Energy Resources, Economics, and Sustainability

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Week – 02

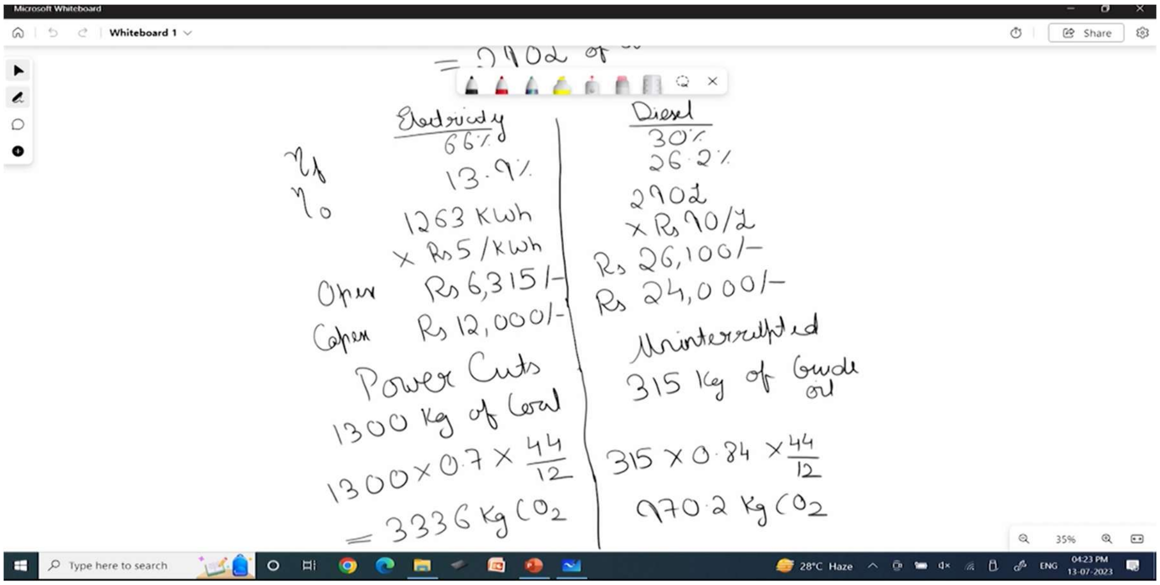
Lecture – 03

Lecture 08 - Energy Flow Diagram-II

Hello everyone. Welcome back to the course Energy Resources, Economics and Sustainability. We will continue with the last class where we have been studying the energy flow diagrams. In the energy flow diagrams, we try to estimate what is the primary energy consumption through the supply chain of different phases of energy conversion. There would be primary sources of energy like the crude oil, the coal extracted from mines or solar energy. They need to be converted into secondary energy in the terms of electricity or maybe heat. And finally, this needs to be turned into useful energy which could be motive energy or heating energy or other form of final energy consumption. And all these intermediate processes have their different efficiencies. So when we are comparing different energy options, both renewable and non-renewable, we also need to be mindful what is the efficiency of the complete supply chain in order to make the most economic as well as most environmentally prediction for the future which pathways has to be selected. In the last class, we have been discussing a very simple case of an electric pumping system or like water pumping system that could be driven by either diesel energy or electricity which is a grid-based electricity powered by coal-based power plant.

So let us try to just revisit that example. If we can go to the whiteboard. So this was the example that we were studying in the last class and we tried to analyse the two supply chains for the same end application which was pumping of water for field for irrigation.

And we tried to analyse the efficiency of the process from two points of view. One was the farmer's point of view and one was from the overall point of view.

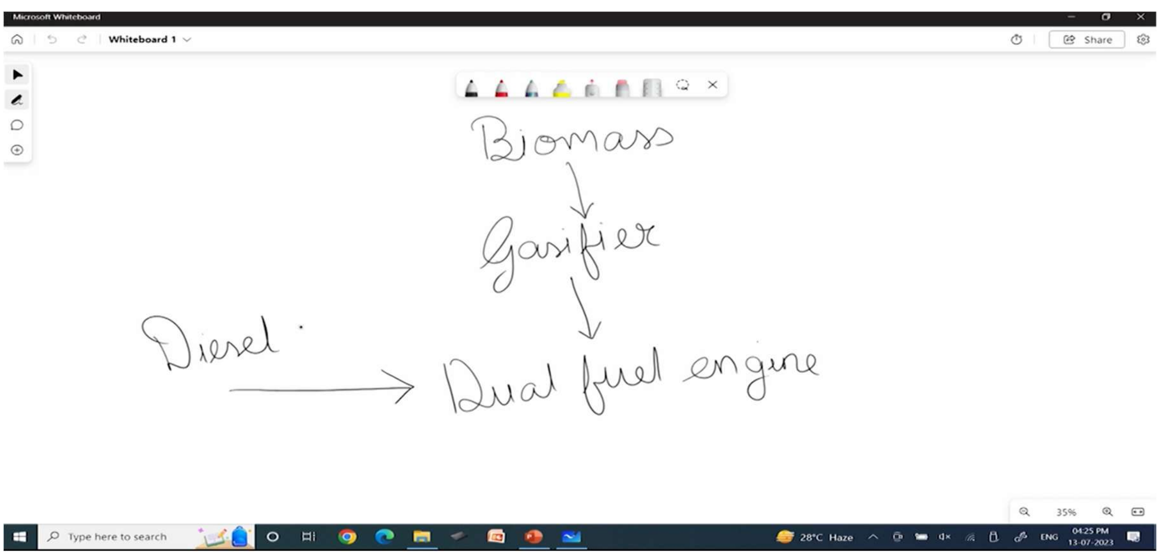


We found that a system that was based on electricity that was coming from grid and eventually coming from a coal-based power plant had an efficiency from a farmer's point of view that was pretty high, almost 66%. And a DG coupled with a pump had an efficiency of almost 30%. Whereas if I go towards the overall efficiency, it was the other way round. The diesel-based system was found to be much more efficient as compared to an electricity-based system. Plus we also tried to analyse what would be the operating cost and the capital cost for these two systems and it was found that electricity-based systems would come out to be more economical although they are not much efficient.

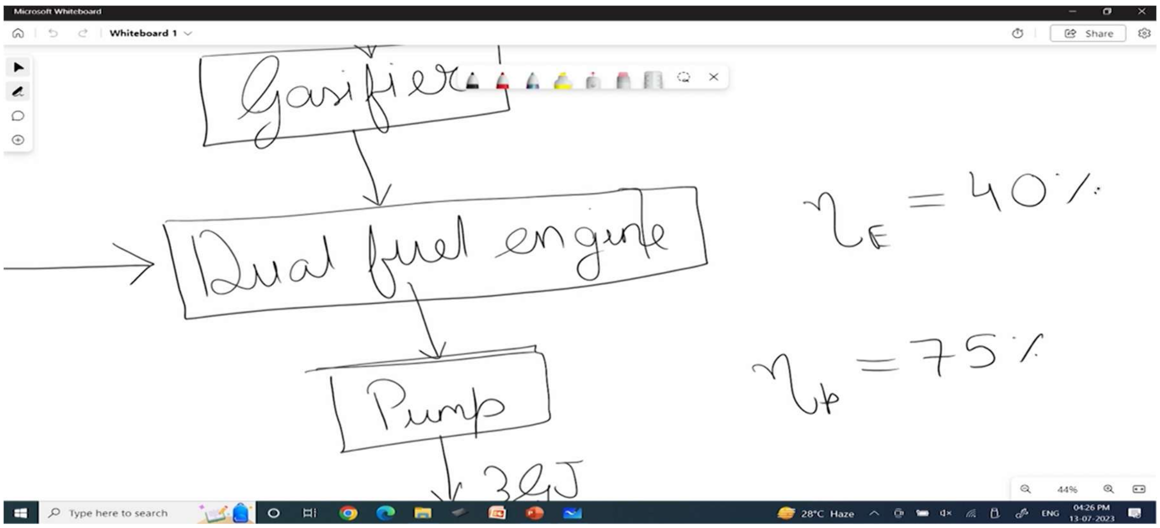
Further, the diesel-based system had the advantage of providing uninterrupted power or operation which was sort of missing in an electricity-based system which would depend on the grid. And finally we tried to see the CO2 footprint and for which we could predict that a system which was diesel-based would have almost one third of the carbon footprint as compared to that of an electricity-based system. So it depends upon like many parameters on which system you would want to go for. From an efficiency point of view diesel seems to be better. From a capital cost or the economics point of view of course electricity seems to be better.

From an operations point of view of course you would go for diesel. From environment point of view again you would go for diesel but from a country's perspective for a country like India which has huge amount of coal reserves we would want to propagate the use of electricity because the resource is inherently available. We do not need to depend on other countries upon the import of the raw material. So we had an understanding how like these kind of systems would have very complex choices at different levels. So let us take this very discussion further and try to see if there are other alternate options to this particular option which is providing in pumping for irrigation purposes.

Another option that has been proposed in the rural area specifically is like there is a good amount of availability of biomass in these areas. Biomass is any organic matter that could burn or that could be converted into useful energy. So it has been proposed one particular process like biomass gasification which is heating of biomass in an insufficient supply of air or an oxidizing agent. The result is primarily a gas that is rich in carbon monoxide and hydrogen that has a good heating value that could be used to run an engine and that could be coupled with the motor and the electric or the pump to for the extraction of water and irrigation of the field. So let us try to analyze another option which is used at quite a few places in India for irrigation purposes.

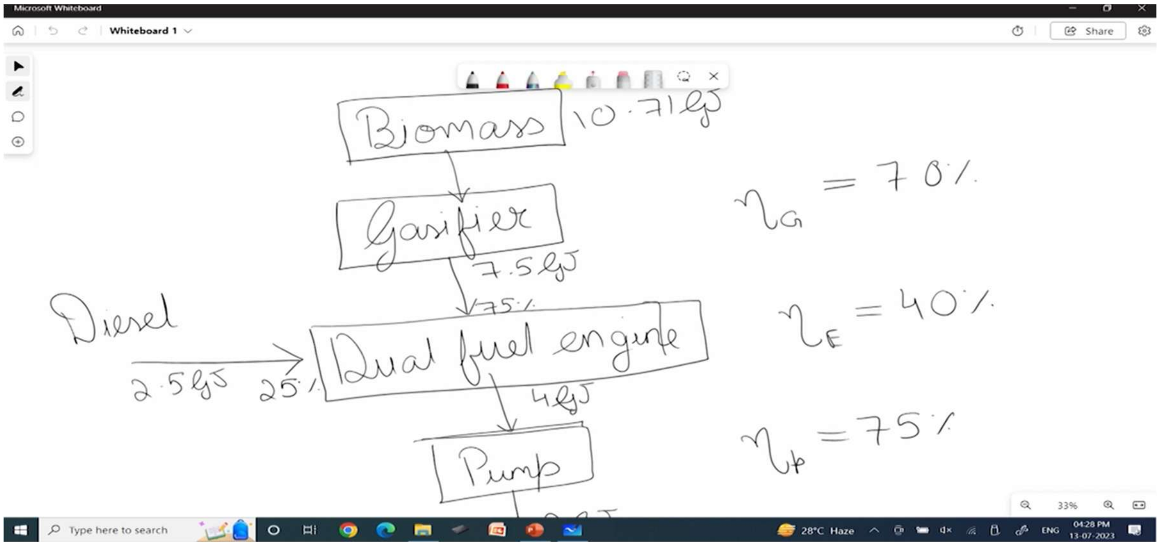


So in this case we would have the energy coming in from biomass and from the biomass we would have the biomass after its harvesting going to a gasifier. Gasifier is the equipment in which the process of gasification takes place. Beyond the gasification would be a dual fuel engine. So in many cases it has been found that the engine would not be primarily operated on the syngas that is produced from gasifier but it would have another intake and in this case significant of energy for this operation engine would also be coming from diesel which again would be coming from a supply chain as we have studied earlier. Now beyond this dual fuel engine we would have a pump and this pump we understand is expected to provide us 3 Gigajoules of energy as in the previous cases.

