Energy Resources, Economics, and Sustainability

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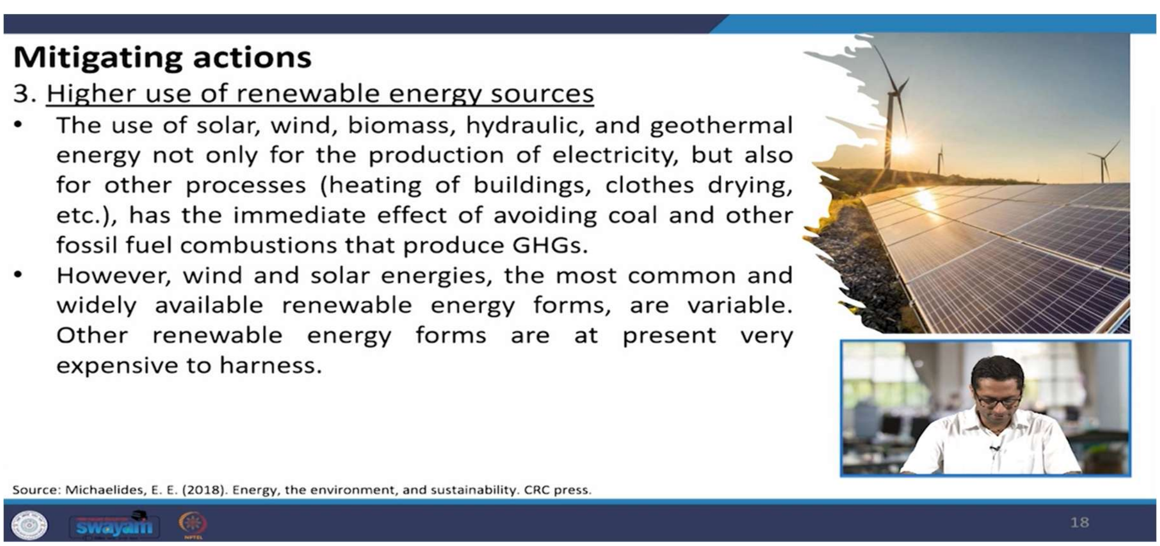
Week – 05

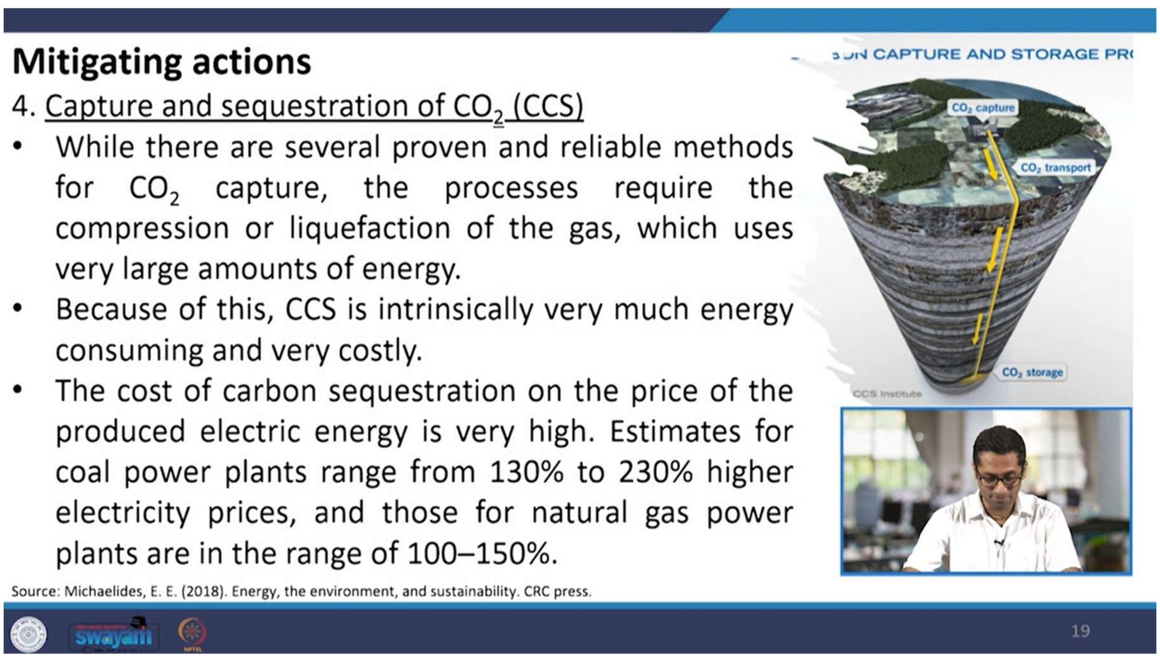
Lecture – 06

Lecture 26 - Global Climate Change Mitigation-II

Hello everyone, welcome to the course Energy Resources, Economics and Sustainability. In the past class, we have been discussing certain measures for global climate change mitigation. We have discussed two options of increasing the efficiency and shifting to technologies like nuclear or hydro. A similar extension of the same problem or one of the measures that could be adopted is going towards the renewables and this is what have been projected to a great extent. Different parts of the world are very actively moving towards reducing the energy from solar wind, biomass, hydro, geothermal wherever it is available and this has been leading to major changes on how electricity is getting used. But one of the major problems that is again encountered is that two major sources of energy which comes under the ambit of renewable source of energy are variable in nature. The sun is available only during the day and similarly winds are available during the certain parts of the day.



Further some technologies like biomass would have their own typical supply chains which are available during the harvest season. So these are some of the problems associated with the availability of renewables and the storage technologies if we talk about them are not coming up in an economical way. Of course we have technologies that are able to store energy for a great amount of time but that comes at an expense and if that was to be included, the conventional sources in terms of coal or natural gas seem appear to be winning in terms of economic terms. So this is again a major issue and we have tried to understand with a sort of example in the last class that if you were to shift a typical coal based power plant or a couple of coal based power plants with an energy source which has a so called very low carbon footprint there could be huge savings in terms of CO2 emissions and that could help countries realize the targets that they have set in terms of net zero to be quite fast. Another pathway that has been suggested for achieving or avoiding climate change is carbon capture and sequestration or use.

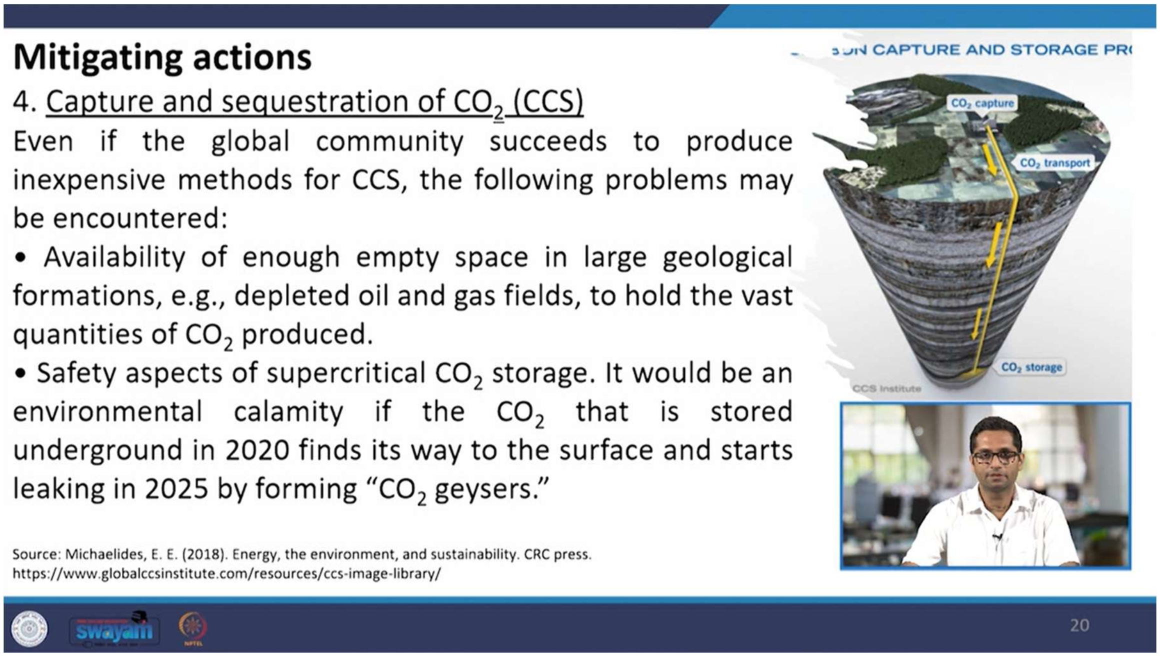


So why do not we capture the carbon through different pathways? It could be coming either from the point sources we have like CO2 getting produced at a very good level in the coal based power plants also in some industries like manufacturing of urea or the production of hydrogen also entail a good amount of CO2 emissions. We also have the iron and steel industry that has a good amount of CO2 emissions. So why do not we just capture the CO_2, do not let it enter the atmosphere and let us try to solve the problem at the source of the CO_2.

