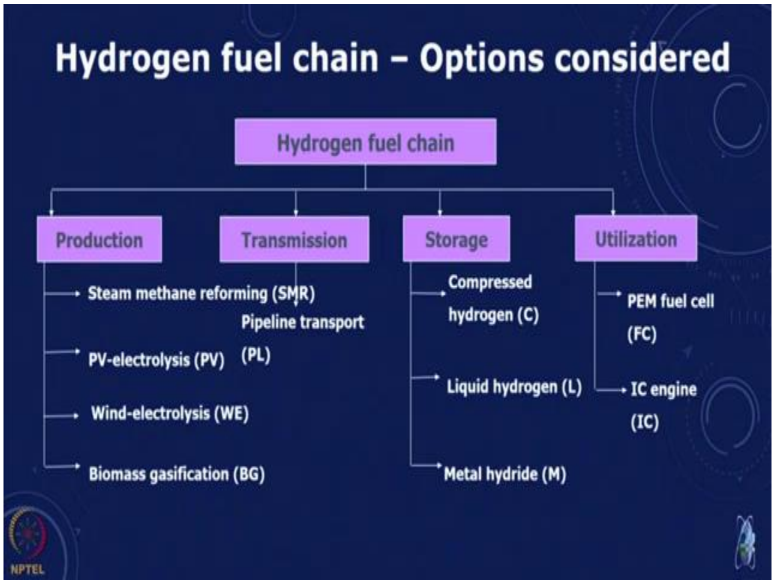

So, essentially with this what we can do also is we have to have not just the vehicle but we also look at the hydrogen fuel chain, then the production, production can be from different sources as we said PV electrolysis, wind electrolysis, biomass gasification, steam methane reforming. And then you have a transport which is the pipeline transport. Storage could be compressed hydrogen, liquid hydrogen, metal hydride and there is, this is an area of research and then the utilization which we are talking of is in the PEM fuel cell.

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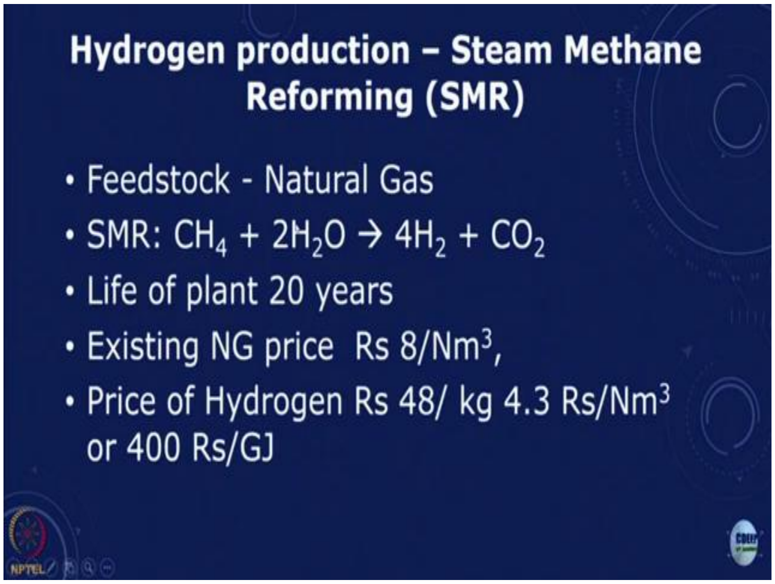

So, in the steam methane reforming, what we are looking at is, CH4 plus a 2H2O, giving you 4H2 plus CO_2 and then you can get a price of hydrogen, based on the price of coal.

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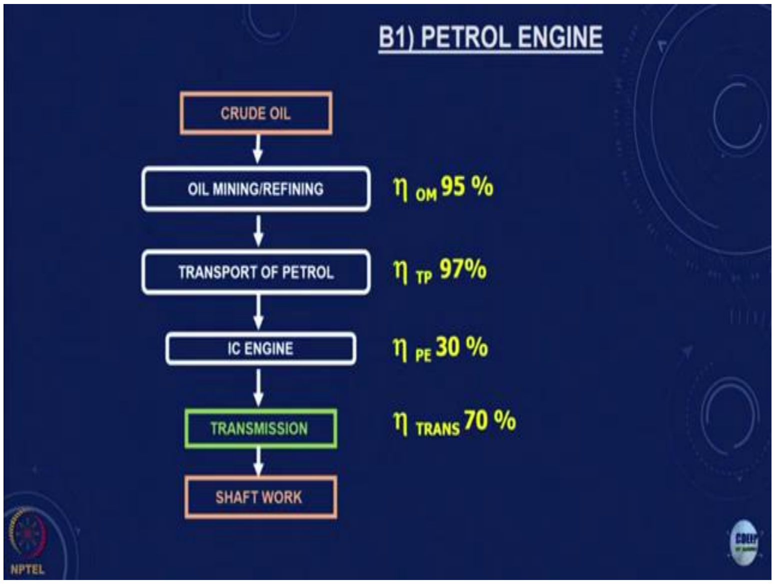

So, if we look at now the efficiencies, you can find them for the petrol engine, this is the transmission, the IC engine, transport of petrol and the oil mining.