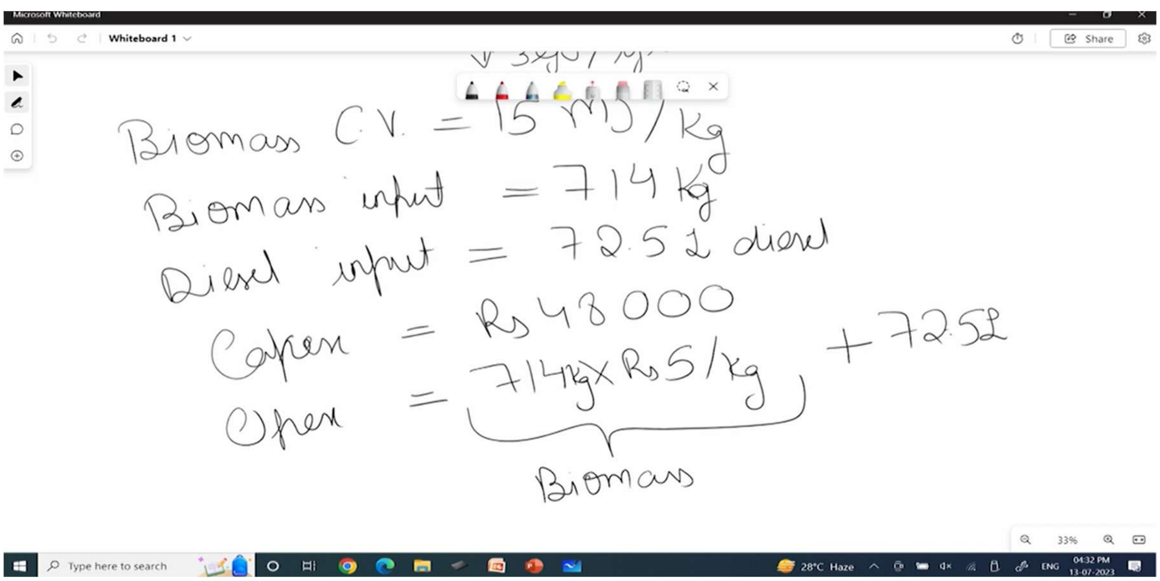


So of course all these processes would have different types of efficiencies which we will try to note down. So the typical pump that we studied had an efficiency eta pump of around 75%. And the dual fuel engine would have an efficiency of around 40%. So eta maybe would have an efficiency of 40%. A typical gasifier maybe eta g has an efficiency of roughly 70% and in this example I am not including the biomass collection, transportation and storage although this could be significant as well so I am overlooking those aspects.

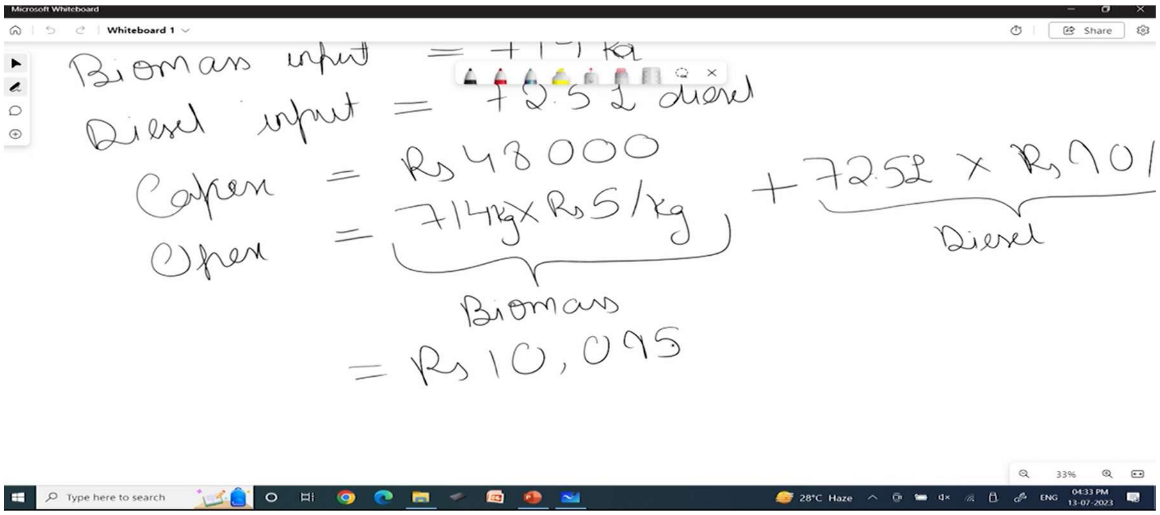
So if I go with the energy requirement so we have 3 Gigajoules in requirement given the efficiency of the pump we would require almost 4 Gigajoules of energy that would be produced by the dual fuel engine and this dual fuel engine almost 75% of the energy would be coming from the gasifier and another 25% would be coming from the diesel. So if this is producing 4 Gigajoules of energy this would require 10 Gigajoules of energy at the input given the efficiency of 40% so which means we would have 7.5 Gigajoules coming from the gasifier syngas and another 2.5 Gigajoul



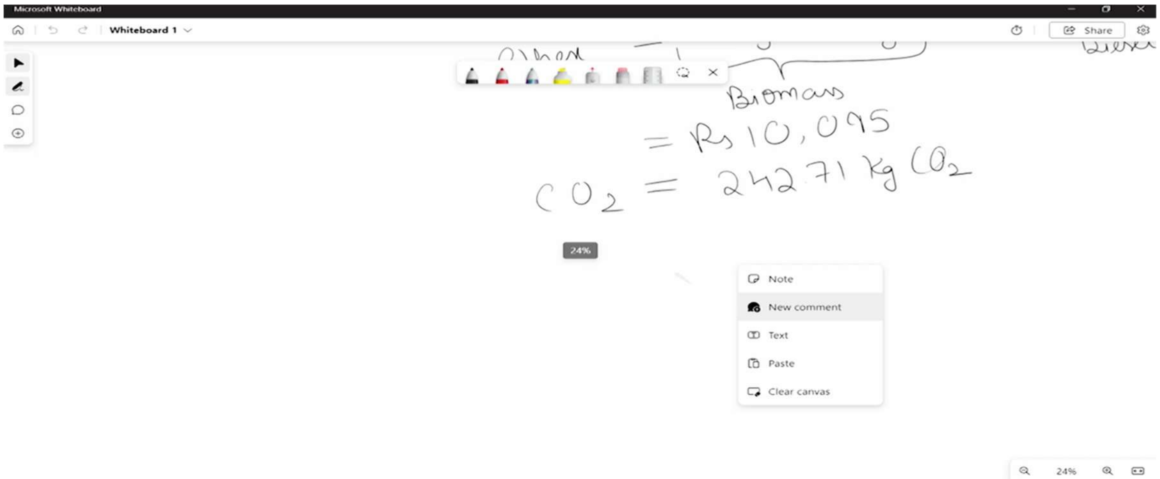
es coming from the diesel engine. And given the efficiency of gasifier of around 70% the input biomass should have calorific value of 10.71 Gigajoule. So again let me repeat we would have biomass of around having an input energy or calorific value of 10.71 Gigajoule that goes to gasifier and produces around 7.5 Gigajoules of energy in terms of the syngas calorific value this goes to a dual fuel engine which also has an input of diesel so the diesel input in this case would be around 2.5 Gigajoules together they produce around 4 Gigajoules of energy giving it to the pump and the pump at the output produces 3 Gigajoules of energy per annum so all these energies are on the basis of per year.



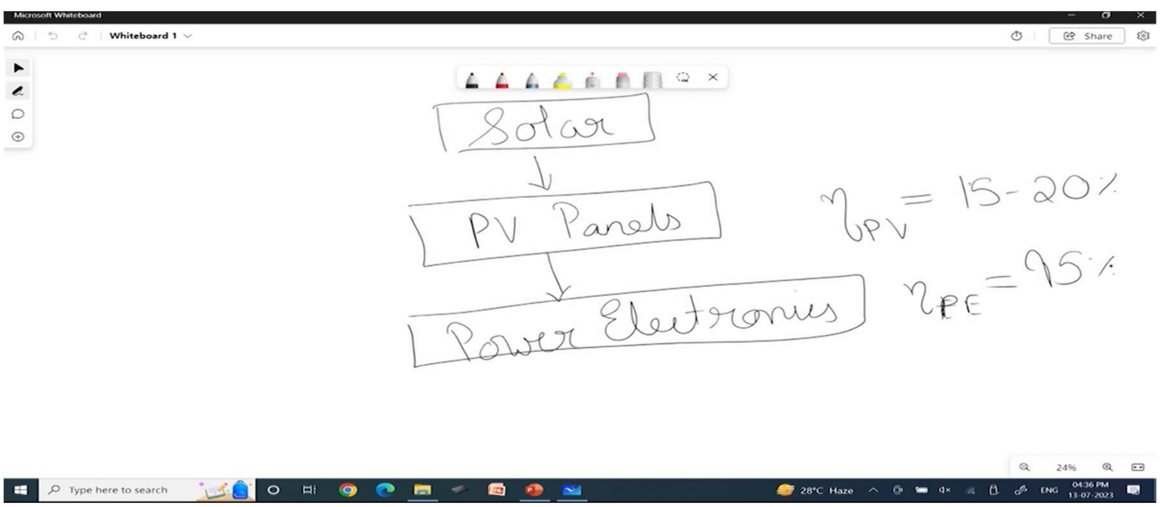
So let us try to assume that taking a normal biomass calorific value of 15 Mega Joules per kg of course this would be a function of the biomass that you choose I have taken a nominal value the biomass input that would be required would be roughly 714 so based upon a nominal biomass calorific value of around 15 Mega Joules per kg the biomass input that would be required would be around 714 kgs per year so this is with respect to the biomass input that would required and on the front of diesel taking the assumption similar to that in the previous case the diesel requirement would be roughly 72.5 liters.