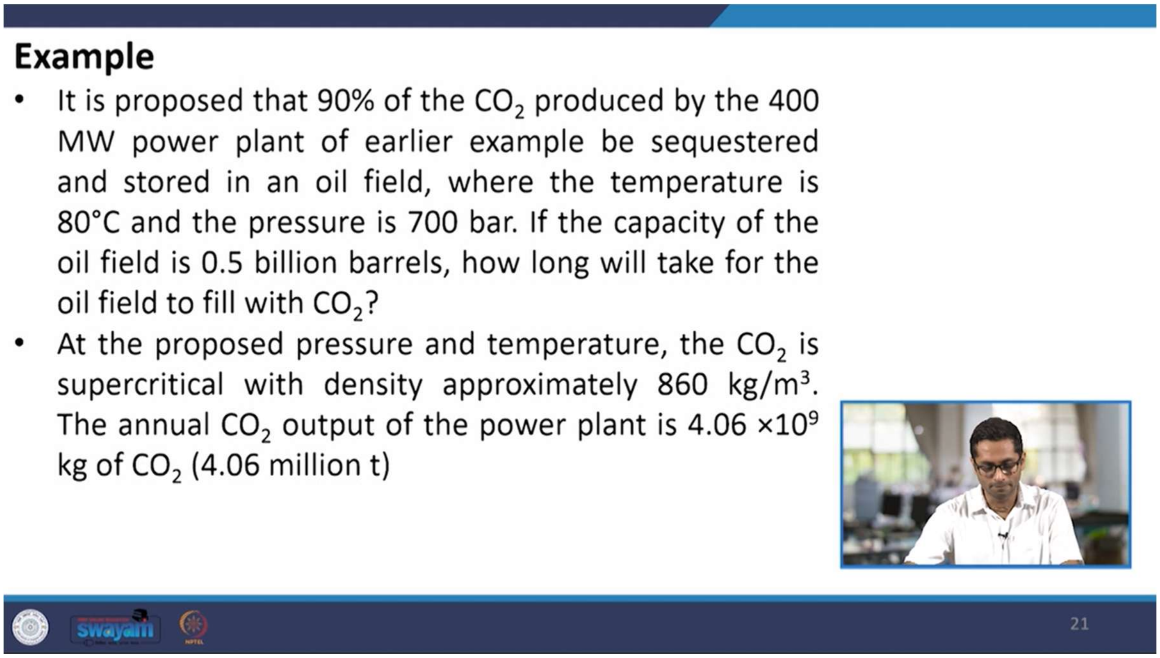
So just capture the CO_2 there are again many technologies which are like pre-combustion capture and post-combustion capture for CO_2 that are available and they are quite available technology and once you capture that the CO_2 could be piped to the depths of the earth where it could be stored in the abandoned mines or oil seams where it is expected to be there for thousands of years and it would not be troubling us. So on face value like this appears to be a very good proposition like let us capture all the CO_2 and then either we compress it to a very high pressure or make it liquefied in the form of a liquid and then we pump it to maybe a few thousand meters in the depths of the earth and is expected that in these coal mines or the oil seams this CO_2 is going to be there. But a major issue that is experienced in this kind of proposition is the cost that is involved. So there will be a good amount of cost that is involved for first the capture of CO_2 then the compression of CO_2 and finally the pumping of CO_2 at depths and the estimates range somewhere between like if I was to couple a coal based power plant with a CO_2 capture unit as well the price of the electricity that I produce would increase somewhere in the range of 130 to 230 percent. So if I take the average I will be almost doubling the price of electricity that I am generating.

Further if I take the similar analysis to a natural gas based power plant the rise could be again between like 100 to 150 percent again almost doubling the price of the electricity that I am producing. So that is again a major issue which is stopping from these kind of technologies to be picked up. Also when we talk about a technology like hydrogen production and if we see that at present most of the hydrogen that is getting produced is from the source from natural gas which is a fossil fuel based source and there is CO_2 emissions associated with the production of hydrogen. So what the different countries and the different industries are propagating is we will produce hydrogen from the same source but they would be capturing the CO_2 to make it blue hydrogen. So the conventional hydrogen is grey hydrogen or black hydrogen because of the CO_2 that is emitted to the atmosphere and because now we are capturing the CO_2 and sequestering it or utilizing it in some of the pathways the hydrogen would turn out to be blue.

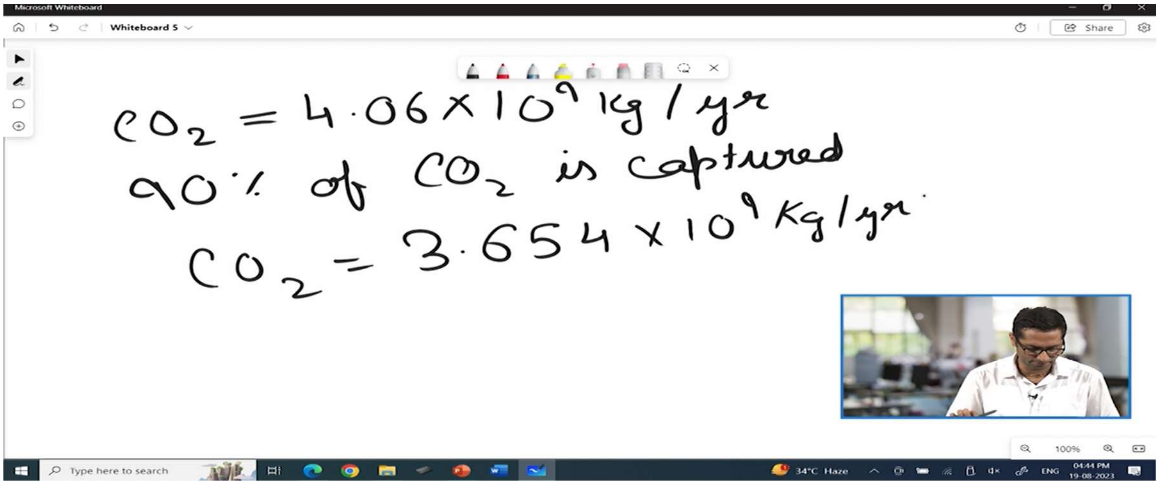
So in the short term many of the leading countries of the world are betting on blue hydrogen. What are the problems of carbon capture and sequestration?



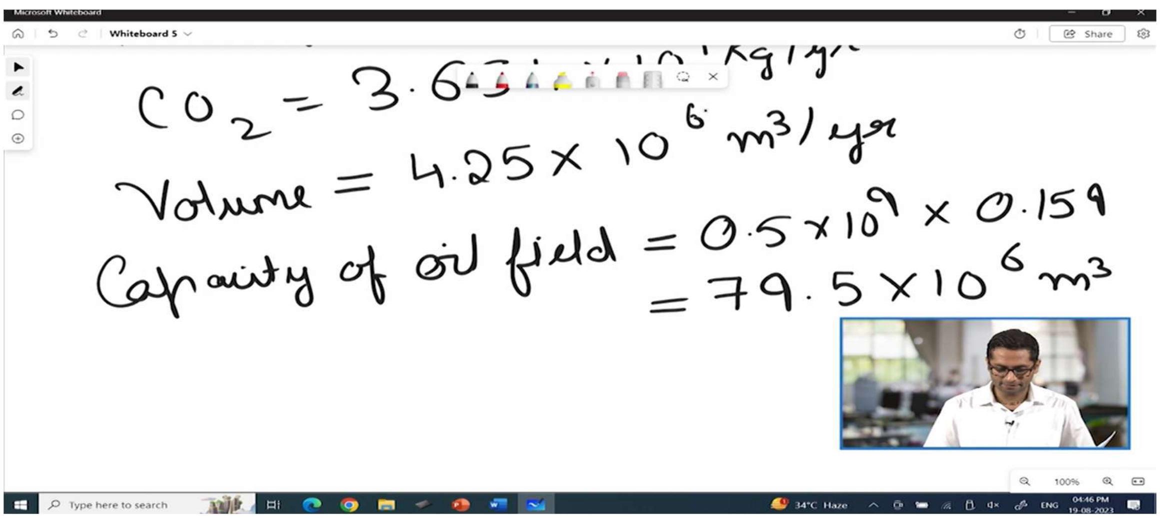
Of course cost is one big element which means like there are huge amount of energy requirement for the pumping and the compression but even after that is a major issue is the availability of the large geological formations. Do we have enough depleted oil and gas fields to hold the quantities of CO2 that is produced in the global level? That is another big issue that we are facing. And also equally strong is the safety aspects of the stored CO2. Now this supercritical CO2 that is getting stored there is a possibility that it might want to escape from the particular storage and might come out to the surface of the earth in the form of CO2 visas which could have its own ecological challenges which we are not sure because such things have not been experienced in the past. But the long term storage of CO2 in any of these natural formation is still questionable and is not 100% safe. And these are two major concerns which is again holding back the implementation of carbon capture and sequestration. Let us try to understand these basic points with the help of simple examples.