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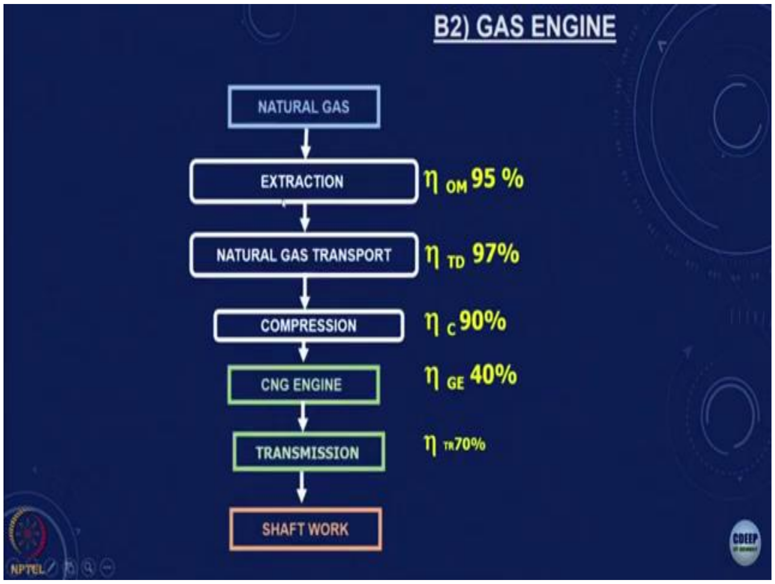

If we look at the gas engine, slightly different but almost similar order of magnitude.

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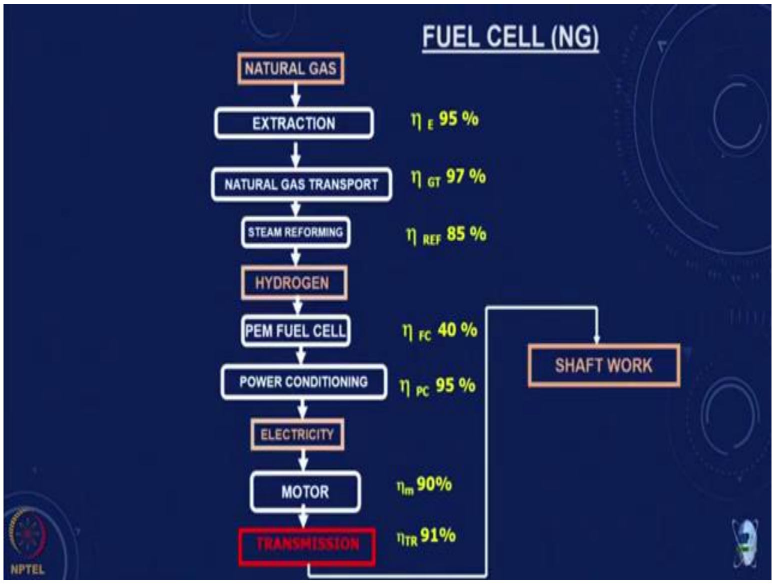

In the case of fuel cell. We look at the, in here, it is the fuel cell efficiency which is the determining factor. The motor and the transmission are highly efficient and overall this is the kind of efficiency.

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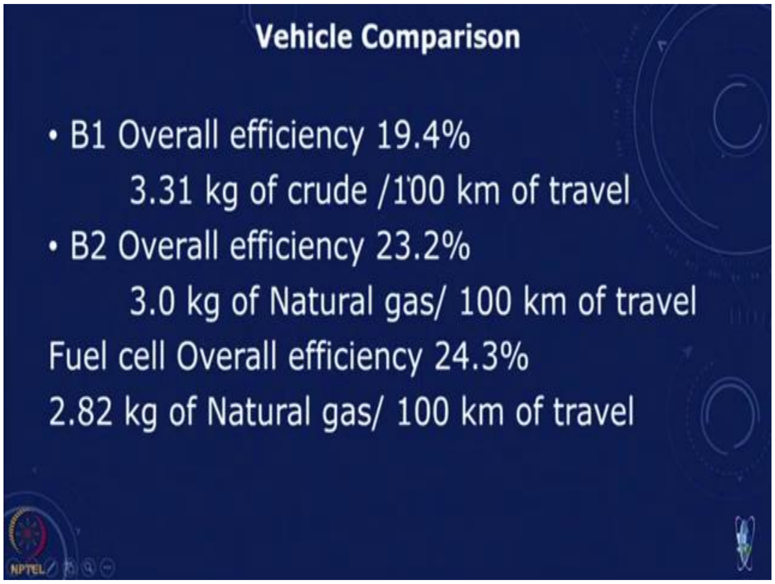