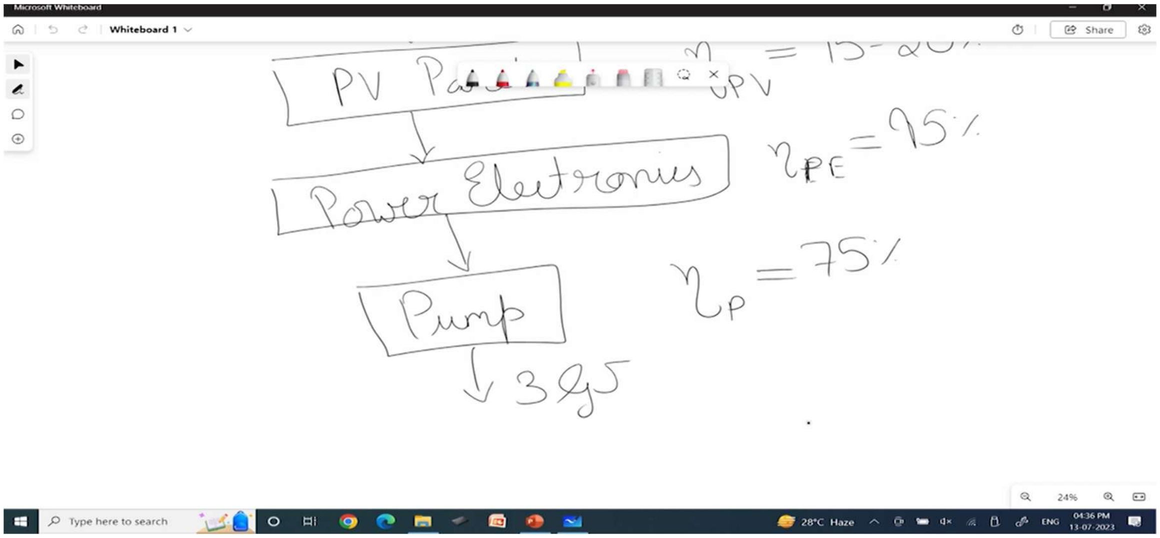
So compare that with around 290 liters in the earlier case and if the energy was to come from coal it was 1300 kgs of coal so we see that the amount has been reduced for diesel although it is not totally based upon a renewable source of energy but significant energy is coming from biomass in this case so if I would have to assume the capex in this case so the capex of a typical system like this would be roughly around 48000 or so so this seems to be on a higher level whereas if I go with the opex the opex would be almost 714 kgs of biomass and if I assume a typical value of 5 rupees per kg so this is 70 of kg and this particular thing is for biomass and I add it with the amount of diesel that is required so I am assuming 90 rupees a liter of diesel so we have 72.5 liters of diesel in here and I multiply that with rupees 90 per liter and this is the case of diesel I add the two and the value that I should be getting would be roughly 10,095 so this is somewhat higher as compared to the electricity but lower as compared to that of a diesel based system so in this case you again have the advantage of providing an uninterrupted power provided you have enough stock of biomass available with you so the capex is slightly or more end but opex seems to be somewhere in the middle plus we can also go towards the co2 emission and like it depends how would you account for the co2 that is being emitted because of a biomass based system this is something that is of a complex nature and we'll be discussing that in the future classes but for this particular example let me assume that this biomass based system the co2 that emits because of the consumption of this energy would not have any carbon footprint. The reason would be because the biomass during its growth would undergo the photosynthesis process and would intake the co2 so in short the cycle is completed and like the co2 that we are emitting would be taken again by the growth of biomass in the near future.



So the co2 in this case is primarily coming from the consumption of diesel which would be roughly around 242.71 kgs of co2 so compare that with the earlier cases so if I go to the earlier two cases we found that the electricity based system has around 3300 kgs of co2 and 970 kgs of co2 for diesel based system so even that has been reduced significantly if you go towards the biomass based system. Then there could be another option wherein which is becoming a lot popular nowadays which is a solar based system so let us quickly go through that type of system as well.

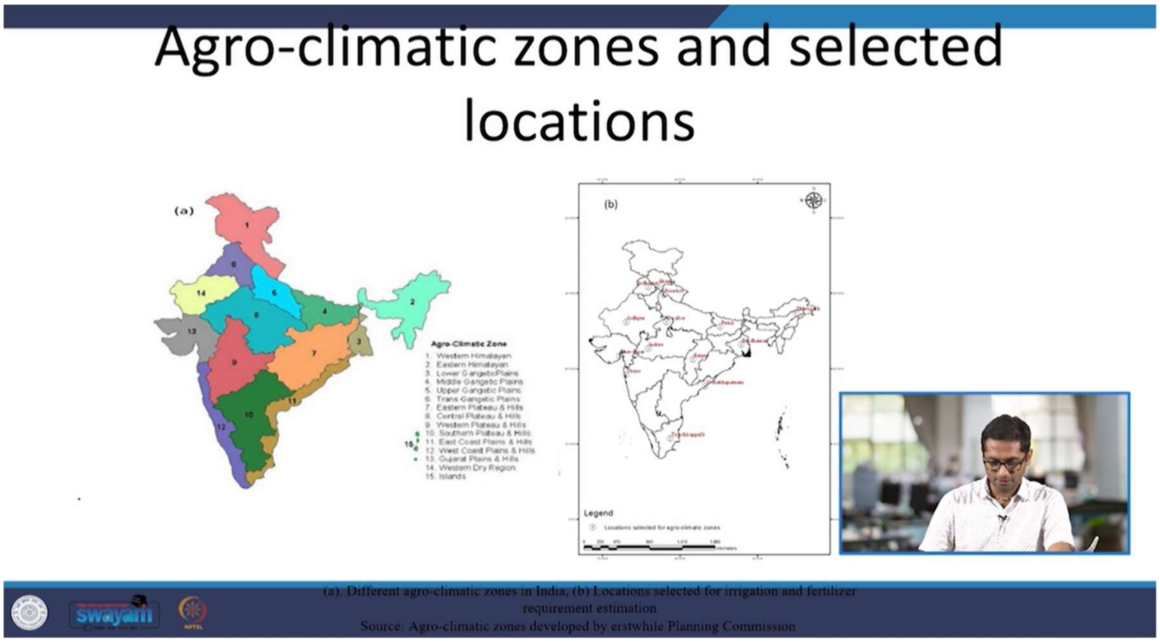


So a solar based system would have the solar radiation coming in then there would be the PV panels so we have the solar irradiance coming in the PV panels coming in and normally the efficiency for PV panels range between 15 to 20 percent it could go slightly higher for the new ones as well then you would have the power electronics coming into play as well.



So normally these kinds of systems are quite efficient and in terms of the power electronics sorry the efficiency would be roughly 95 percent and finally this would be coupled to a pump and the efficiency of the pump would be around 75 percent and finally we would have 3 gigajoules of energy coming at the output. Now these kinds of analysis might not make much of a sense if you are dealing with a system which is based on solar power because inherently the input is unlimited and freely available in the form of solar irradiance although there are variations during the day and the night times and even the monthly variations are there but the input as such or the primary energy solar is freely available. So this kind of analysis might not make sense if you are comparing them with fossil fuel sources of energy and but anyway we can get an analysis how efficient the system is.

If you can go to the slides so I just wanted to give you a feel like this is what a gasifier looks like in reality so this is one of the gasifiers that we have in the lab so you would have the feeding taking place from the top this is the biomass getting fed and the gas is being produced and then this gas is going to an engine for production of electricity but it could also be linked to a pump for the pumping power.

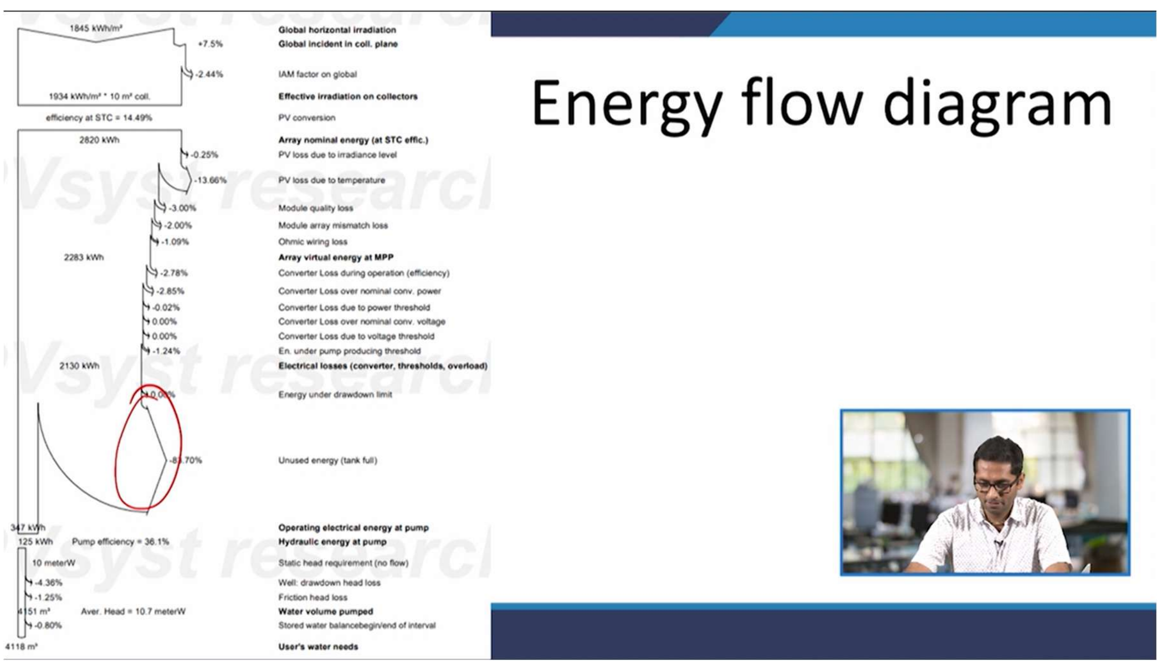


In the case of a solar based irrigation systems we did an analysis where we tried to compare the solar systems based systems for different agro climatic zones in India. So India is a very diverse country we have different crops being growing and these all crops would have very different irrigation requirement. Further the solar irradiance or changes quite drastically throughout the country and in another addition would be the water table. The water table could be very different in different parts of the world. So we did an analysis where we chose a particular district to represent an agro climatic zone and we did solar PV analysis for the pumping applications for those selected cities or those particular districts and there were total of 14 districts in total we did like what would be the water requirement given the primary crops that are being planted there.