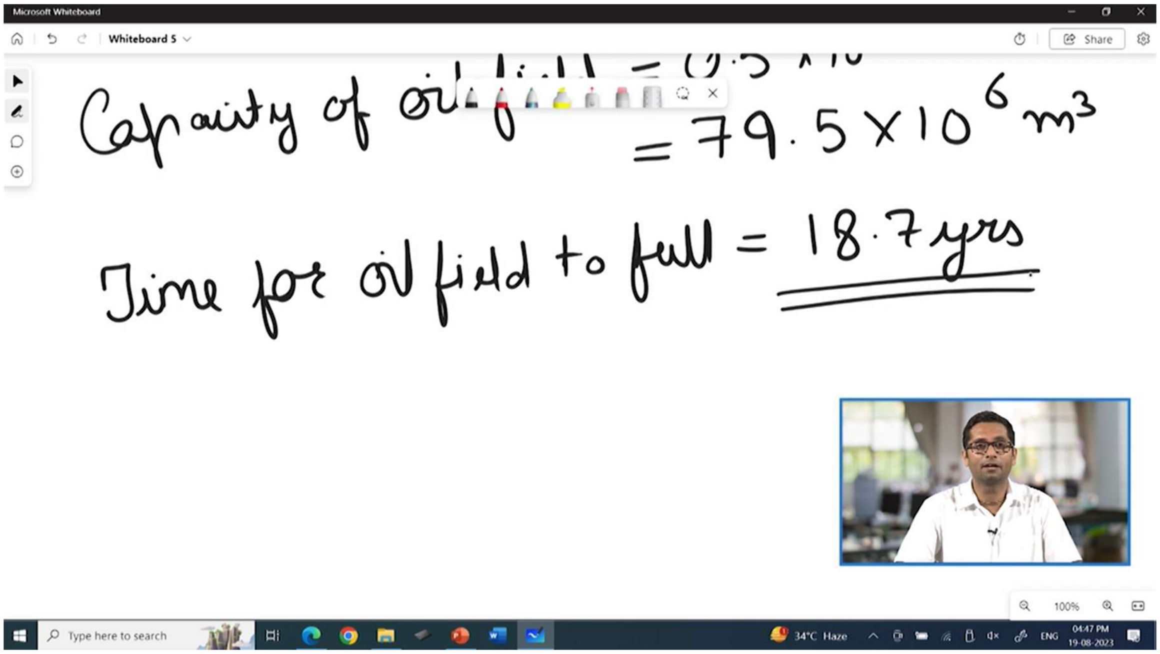
So let us again go back to the example that we tried to analyze in the previous few classes where we took a typical 400 megawatt coal based power plant and in that example we tried to estimate the amount of CO2 that was produced in a daily, weekly and in yearly level. Let us pick up that same example and suppose if I was to capture 90% of the CO2 that was being produced by that plant I would want that to be put into the supercritical form and that is would be almost 80 degrees Celsius and 700 bars. This is above the critical temperature and pressure of CO2 and I would want to store this in an oil field and the measurement for that oil field that is that I have access to is almost 0.5 billion barrels. Barrels is again a unit of volume. So one barrel is roughly equal to 159 liters mostly used in the western world but like just for the sake I have like used like the capacity as 0.5 billion barrels and let us try to estimate how much time it will take for this typical rather typical oil field to fill up with the generation capacity that I have. Further I can assume that like the density of CO2 at this supercritical conditions could be approximately 860 kg per meter cube and the annual CO2 output as we have calculated earlier in that example was around 4.06 into 10 to power 9 kgs of CO2 or 4.6 million tons of CO2 that was being emitted every year. So let us go to the whiteboard and try out the simple example.



So let us start with the production rate of CO2. This 4.06 into 10 to power 9 kgs per year. So this is the annual production of CO2 that I am considering and I am also hoping to capture 90% of this CO2 is captured. So this brings in the CO2 level to be around that is to be captured to be 3.654 into 10 to power 9 kgs per year.

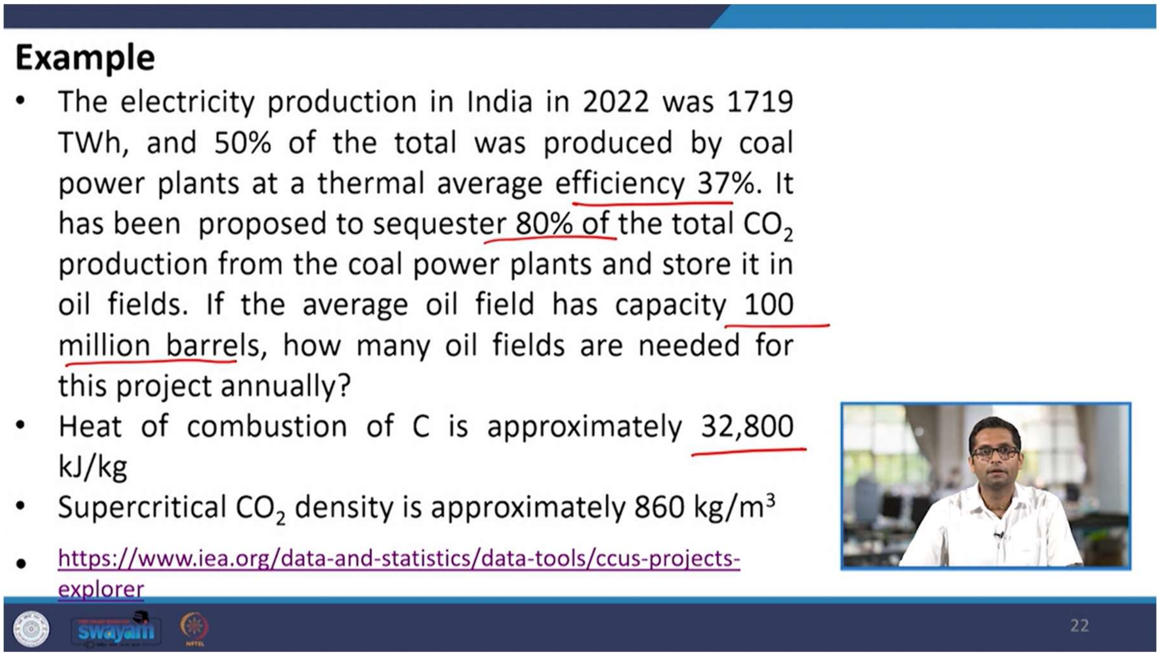


Now if I multiply this with or divide this with the typical density of supercritical CO2 which was given to me 860 the volume of this would come around to be 4.25 into 10 to power 6 meter cube. So this is the amount of CO2 or the volume of the CO2 at supercritical conditions that I would be emitting every year. Now let us also try to estimate the capacity of the oil field. The capacity of the oil field that I am considering is almost 0.5 billion barrels or what I can do is 0.5 a billion is 10 to power 9 and 1 barrel is roughly equal to 159 liters or 0.159 meter cubes. I multiply this and the amount or the capacity of the oil field comes out to be 79.5 into 10 to power 6 meter cube.



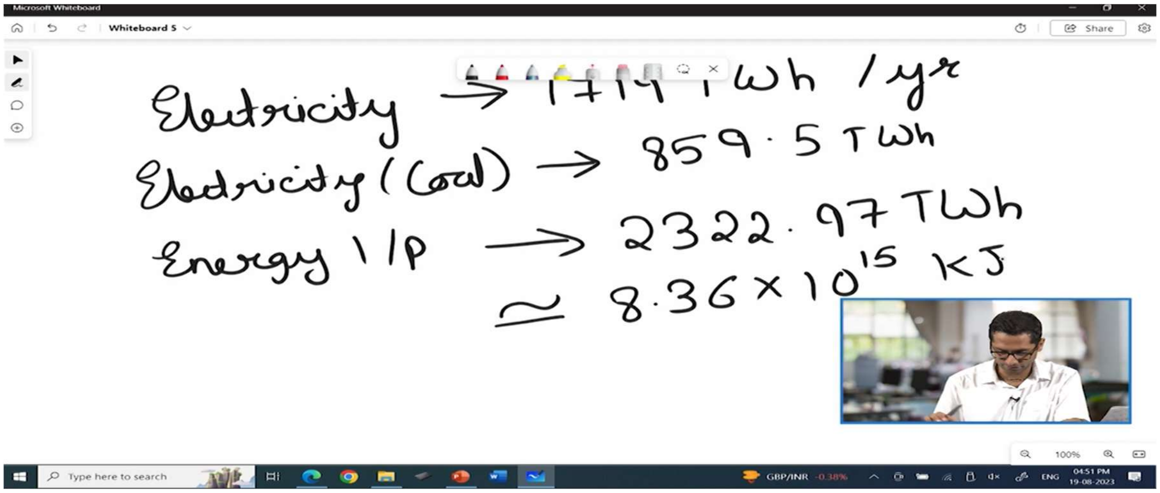
So above I have the production capacity in the terms of 4.25 a million meter cubes per year and the capacity of the oil field comes out to be roughly 80 million meter cubes. I divide the two and I can get the time that would be required for the oil field to fill up and this would come out to be almost 18.7 years. So this typical oil field is going to get exhausted in just the span of 18 or around 19 years. If I compare that with the typical life of a power plant which varies around 40 years or so, so I can estimate that I would require almost 2 or 3 empty coal mines or empty coal seams in the vicinity of this rather typical power plant so as to sequester whole of the CO2 that is generated throughout the lifespan of this plant.

So these kinds of combinations are quite rare. Initially like the coal plants are near the supply case but to get so much amount of coal fields in the vicinity of the plant is again a very difficult thing to achieve and in case the sequestration platforms are not available near the power plants you would have to pump this CO2 for long distances which would have its again its own cost implications. So this presents one of the major challenges with respect to the sequestration of CO2. Let us go back to the slides.

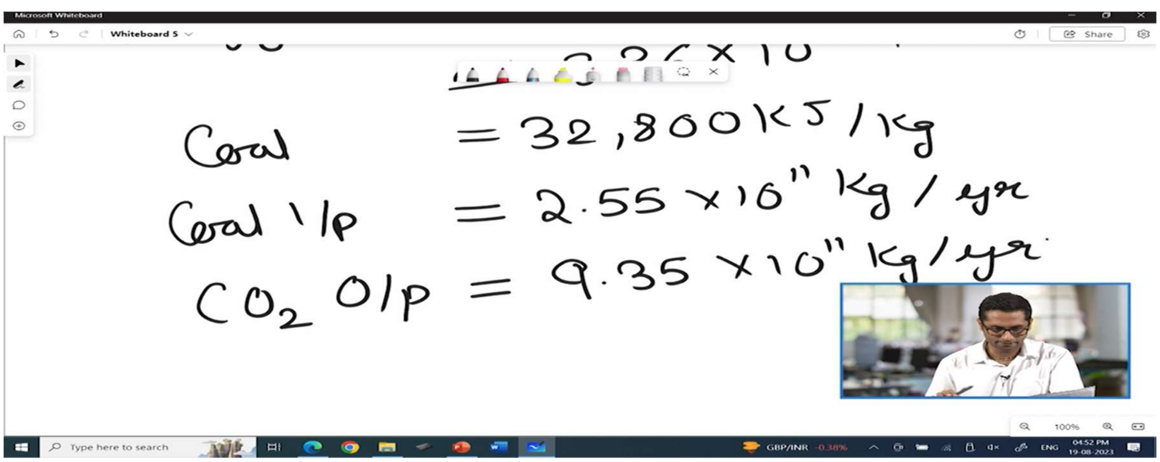


We can also understand some of the challenges associated with the carbon capture and sequestration with the help of another example. So here let us take the case of India and take the year 2022 and in that particular year India was producing almost 1700 terawatt hour of electricity and let us assume that 50% of that total electricity was coming from coal based power plants with a thermal efficiency of around 37%. Now it is proposed that I would want to sequester 80% of the total CO2 that is coming from these power plants. The average oil field or the coal mine that is available might have a capacity of around 100 million barrels. So in the last example we have taken a bigger oil field of a capacity of 500 million barrels or 0.5 billion barrels but let us go with an average capacity in here and let us try to estimate the number of fields that it would require if I was to sequester all of the CO2 that is coming from the coal based power plant in India.