So, based on this you can multiply the numbers and cross check. You would find that the overall efficiency of the fuel cell is higher than this, that in both the cases. In the gas, gas engine, CNG it is almost similar and the interesting thing is there is an incentive in terms of efficiency. There is also an incentive in terms of the CO_2. I have not shown you these numbers, but you can cross check and you will see that the CO_2 emissions per 100 kilometre of travel, is lower and you can actually calculate this from the first principles.

We have in India, like in most parts of the world, we are looking at a transition, to electric vehicles and there is a policy where we would like to have much more of electric vehicles in our mix. Currently, of course electric vehicles are a very, very small almost negligible percentage of our mix. Now, when we talk about an electric vehicle and comparison of electric vehicles with the IC engine vehicle, whether it will result in a saving in CO_2 or not, will depend on what is the mix of our is electricity.

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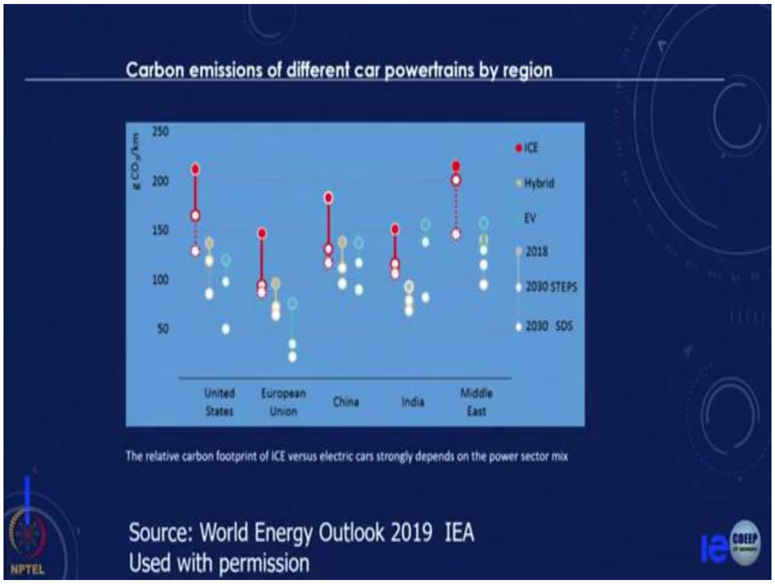

So, there is this interesting graph, which is from the world energy outlook of 2019, which talks about the gram CO_2 per kilometre of travel and it shows different countries. And this is the, value which you can see for India and you can see currently this value is, the IC engine is of the order of 150. And when we look at an electric vehicle, we are looking at something which is actually today it is higher than that and it depends on the of course the way in which you do the calculation. As the mix changes with this, this is going to be, so hybrid vehicle may be higher, the existing, this is the kind of difference that we can get.

As the mix changes with the sustainable scenario, the electric vehicle can be significantly lower. And so that is the, that is the kind of thinking but basically what happens is you can calculate that the relative carbon footprint of IC engine versus the cars will strongly depend on the power sector mix.

And so, because of that the trade-off that we are talking of, this is the IC engine, which will go through if we looking at the, hybrid, this is the kind of thing that we are looking at, and. So, depending on the calculations and depending on the type of mix, if our mix is completely going to be more coal. In some states, that it may actually, there may not be significant CO_2 savings.

However, of course local emission savings would be there and as our mix gets reduced, we can, the share of CO_2 in our electricity mix gets reduced. We can actually move towards something like this, much lower value and that is the kind of target that we are thinking of. So, just to summarize what we have looked at in this module is, how do we calculate and compare different routes from the primary energy viewpoint and we start by drawing the energy flow diagram, put down efficiencies and then compare them with primary energy. There are different, sometimes the two different sources are compared.

So, then we are comparing coal versus oil and then can also calculate the total CO_2 emissions over the chain. We can compare not just based on the energy, but then we can see, what is the relative scarcity and from an energy security point of view what is the trade of between these fuels. We will take this forward in the next module, where we will now go to the next step, where we talk about net energy analysis. And we will look at everything from an energy viewpoint. Thank you.