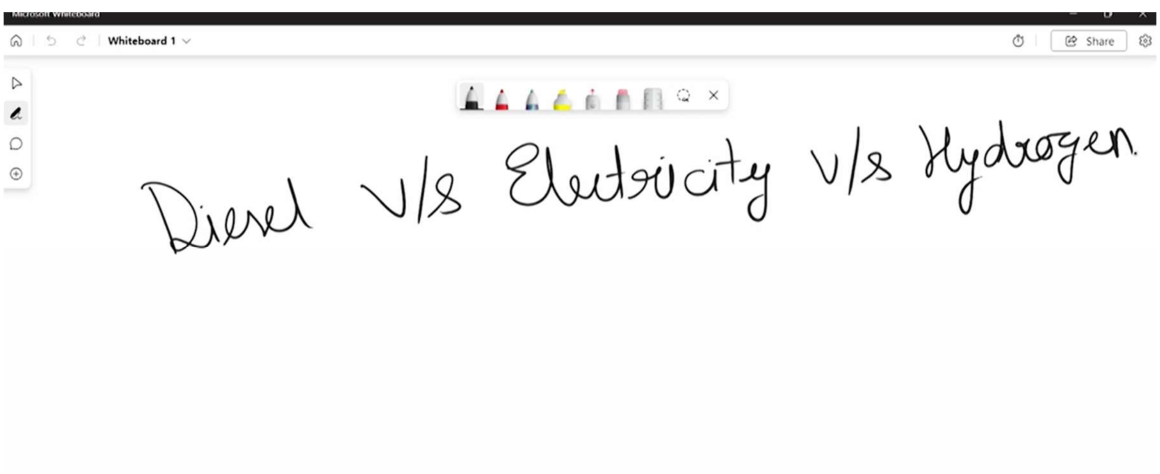
Zone wise irrigation and pumping requirement with module rating

Zone	Total water pumped (m^3)	Effective global irradiance (kWh/m^2)	Nominal power (Wp)	Energy for pumping (kWh)
Zone I	1309	1729	100*9	204
Zone II	3357	1393.6	100*15	185
Zone III	6054	1606.5	220*10	752
Zone IV	4934	1567.3	100*16	345
Zone Va	7923	1672.7	430*16	1424
Zone Vb	5572	1691.9	430*3	695
Zone VI	7684	1579.3	200*24	1064
Zone VII	4843	1815.5	220*12	392
Zone VIII	5667	1756.2	220*8	567
Zone IX	4474	1856.6	200*6	484
Zone X	5656	1757.0	200*6	577
Zone XI	4717	1779.3	180*14	519
Zone XII	3147	1879.7	200*6	189
Zone XIII	4151	1934.5	140*10	347
Zone XIV	2141	2049.1	200*14	555

What is the irradiance the average irradiance throughout the year? What would be the power that would be required given the depth of the water table and we found that there could be a huge variation like you can see the variation could be almost 10 times so in zone 2 it could be a pumping power of 185 kilowatt it can go as high as 1424 kilowatt hour for another location. So these are other nuances that occur in a system that is primarily renewable based there could be huge variation that is happening and also in this kind of system there could be again many different kinds of efficiency and this could be inherent for any case.

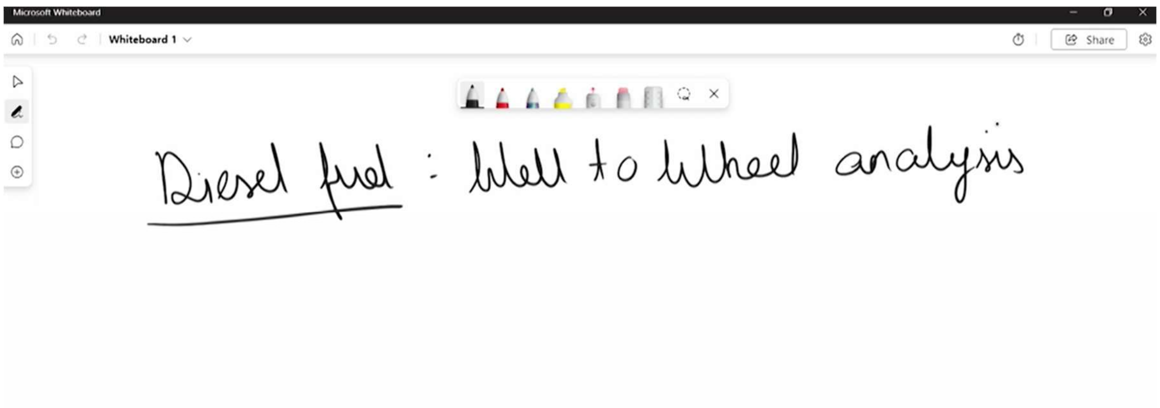


So I am just giving an option so these simulations were done in a professional software by the name PVsyst and in that we did this analysis and you can see what are the losses that take place of course we are doing an analysis like this but we cannot take into account all these losses so for this we need software like PVsyst or other similar software and one important thing to note down here is like when we go for a system like PV a solar based system there could be huge amount of unused energy that is produced as well because the system is going to produce energy whether you are using it for irrigation or not. So irrigation as a requirement would be only needed maybe thrice or four times in a year in the span of one or few months what happens to the system in the remaining time it will keep on producing electricity and what do you do with that you give it back to the grid or not so many of the cases these systems are over designed and also there is a trade off between like whether you go for a bigger pumping capacity or a bigger solar pump or bigger storage capacity. So there is a nice trade off that could be explored is that like whether you would go for a bigger pump and a PV panel so that they can pump at a faster rate and but a smaller storage or the other cases you can reduce the size and increase the size of the storage so that could be efficiently utilized later on. So with this we have been discussing some of the cases for a typical example. Now let us also discuss a similar example with respect to the different kinds of fuels that are propagated in the market.

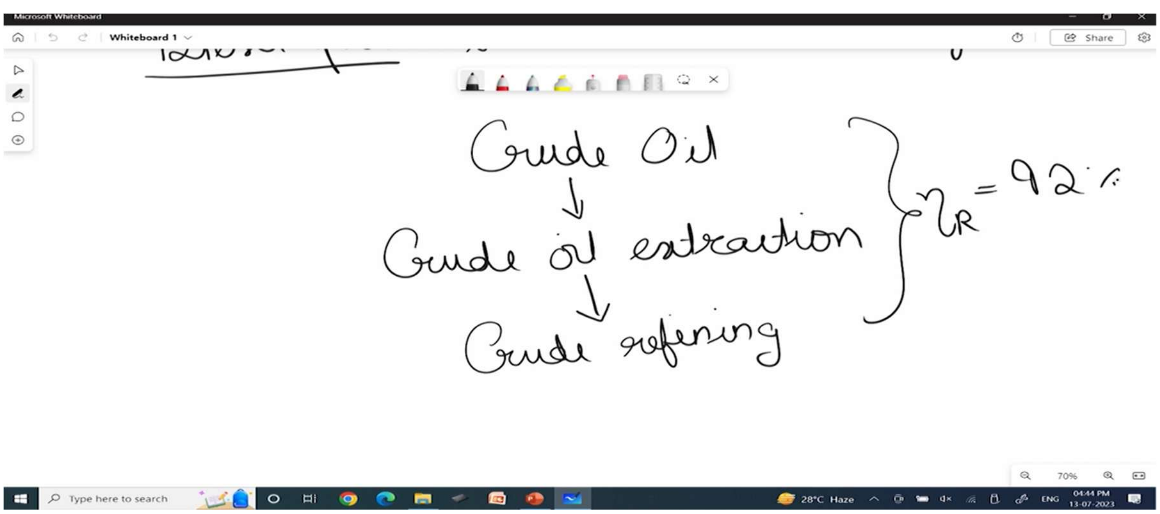


So if we can go back to the whiteboard so lately we have been seeing there is a lot of interest upon EVs, hydrogen fuel cell vehicles and similar kind of variations for the different transportation pathways. So let us try to do a similar kind of analysis for the different kinds of vehicular options that are available and try to analyze how do they compare among themselves. So this is again to deepen our understanding of the energy flow diagrams.

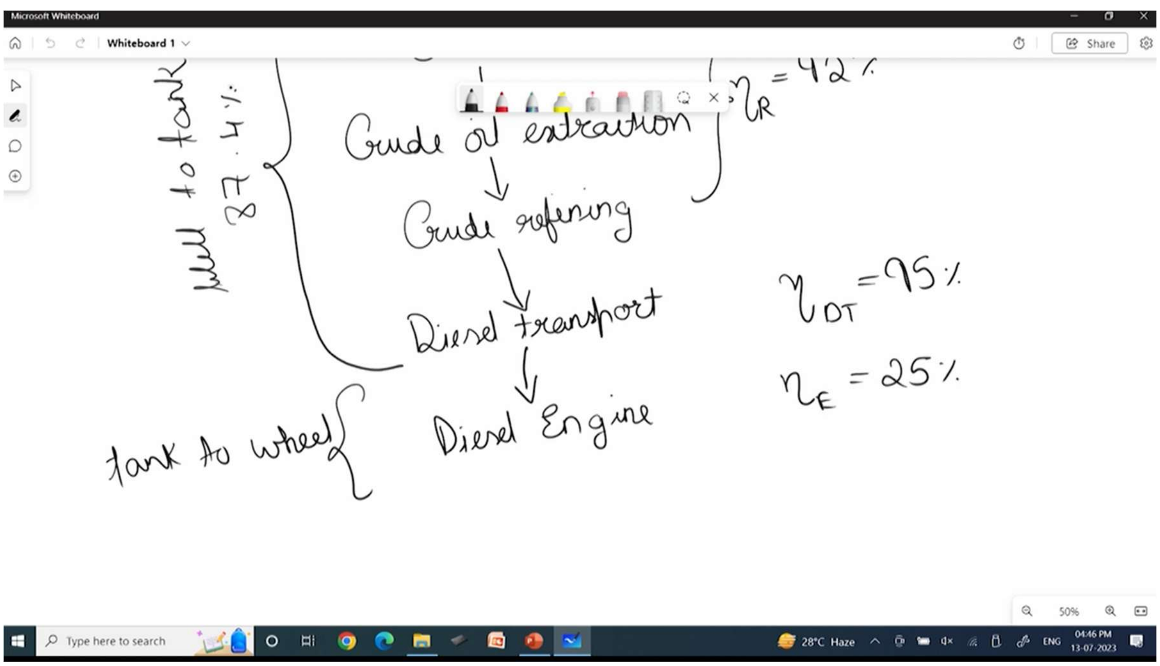
So we are going towards a new example where we are going to compare basically 3 different options it will be diesel versus electricity versus hydrogen. So the data that I would be presenting here is coming by a study that was done by IOCL and of course the results would depend upon the assumptions that are taken into place but still it will give us some meaningful understanding of the different supply chain that is available for different fuels in the transportation sector.