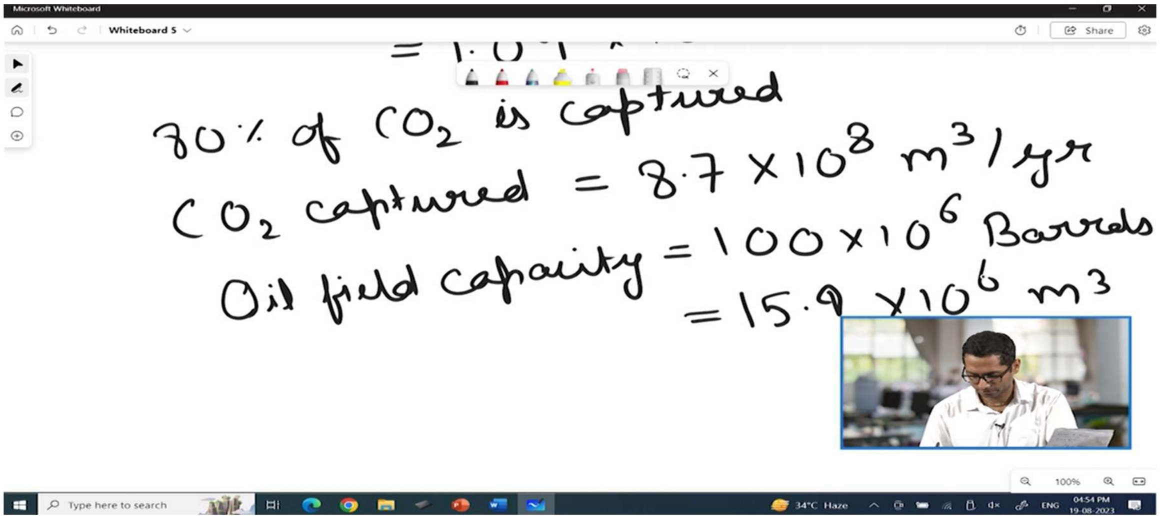
And again we can assume the heat of combustion of coal here to be around 32,800 and the density of CO2 can be 860 at supercritical condition which is 80 degree Celsius and a very high pressure. So let us go back to the white board.



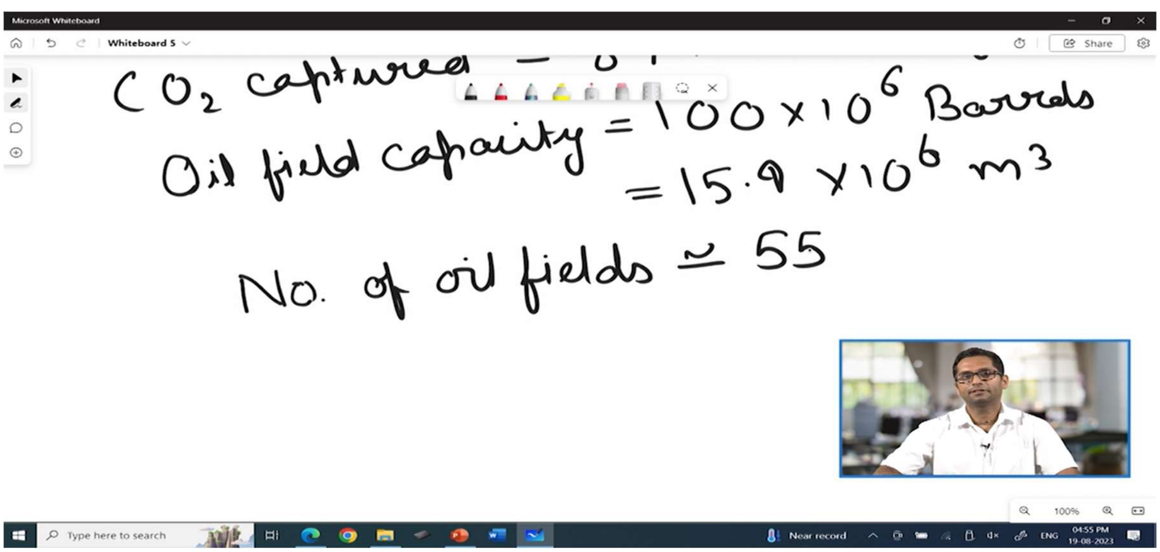
Let us start with electricity that is being produced. So this is here and I am giving electricity in terms of the energy units. So the electricity that is getting produced is almost 1719 terawatt hour and this is per year and this was specifically for the year 2022. If I talk about the electricity that would be generated from coal based power plant and I am assuming almost 50% was coming from coal and half of it would be almost 859.5 terawatt hour. If I talk about the input energy I can take the typical efficiency of around 37% that I was assuming and the input would be almost 2322.97 terawatt hour. And in terms of I can compare this in terms of joules. This would come around to be 8.36 into 10 to power 15 kilojoules. I have just changed the units. So both are energy units and I have just changed from terawatt hours to kilojoules.



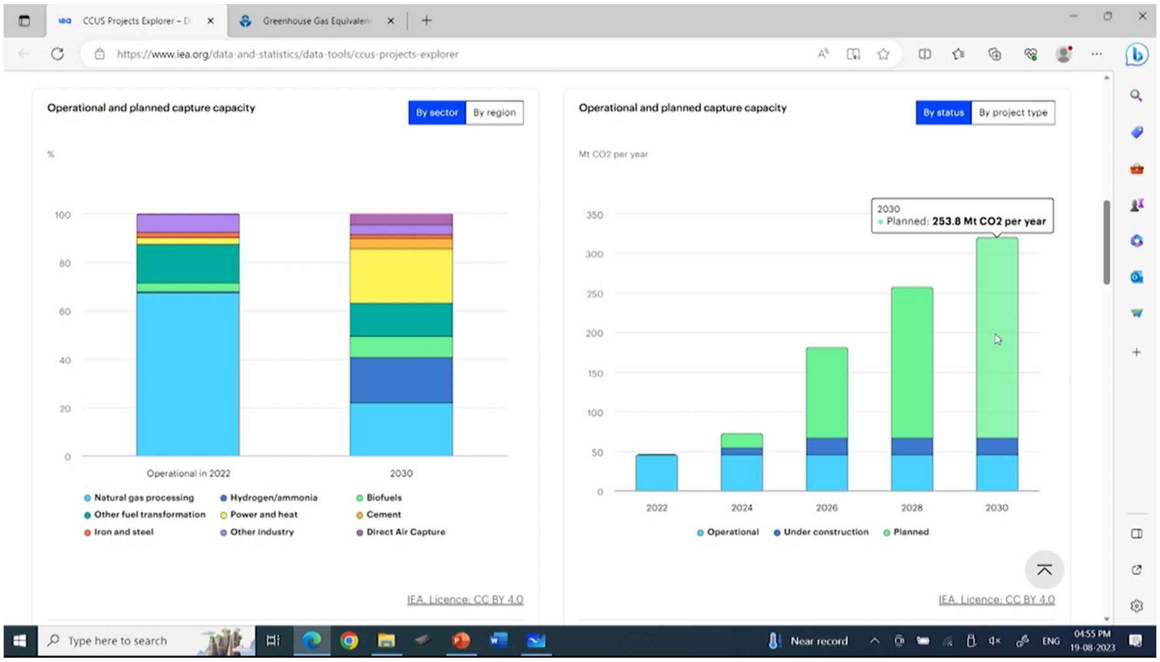
And the coal I know would have a capacity of around 32,800 kilojoules per kg. So I divide the energy input with the energy released from the combustion of coal and this is going to give me the coal that I would be utilizing. And I do the same thing the coal input would come out to be roughly 2.55 into 10 to power 11 kgs of coal that I will be consuming in a year. And on the basis of the coal I can also calculate the CO2 that I am emitting multiplying it by 44 and dividing by 12. And this gives me the emission in terms of 9.35 into 10 to power 11 kgs of CO2 that I am emitting per year.



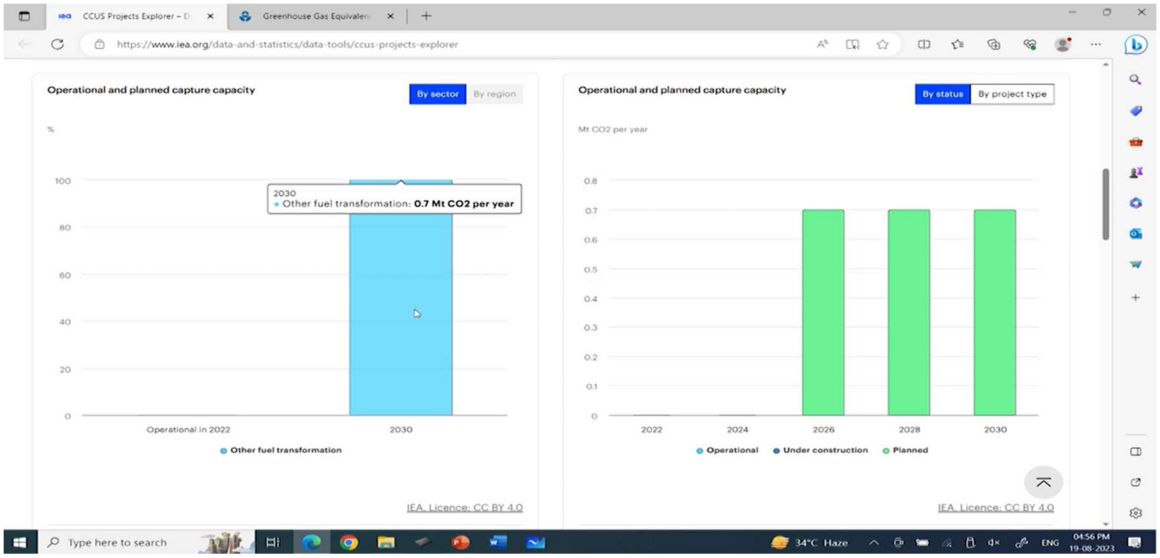
Again I can multiply this with the density of supercritical CO2 that happens to be around 860 and the same value would be around 1.09 into 10 to power 9 meter cubes of CO2 that I am releasing every year. Again for this particular example I am assuming that 80% of CO2 is captured. And if that to be the case the CO2 that I would capture would be around 8.7 into 10 to power 8 meter cube per year.Now the capacity of a typical oil field would be around 100 million barrels, so 100 into 10 to power 6 barrels or I can say around if I was to convert into meter cube by 15.9 into 10 to power 6 meter cube.



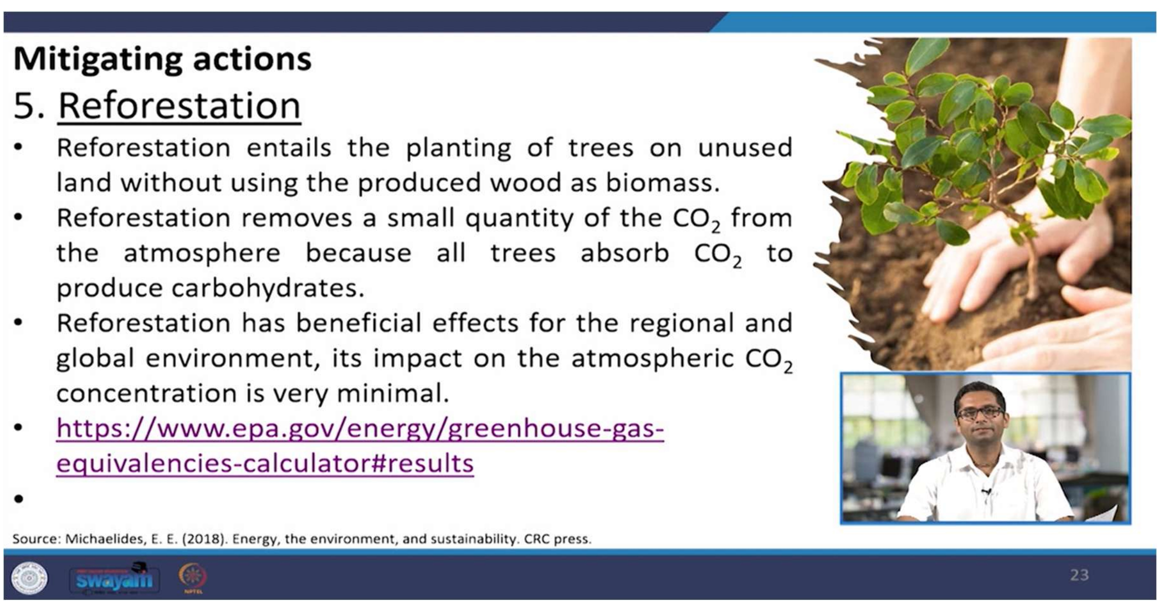
So I know the amount of CO2 that I need to capture. I also know the typical capacity and if I divide the two the number of oil fields would come out to be roughly 55 which is a huge number. Let us also try to compare this number of sequestration sites that are already in operation. So let me take you to the IEA statistics.



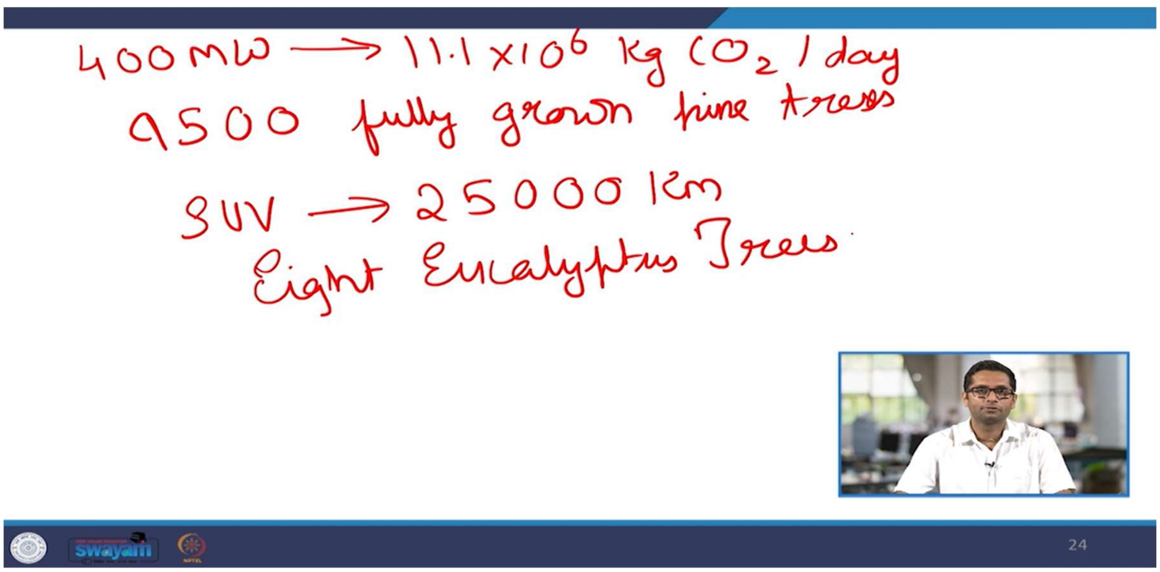
So if you can go to the browser what you see in front of you is the current amount of carbon capture sites as well as the capacity that we have in operation. So these kinds of captures are used for different kinds of industries wherein you can see the natural gas industries and the power plant, the yellow one are the power plant. So this is once an operation in the year 2022 and what is projected for the year 2030. So you can see power plants being captured in a good amount of CO2 and getting sequestered. And you can see the capacity in terms of million tons of CO2 and it is expected to increase in the future. But this is the world taken as a whole.



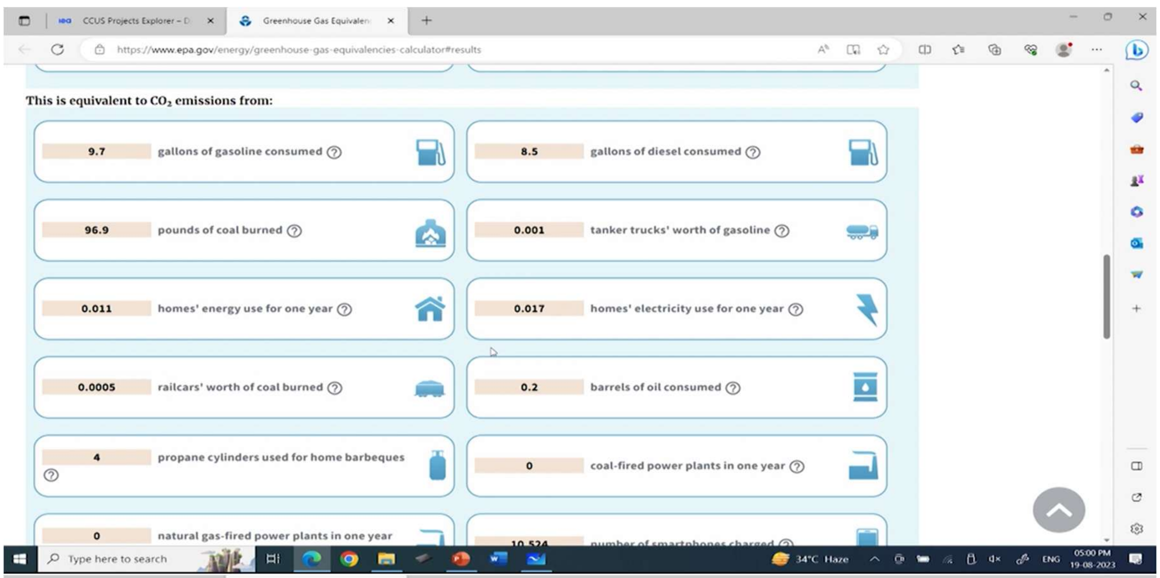
If I was to choose India in here, maybe I can just scroll to India, I can see currently there are zero sites in operation and again in the future there are no plans for power plants and if you see the capacity that is estimated to come up in the next seven or eight years it is expected that it would be almost 0.7 million tons of CO2 per year. And compare this with the estimates that we have just made in the previous example. So of course this is a viable option for capturing the CO2 but if you see the current scenario, the availability of the storage sites available, we have a serious limitation as far as India is concerned. And again this kind of technology has not been propagated by the government policies as well in the past.