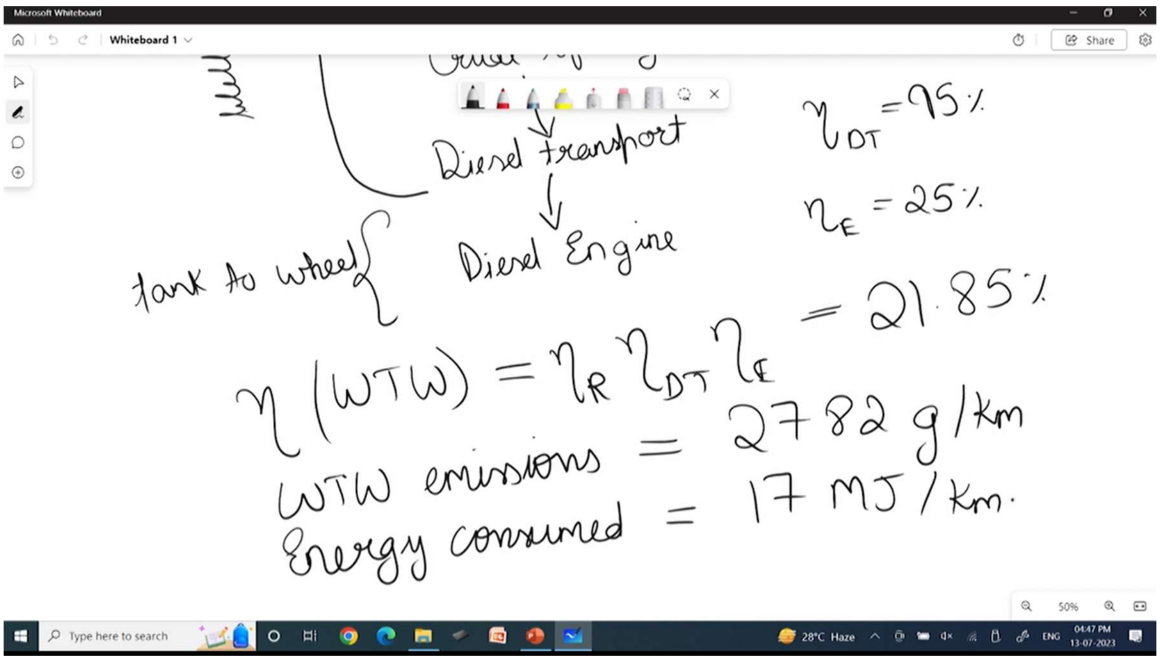
So first let us begin by the diesel fuel and we will go with the diesel fuel and what we will do is a well to wheel analysis. So when I say well to wheel analysis it means I start all the efficiencies all the emissions that start from the extraction of oil from the well and end up in the tail pipe of the vehicle. There could be other analysis that you come across that could be well to tank which means they start at the extraction of the raw material the crude or coal for electricity and end up at the filling station that is the tank.



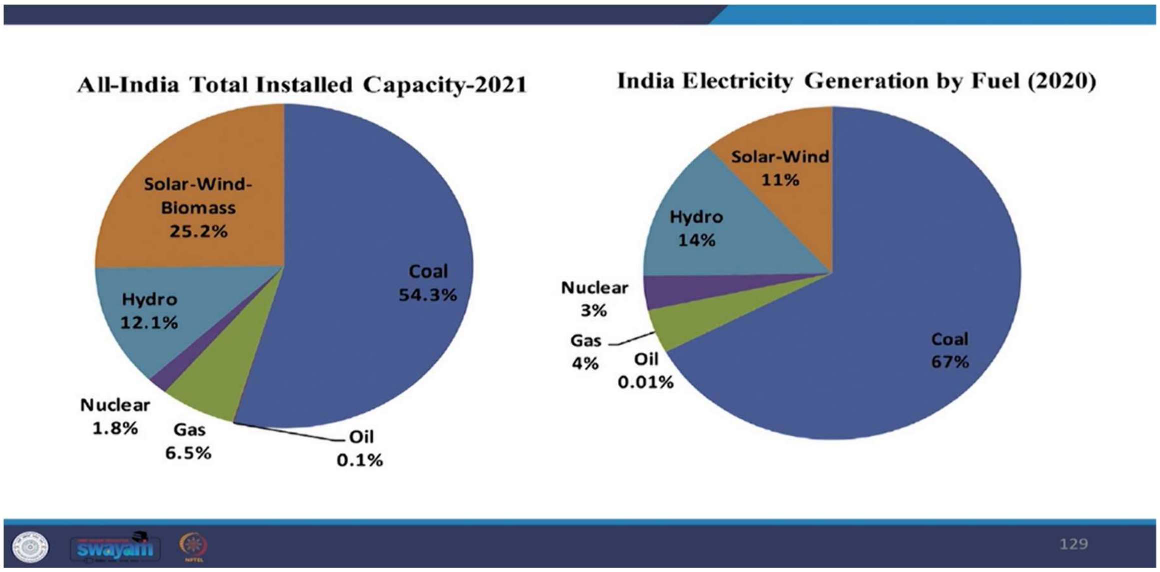
They are not concerned about the emission that happen after during the running or the combustion of fuel for the running of the vehicle. Further there could be another analysis that could be tank to wheel so that starts at the fueling station they are more concerned about what are the tail pipe emissions of a particular vehicle which could be the least for an EV because there is hardly any emission by the burning of or the using of electricity in the tail pipe. So let us start with the diesel fuel so we start with the crude oil and that is available this needs to be extracted and this and then it needs to be refined as well. The overall efficiency for these three processes eta r, I am assuming to be around 92% then the crude after refining would be producing the diesel fuel and then this diesel would have to be transported to the filling station and this transportation would have efficiency of 95% and finally this ends up in the diesel engine in a typical car or four wheeler where this would have an efficiency of around 25%. So if I see in the supply chain this is how it would look like so in this case the steps that is still the diesel transportation would be called well to tank and this particular step in the engine would be tank to wheel and the total analysis would be called well to wheel.



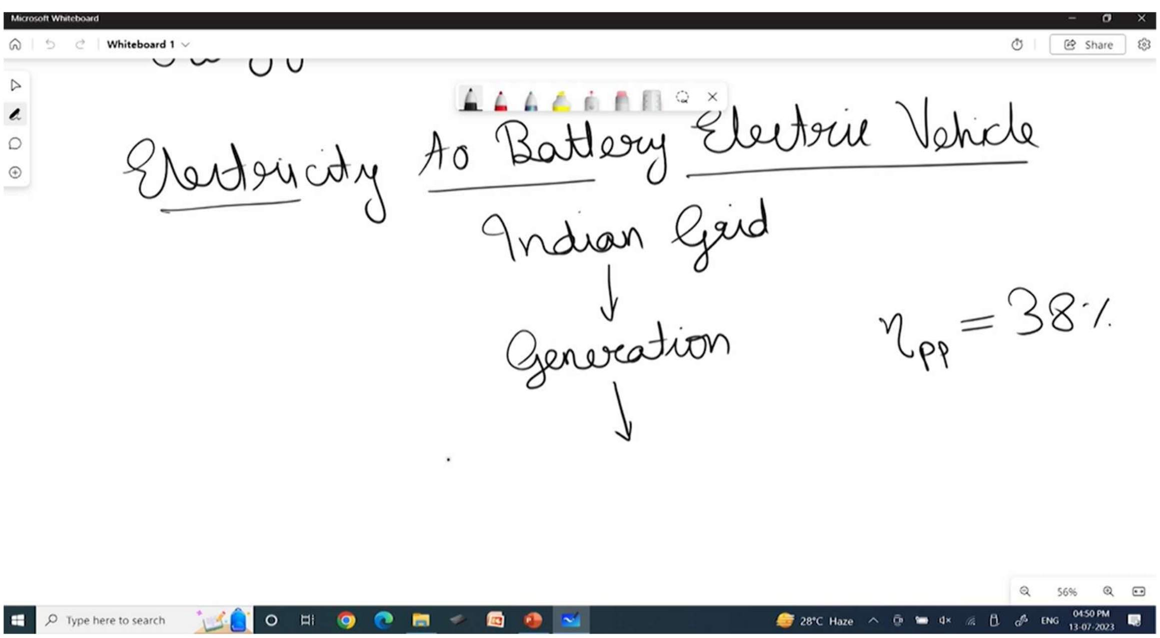
So if you multiply the individual efficiencies in here the total efficiency from well to tank would come around to be 87.4% which is quite efficient and then the tank to wheel efficiency would be roughly 25% and if you see the total efficiency which is well to wheel this would be the multiplication of eta refinery, eta transportation and eta engine multiply the three and the total efficiency of a diesel engine used for transportation purposes would be roughly 21.85%. You can also analyze the emissions the well to wheel emissions I am not going into the intricacies of this have been reported to be around 27.82 grams per kilometer. So here the units have been changed for per normalized for per kilometer of the vehicle travelled and if I go with the energy consumed this energy consumed would be roughly 17 mega joules per kilometer travelled. So this is the case for a normal diesel fueled vehicle.



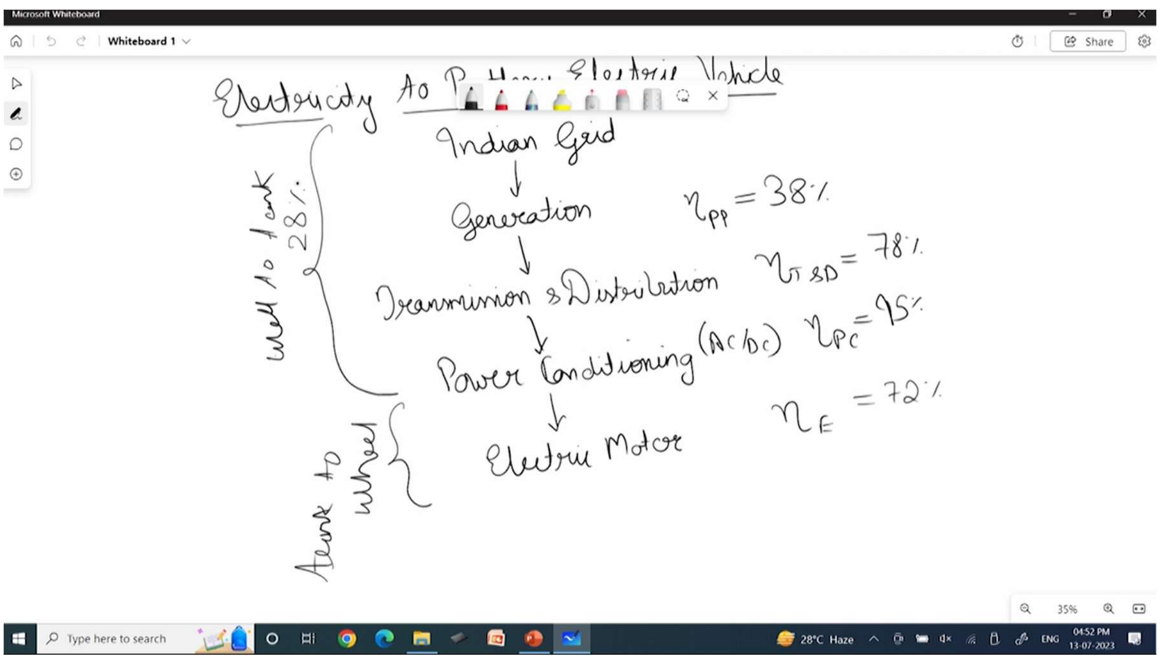
Now let us go towards the analysis of vehicle fuel which is much into the picture the electricity. So we will be assuming a battery electric vehicle with the primary source or the only source of power in that vehicle would be electricity. So we will go with electricity to electric vehicle. So in this case we would assume that the electricity is coming from the Indian grid. Now Indian grid is a function of different types of electricity if you can go back to the slides. So this is on the typical installed and the generation capacity of the Indian grid. If we go with the installed capacity we see like almost 50% or so is coming from coal and then a significant coming from solar, wind and biomass 12% from hydro. So if we look at the installed capacity it seems to look like a significant part of our installed capacity more than almost like 35% is coming from renewables but if we go with the generation capacity it's not very similar.