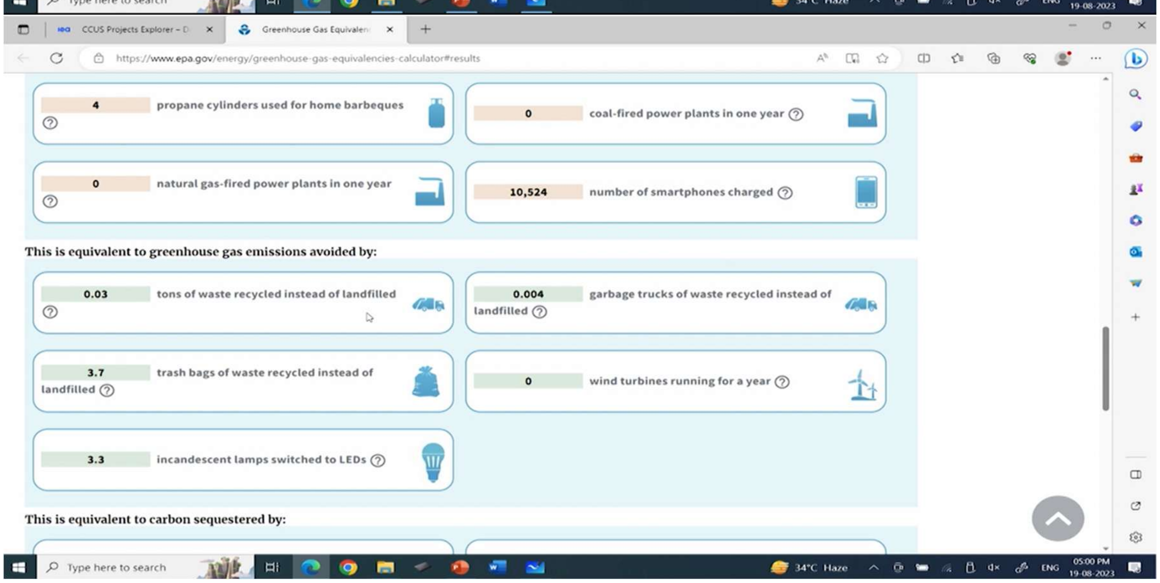


So if you look towards some other pathways for the reduction of CO2, one particular pathway that comes again and again is the reforestation. Or you just go for planting more and more trees and these trees are specifically for the purpose of absorbing CO2 and you are not using this for biomass generation or using in the energy application but the sole purpose of growing these trees would be they take in CO2 during the process of photosynthesis, produce more biomass and the tree grows in size. Overall it will be sequestering certain mass of biomass over the years. So it has not been propagated like we do not need any measures, just grow more and more trees and you should be able to solve the climate change problem. Well, true to a certain extent that like that trees take in CO2 but if you consider the quantum of CO2 that is getting released in the atmosphere because of the energy change that is vast.



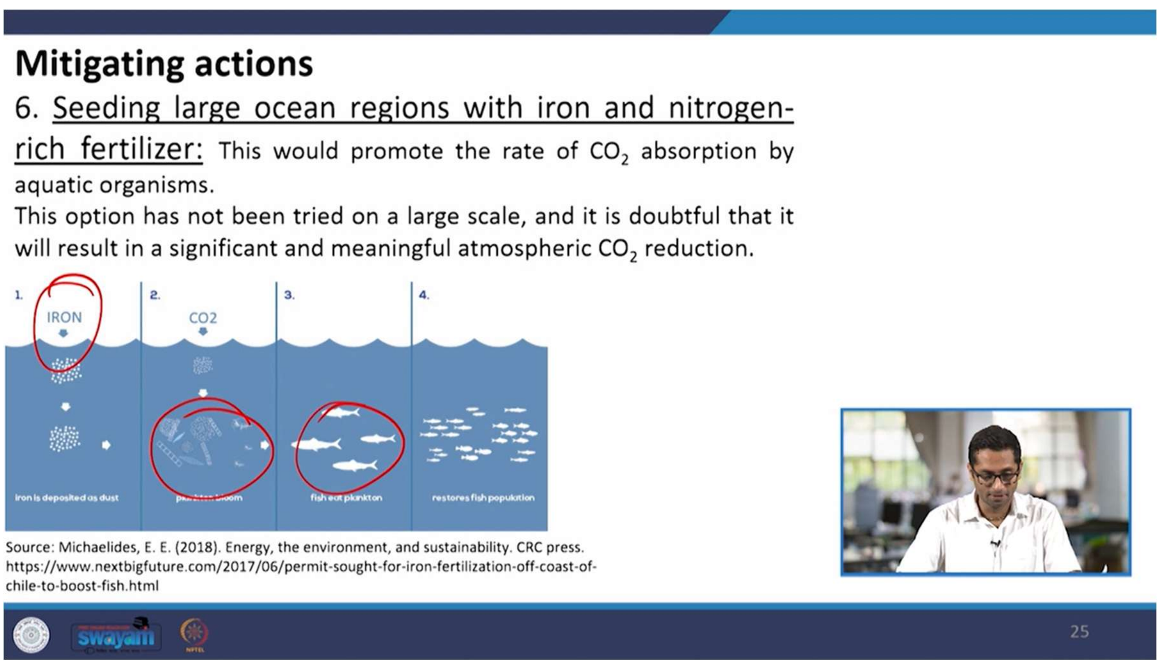
And just to give you a simple example, so we have considered earlier that a typical 400 megawatt plant would be releasing almost 11.6 into 10 to power 6, 11.1 into 10 to power 6 kgs of CO2. So this was a daily figure and if I was to sequester this much amount of CO2, I would need to plant almost 9500 fully grown pine trees. The pine trees is something that you find in the hill stations in the states of Uttarakhand and Himachal and other Himalayan states. So you would need 9500 fully grown pine trees to sequester the amount of CO2 that is released in one day by a typical power plant. So you can just imagine the type of CO2 that is coming in a year. So of course the proposition is correct that CO2 can be absorbed by trees but the quantum of trees that would be required to even absorb the CO2 that is coming in one day emissions of a typical power plant could be huge. And do we have enough land for that? Would be using this land for growing more food for our population or should we just be growing trees? So that is another question that needs to be answered. Another typical example could be if you take a SUV that you might be driving and if you are driving around 25000 km that SUV you would need 8 eucalyptus trees to absorb the amount of CO2. So again like you can see like the amount of vehicles that are running on the roads and the quantum of trees that would be required. So again this is again a challenging problem like can we just rely on growing of trees for a problem like this.





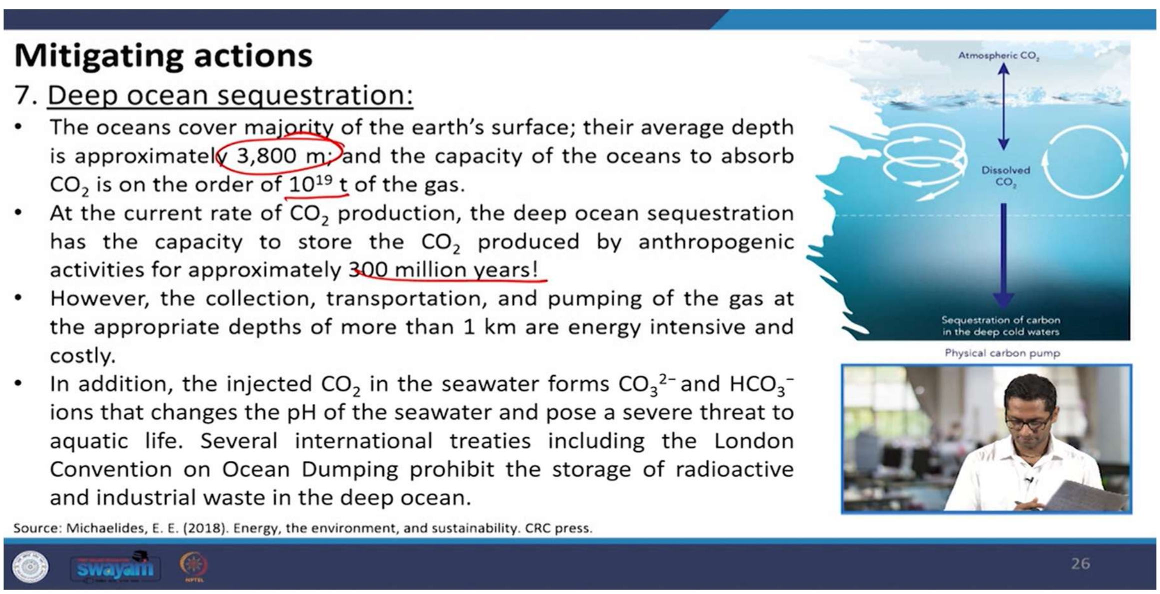
Also you can explore some tools so I would just like to take you through a simple tool. This again is from the website of the US environment protection agencies and they have used something so if I just put in the amount of kilowatt hours used. So if I put in the typical electricity consumption of a household maybe a typical household is using 200 units of electricity it gives you basically the equivalence of in terms of the different kinds of fuel used and it also gives you the equivalence that can be avoided. So you can see that for a typical month's bill you would have to plant 1.4 seedlings for 10 years so that again this is for a typical household and that is consuming just 200 units. So you can play around with this and see the equivalence that is happening.

Again like this is based on certain assumptions but can give you some meaningful estimates in terms of like how much emissions can be avoided through different kinds of methodologies. So let us go back to the slides and try to see what other pathways could be utilized for achieving and the listening of the carbon or removal of carbon or reduction of carbon in the atmosphere.



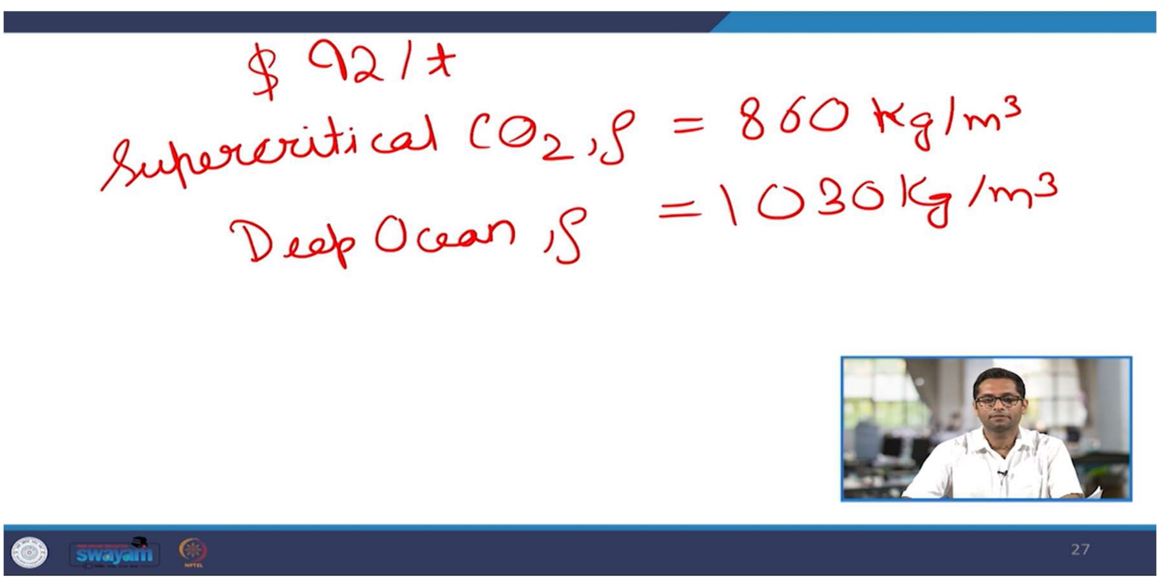
So one of the methodology that has been proposed is can we seed the ocean regions with certain compounds of iron and nitrogen. So what that is going to happen is like these compounds can help in promoting the growth of certain kinds of weeds or planktons which might grow in a large capacity and they might be able to feed the larger amount of fishes. So what would happen in terms like because of there would be an increase in the population of planktons because of the increased nutrients that we are supplying they might would be wanting to absorb much more CO2 from the atmosphere because of the photosynthesis process that they do and in that case the ocean becomes a sink for the CO2.

So what is happening is here is like we will be putting good amount of iron on other fertilizers and there would be the plankton blooms that will be generating and in their growth they will be absorbing a good amount of CO2 which would eventually be coming from the atmosphere and then there would be the larger fish feeding on this and this will also help us restore the fish population. So far so good but this kind of solution has not been tried on a large scale and further the effect of this kind of methodology on the bigger food chain or the ecological consequences in terms of the marine ecosystems is still unexplored. So people are not very confident about this option like because of what could be the effect on the supply chain of or the food chain of the different organisms because it is a very complex ecosystem in itself.



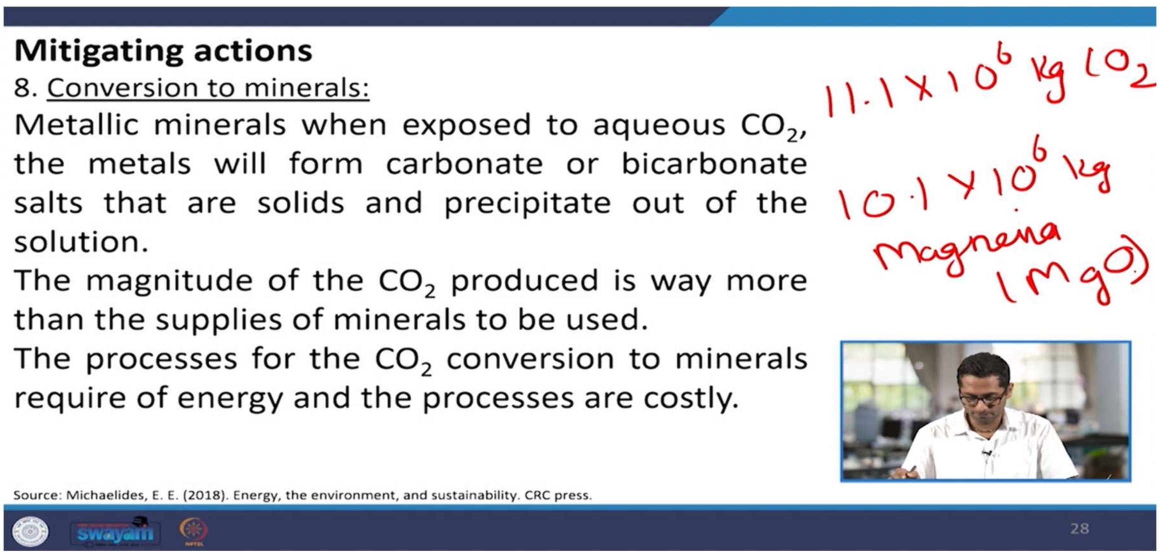
Then another methodology that is suggested is again this is again similar to carbon sequestration is that can we have a deep ocean sequestration. So forget about the oil seams or the coal mines where I would want to sequester CO2 I have huge amount of oceans. So almost 70% of the earth surface is compared with oceans the average depth is around 3000 or 3800 meters. So I have huge amount of volume at my exposure and if I go with the simple estimates in this the CO2 that could be absorbed in the ocean could be of the tune of around 10 to power 19 tons of gas. So if I take about the current rate of CO2 production possibly I have enough space for sequestering CO2 for the next 300 million years. So that goes in a very well way but again one of the major challenges here remain the same. If I would have to transport the CO2 to a depth of maybe 1 kilometer in the depth of the ocean that would consume a lot of energy in terms of compression as well as the liquefaction of the CO2 or taking the CO2 to the supercritical states and this is one thing that is holding the process back.

In addition the injection of CO2 into the ocean floor or it is also expected to lead to the different types of carbonate ions which would eventually increase the pH of the sea water and this could again be a threat to the aquatic life. We have discussed this aquatic life is able to sustain within a narrow pH range of around 6.8 to 7.4. So any further change in the pH would have drastic consequences. Further we have international protocols in the form of the London Convention of Ocean Dumping that prohibits the storage of radioactive material and industrial waste in deep ocean. So CO2 is again considered to be an industrial waste and by law it is prohibited to dump any amount of CO2 into the atmosphere.

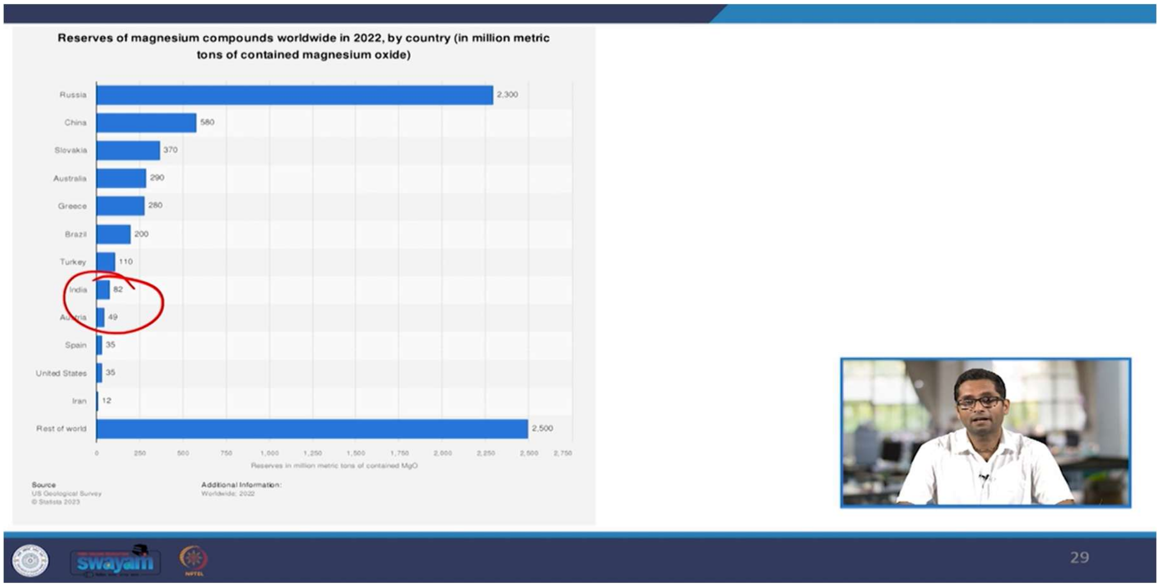


Further we can again carry out a simple estimate wherein we can see that the first problem is that if we consider the ocean dumping the average cost of CO2 dumping is somewhere around $92 per ton. So this is very prohibitive and much more than the carbon tax that different countries would apply. And further another major issue that have been brought in that the supercritical CO2 would have a density of roughly 860 kgs per meter cube and if I talk about the deep ocean the density of water at that point would be around 1030 kgs per meter cube.