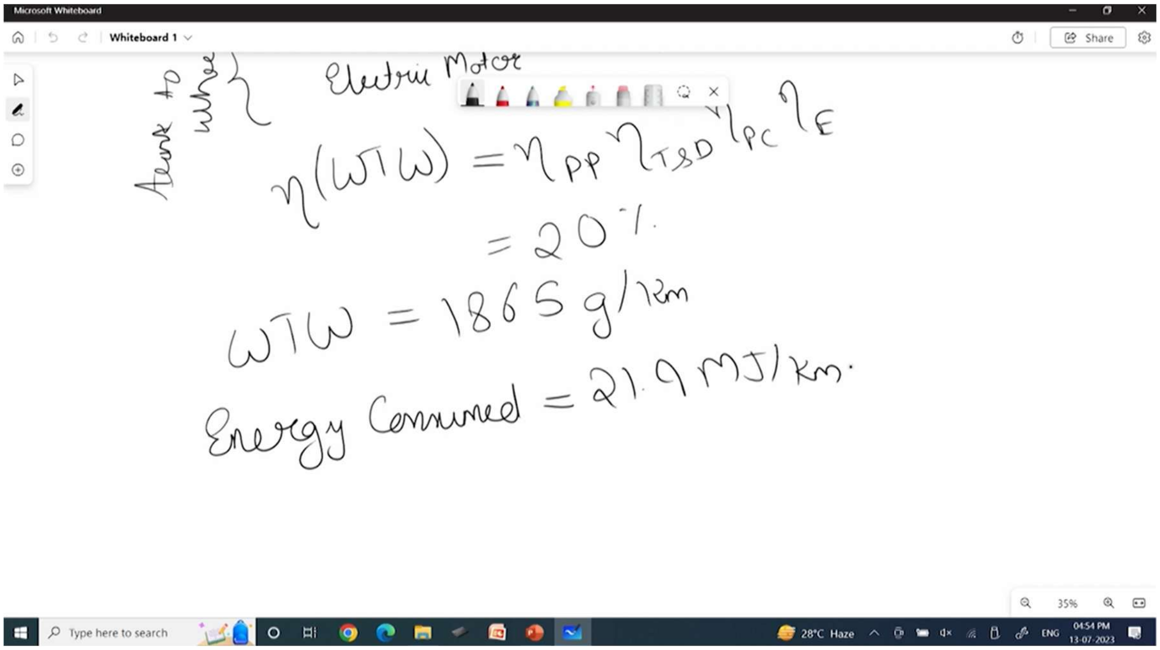
Almost 67% of the electricity is coming from coal and then around ,4% from gas, 3% from nuclear and roughly around 25% is coming from other sources which come in the bracket of renewable sources of energy. The reason being like sources like solar and wind are available only during the daytime and during the peaking hours we would have to shift towards sources of energy which are much more flexible in terms of coal and oil or natural gas. So if we assume that the electricity is produced by a mix that is shown in this figure that is the assumption that has been taken so this is quite different from the assumption that we have taken in the earlier case. Can we go back to the whiteboard?



So the Indian grid would have the electricity generation and this generation would have been taking place in a power plant and for this efficiency I am assuming to be 38%. I have increased the efficiency in here because like we would have gas fired power plants and other power plants which could have slightly higher efficiencies. Then would be the transmission and distribution and this transmission and distribution would have an efficiency of around 78%, so Indian grid has a lot of losses that take place and it is not very efficient as such. And then there would be a power conditioning unit which would be basically conversion of the AC power into the DC power for running of the electric motor and this would be pretty efficient at around 95%. And finally we would have the electric motor which would be running the car and this would typically have an efficiency of 72% so looks to be very efficient and also you would have heard at many places that the efficiency of an electric powered car or EV is significantly higher than that of an IC engine vehicle and that is one of the reasons that you should be switching from an IC engine to an EV.

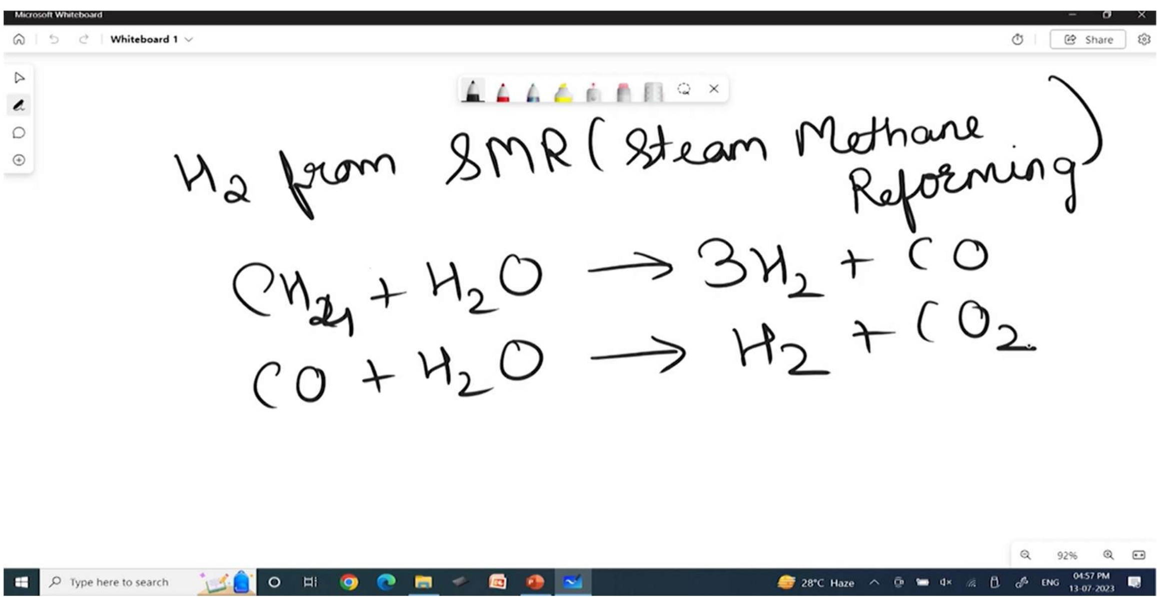


So of course if you take at the car level we see a significant rise in the efficiency so a typical diesel engine has an efficiency of 25% whereas an electric motor could have an efficiency of 70% or more. But let us also try to analyze from the complete supply chain as well so again we would have in here the well to tank and the tank to wheel so this is the well to tank and the tank to wheel coming in here you multiply the efficiencies and the well to tank efficiency would come out to be 28% compare that with the efficiency for the earlier case which was around 87% or so.

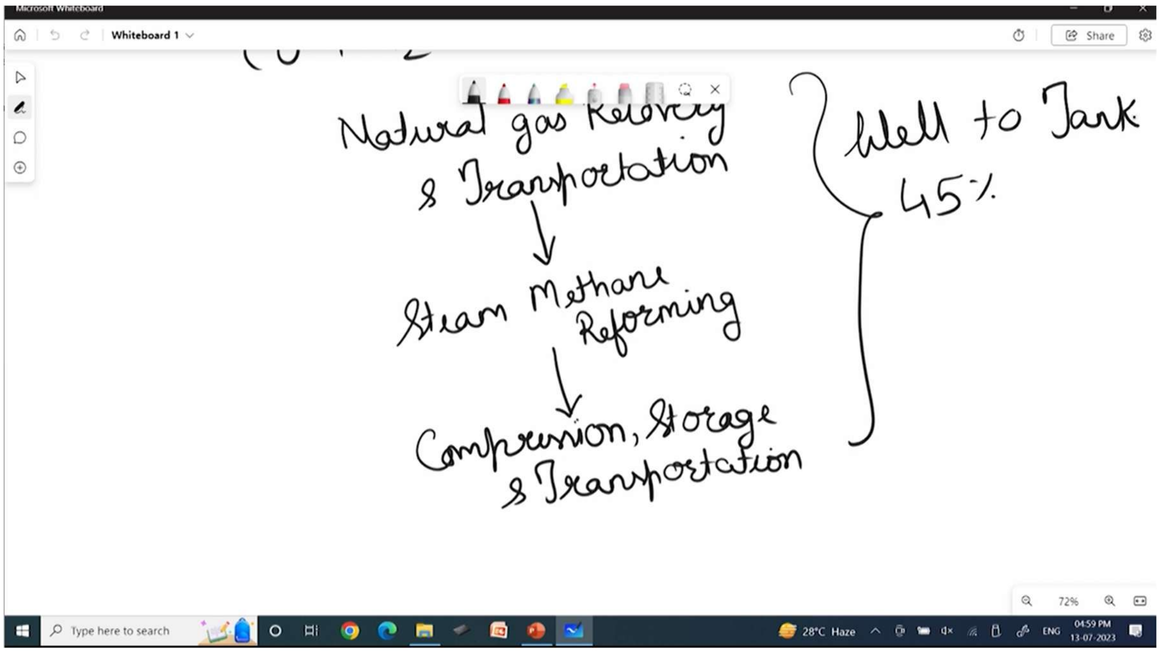


You multiply this 28% with the tank to wheel efficiency or get the final overall efficiency eta may be well to wheel and this would come around to be like you multiply all the things power plant eta transmission and distribution, eta power conditioning, eta engine you multiply the four things and the efficiency would be roughly 20%. So you see that both the supply chains have almost similar efficiencies diesel engine giving you 1% advantage but like given over the assumptions they would come out end up to be very similar in terms of the overall efficiency. If I talk about the well to wheel emissions for an EV they could be around 1865 grams per kilometer so this would be around 30% reduction from what have been reported for an IC diesel based system but again this would depend upon the assumptions so in this case I am considering a conventional grid but even in the grid like if you see the northern part or the southern part of India they could have very different emissions so based upon how this electricity is produced this number could be highly variable and if I go towards the energy consumed the energy consumed would be around 21.9 mega joule per kilometer so this is on a higher side as compared to a diesel based system. So we try to understand that in this case there could be a significant difference even in terms of the energy that is consumed in a car on the basis if you are considering a well to tank or a tank to wheel analysis.

So another option towards travel could be the use of a hydrogen based vehicle which is gaining a lot of prominence nowadays like India is putting a lot of emphasis on moving towards a hydrogen economy and while only India like all the major economies of the world are moving in this direction it's towards either hydrogen or the derivatives of hydrogen in terms of methanol ammonia or similar kind of fuels. So let us also try to understand like how would these kind of efficiencies change if we are moving towards a hydrogen based system. So the hydrogen and that you would typically use in the vehicle could come from three different sources and these are the major sources I would say this is not an exhaustive list the primarily if you see today hydrogen is produced from fossil fuels mainly natural gas and the conversion process is steam ethane reforming. Then the other process could be through biomass gasification wherein you use biomass and produce a syngas out of it and that syngas being a rich source of hydrogen could be used for extracting hydrogen and use of hydrogen in the downstream applications. The third one could be production of hydrogen by the splitting of water using an electrolysis process.

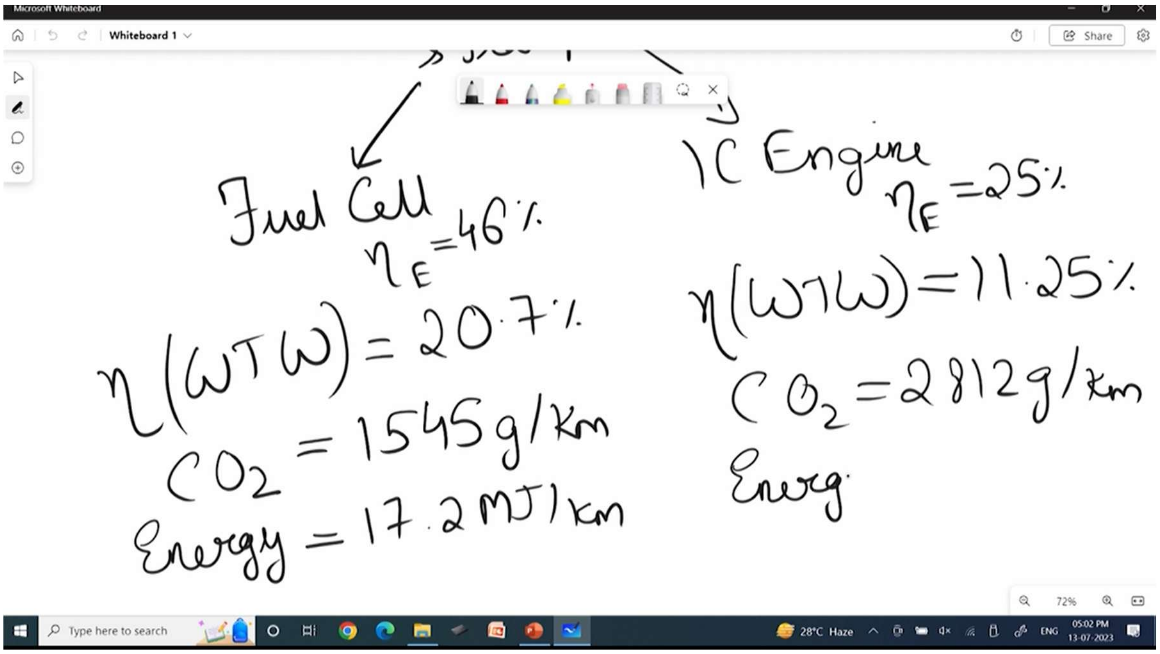


So let us try to analyse these processes in detail. So let us first try to see if I am producing hydrogen from SMR process. So by SMR I mean steam methane reforming. So the typical process that occurs in here is like natural gas is nothing but methane. So you have methane that reacts with water and produces three molecules of hydrogen and one molecule of carbon monoxide and even this molecule of carbon monoxide is made to react with more water to produce another molecule of hydrogen and carbon dioxide. So ultimately like one molecule of methane is expected to give you four molecules of hydrogen. So this is the conventional process that is highly driven by the fossil fuels almost all of the hydrogen that is produced in the industry that is specifically used for refinery operations as well as ammonia production is coming from this 100 year old technology which is called the steam methane reforming. So let us try to understand the supply chain that happens in this case.

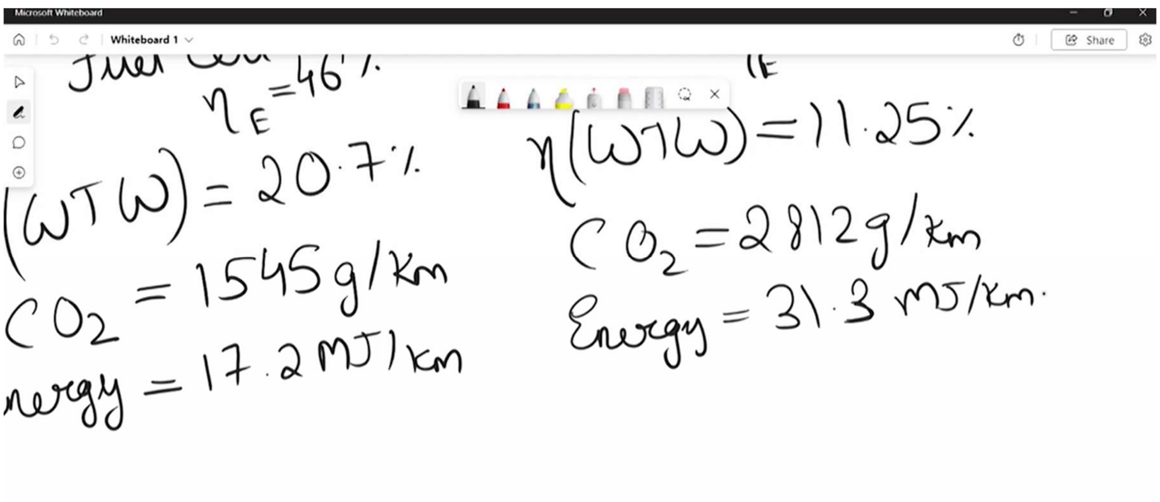


So first thing would be the natural gas recovery and transportation and once natural gas is recovered we would go with the steam methane reforming. So once we have this reforming being done so this gas would have significant amount of CO2 in it which means you would have to reduce the CO2 using some kind of capture also you would need to compress the gas as well as store it and then transport it.

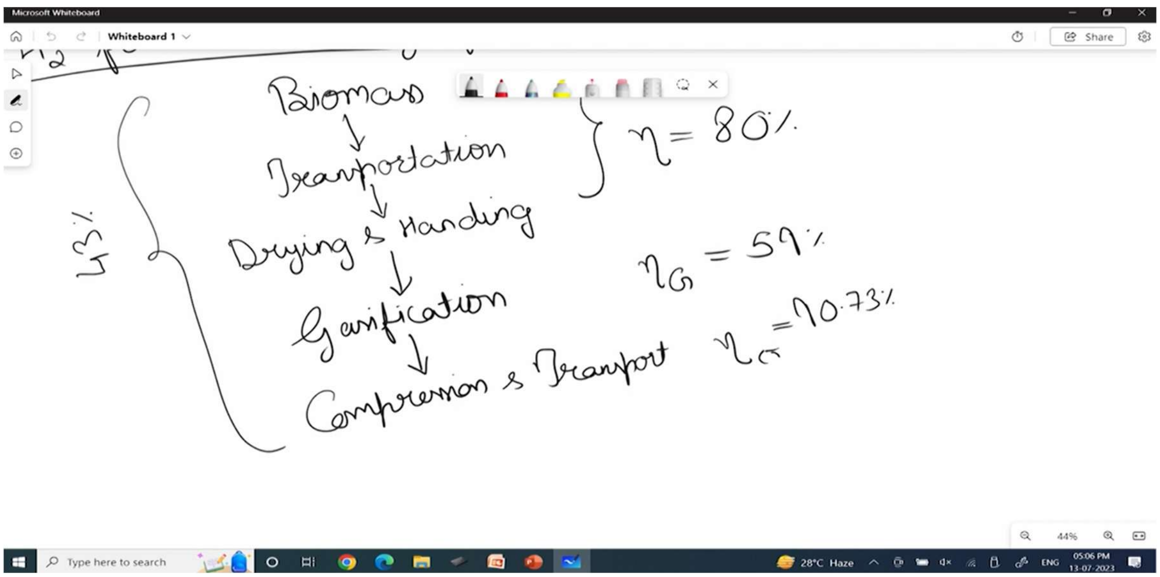
So we would have the compression, storage that occurs at high pressures and transportation. In this case I am not giving you the individual efficiencies because it becomes quite complex and you would have to go towards the individual flow sheet how it looks like. So I am giving you the total efficiency of this process this would be somewhere around 45%. So this would be the well to tank efficiency for the hydrogen production. Now once the hydrogen has been produced you would have two options either you can use a fuel cell or you can go towards an IC engine.



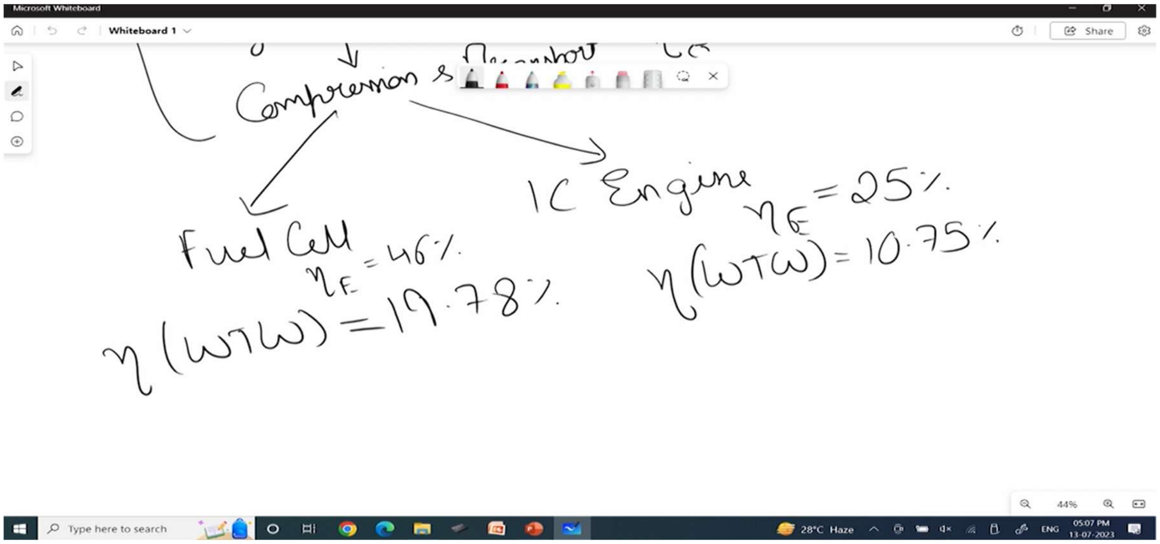
If I go with the fuel cell the typical efficiency of the engine in this case may be around 46% and if I go towards an IC engine the efficiency would be roughly 25%. So there would be somewhat of a different efficiency if you go towards the fuel cell or an IC engine and based upon the efficiency you can calculate the well to wheel efficiencies. So if I go with the well to wheel efficiency for fuel cell so eta that is well to wheel for a fuel cell based system this would around to be 20.7% and in this case the overall efficiency would be around 11.25%. So you can see there could be significant efficiency differences on the way how we end up using the hydrogen whether we are using the conventional or engines that have been modified for the hydrogen requirement or if you go with the fuel cell and this is one of the reasons why fuel cells have been proposed to be used in the future but if you see the overall efficiency this is not very much different from a conventional diesel based engine or an electric vehicle. However the difference could be seen in the total CO2 emission so the CO2 emissions for this particular process could be around 1545 grams per kilometer of vehicle travel and this could go as high as 2812 grams per kilometer for an IC engine based hydrogen requirement. So you can see a significant reduction happening if you go towards the fuel cells but if we stay with the hydrogen being produced through the conventional path and end up in the IC engine the emission reduction might not be much significant. If I go with the energy requirement for the total energy that is consumed this would be around 17.2 mega joules per kilometer and in this case of the case of IC engines the energy that would be consumed would be much more at around 31.3 mega joules per kilometer. So depending upon the pathway that we assume there could be huge differences even if the hydrogen is produced from a source that is a fossil fuel there could be significant CO2 emissions reduction. So that is again like pathway that is being proposed in the future. This hydrogen is also expected to be produced through renewable pathways and two major pathways that have been proposed or are being proposed are through biomass and the other one is through electrolyzers. Let us also try to quickly go through these two proposed pathways and try to analyse how do they fare in terms of the efficiencies.



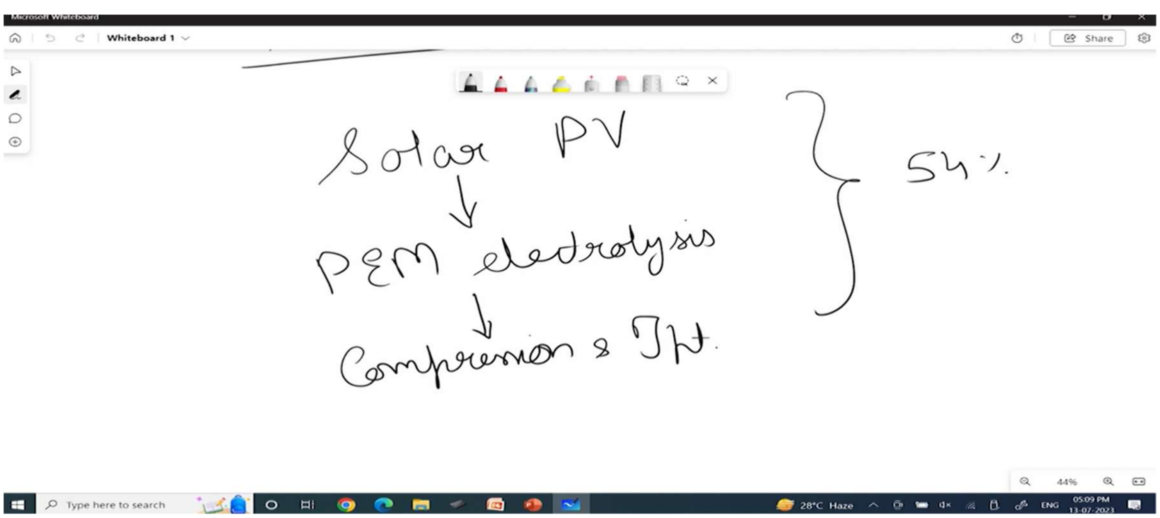
So let us first analyse the hydrogen from biomass gasification. So in this case you would have the biomass being cultivated on scale or it could be even waste biomass in the form of agricultural residues which is available in plenty in a country like ours. Then this would involve transportation and after transportation we would also have a significant amount of drying and handling. So biomass as such could have a moisture content that varies from 10 to 50% and gasification being a thermochemical process has an optimum amount of moisture intake that is necessary. So typically the biomass has to be dried to around 10 to 15% of the moisture and also depending upon the size of the biomass it has to be either chopped or bricketed to increase the density and that is where the drying and handling would come in. Typically this whole process would have an efficiency of somewhere around 80% then we would have a gasification taking place. Now this gasification could happen in the form of different oxidizing agents. So typically what is being proposed is the oxy-steam gasification where you are giving an oxygen and steam as the oxidizing agent and the typical efficiency of that process could be assumed to be around 59%. Further this process in the gasification or the hydrogen that is produced would have to be compressed so we would have compression and transportation and also some kind of gas conditioning would be needed. So an efficiency of compression and transportation could be assumed to be around 90.73% and this overall gives you the total efficiency in terms of the well to tank and in this case this would come around to be roughly 43% and after that again you would have the two options which could be going towards the fuel cells or it could go towards the IC engine.



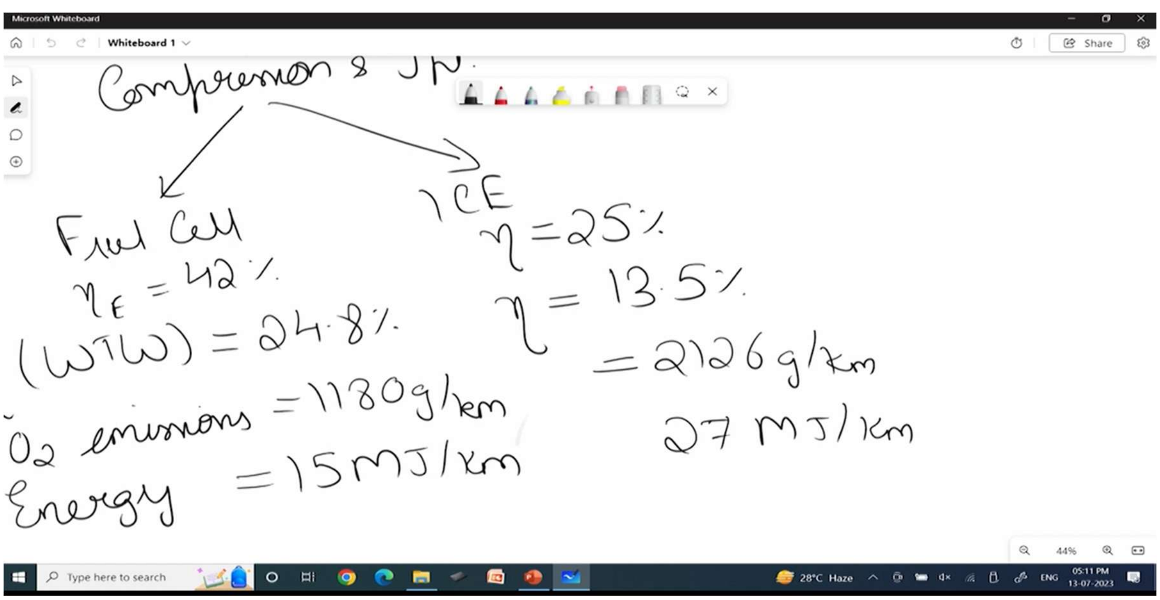
The efficiency of these remain the same at 42% and 25% and finally the well to wheel efficiency if I talk about would be around 19.78% and for an IC engine the well to wheel efficiency would come around to be 10.75%. So we see that the well to wheel efficiency if I am going towards the fuel cell is almost similar to the earlier cases roughly around 20% or so. The option or the only benefit that I am getting is like I am not relying on the import of natural gas for the production of hydrogen I am using a resource that is available in plenty in our country and that is a sort of nuisance in many places so that has to be disposed of and that is why like a lot of traction is being given to biomass based hydrogen production.



I am not giving you the CO2 emissions in this case because there is a huge variation based upon the biomass that you choose and further there is also a debate like what kind of emissions should be considered or not so to make things simple I am not giving the emissions in here but we will be analysing that in the future classes. Now comes in the last option and the most propagated option which would be use of solar energy and this energy is used to run electrolyzers and this electrolyzers would be producing hydrogen for the running of the cars. So let us try to analyse this last option which would be solar PV to hydrogen. So again in this case we would have the solar PV and this solar PV would be giving in or producing electricity for an electrolyzer which I am assuming to be PEM electrolyzer. So there are many different kinds of electrolysis technologies that is available.



The most used and the most famous or the most equipped is the alkaline electrolyzer that have been used in the past but we are choosing a technology that is proposed to come up at like quite nicely in the future which is the polymer electrolyte membrane electrolysis and this is the technology that we have chosen in this case and finally we would have the compression and transportation of this hydrogen and overall efficiency of this process that has been chosen would come around to be around 54%. Then the hydrogen that you produce again could go either to the fuel cells or the IC engine ones. The typical efficiency remains in the same 42% and almost around 25% in here and if I go with the well to wheel efficiency this would come around to be 24.8% and for the IC engine this would be around 13.5%. So here in we see there could be a significant advantage in terms of the overall efficiency and it is also a bit different how the efficiency is calculated in this particular case. We have also taken into account the construction and the manufacturing of the solar panels and the energy that goes into it. If the CO2 emissions are to be considered this would be roughly 1180 grams per kilometer and for the IC engine one there could be around 2126 grams per kilometer. So there could be significant amount of CO2 emissions as well and the energy requirement the total energy requirement has also reduced in this case around 15 mega joules per kilometer to almost 27 mega joules per kilometer. So again this would be a function of the assumption that have been taken into place but there could be significant emission reduction that could be happening.



So in this particular class we have tried to discuss the different pathways for the production of hydrogen like it could be either the conventional steam methane reforming, biomass or PEM electrolysis and how do they compare with the diesel based engine as well as an EV and the efficiencies if you see are not much different. They tend to be almost in the same range however there could be a significant amount of difference in emissions that they produce and these emissions that I have shown are only tentative it would depend upon the supply chain considered in detail. The type of grid mix that you are taking, the type of biomass that you would be assuming and again a lot of assumptions that go into it and this is something we will be learning towards the end of the course when we go towards life cycle assessment. But this was just to give an understanding why the different kinds of fuels are being propagated and how different the supply chain looks and how we can do an energy flow diagram or a primary energy analysis to understand the supply chain in detail. So with this we end today's class. Thank you.