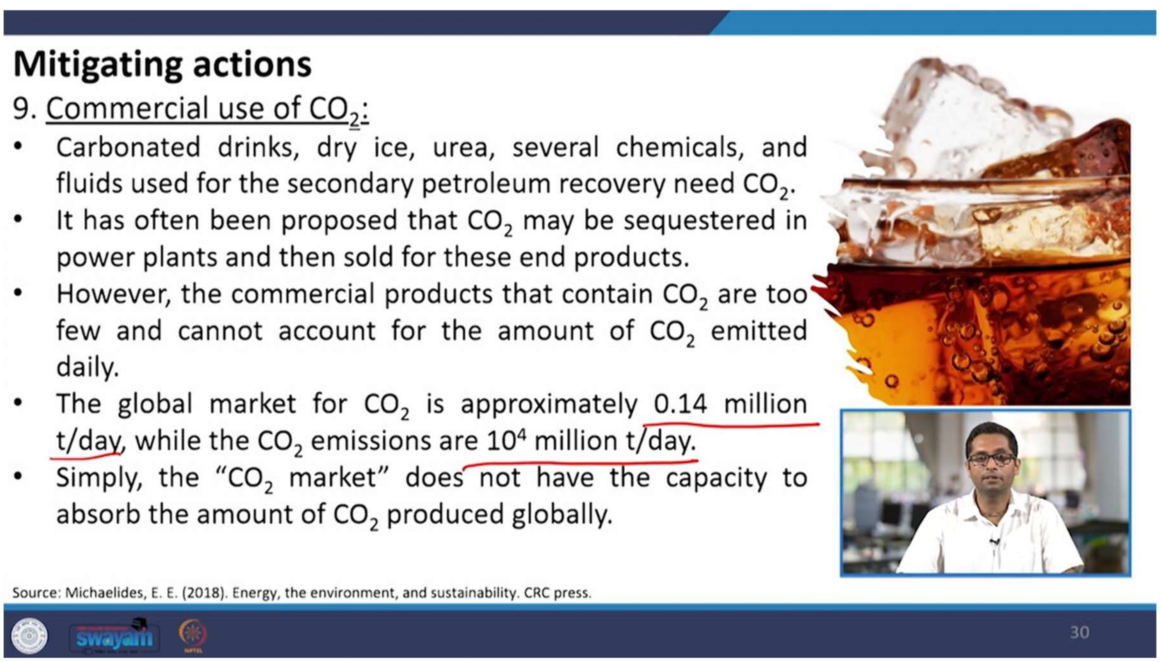
So it is also an apprehension that supercritical CO2 having a lesser density might want to rise up the ocean floor in the form of the bubbles and when it comes out like the storage is not going to be perpetual but might be very short lived. So that is again a major apprehension that has been brought about by the scientific community.



Then other options which have been propagated is the use of certain metallic minerals. An example could be a sort of like magnesium oxide which would react with carbon dioxide to perform a magnesium carbonate. So you could have different metallic minerals being reacted with CO2 to form solid products which are leached as a precipitate and you would want to store those products. But again the same problem persists that the magnitude of CO2 that we produce is quite high. And again do we have enough supply of those minerals to capture the amount of CO2. So just to give you an example again here so if I am talking about around a daily production of CO2 of around 11.1 into 10 to power 6 kgs of CO2 that was coming out of a 400 megawatt plant. It would roughly need almost 10.1 into 10 to power 6 or a million kgs of a magnesia. If I am using magnesium oxide as the capturing this is also called MgO as input.

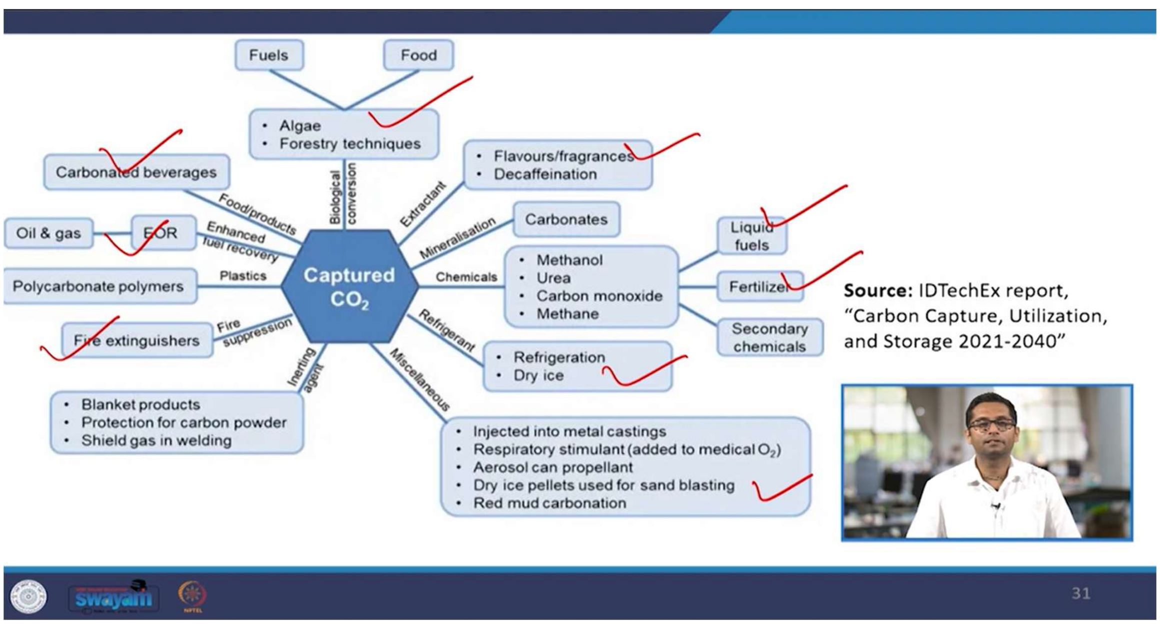


And if I look towards the available reserve of this particular magnesium compound we will find that India does have some reserve but they are not very much and we might not be able to carry out this activity sustainably. Because the supply of these kind of metals is not very high and further there are other applications where the need of these metals could be even higher. Then there is another type of methodology that has been propagated that we all use CO2 somewhere in our life.

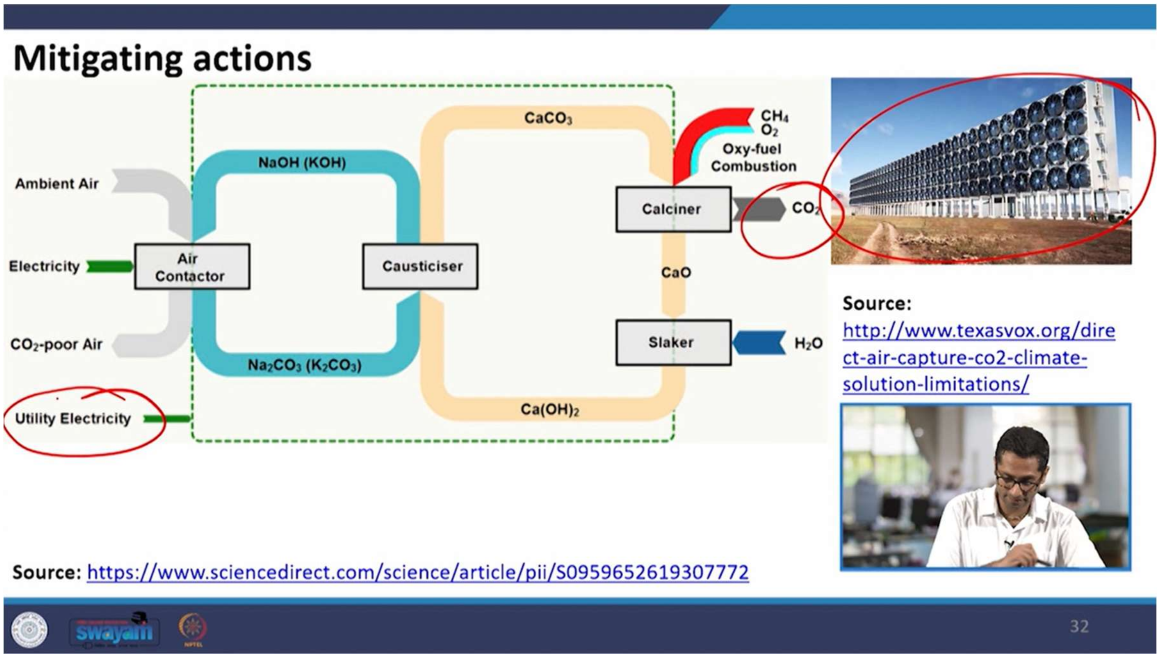


A typical use would be the carbonated drinks that you would be drinking every day for some occasions. Then we have application for dry ice which is the solid CO2. The urea production consumes a lot of CO2. Then there are certain chemicals or certain petroleum products which use CO2. So again it has been proposed why not we just capture CO2 and use this for the products.

So if we consider the global market of or the global market for CO2 is approximately 0.14 million tons a day. And if I compare that with the CO2 emissions that are happening on a daily level they are almost 5 magnitudes higher, 10 to power 4 million tons a day. So this proposition that we can have a significant market for CO2 again does not have much substance to it. Of course like we agree there is a big market for CO2 products but compared to the amount of CO2 that we are producing in a daily level the market is not that high.



And again there are also a lot of supply chains which have been proposed that you can capture CO2 use that in fire extinguishers, you can use it for enhanced oil recovery, the carbonated drinks we can use it for growing algae which could be used for fuels. Again this could be used as fragrances, there could be certain kinds of fuels, alternate fuels like the liquid fuels, fertilizers that can be preparing or dry ice or it could be going for the metal casting. But again the combined use doesn't stand anywhere as compared to this CO2 that we would be releasing on a daily level.



Also there are also companies or different big researchers working on the direct capture of air from the atmosphere. So this is one particular process wherein they would want the CO2 to be captured directly from the air. So it is not about the point sources from the power plant that I am talking about, they are capturing CO2 from the atmosphere which the concentration is almost 400 ppm. So they have two loops, one is of sodium hydroxide as well as sodium carbonate and the other is calcium carbonate and calcium hydroxide. And with the use of these two loops they are able to capture or produce concentrated streams of CO2 and this is what a typical plant would look like. It is gaining a lot of prominence in the developed world so we have a lot of companies coming up in the US, Canada or the Europe which would be able to capture the CO2 directly from the atmosphere. A typical application that they are looking for is in the greenhouses but again a major issue here is these kinds of processes are also very energy intensive.

So if you see this typical process it has a good application of electricity. Also it is using a consigner which would be consuming a good amount of methane which is coming from the fossil fuels. So here again like if you consider the amount of energy that it is consuming for the capturing of CO2 it might come to light it is also the amount of captured CO2 comes out to be almost half and plus the cost that is involved in these kinds of capture processes again quite high. Currently it stands at around 200 dollars per ton of

CO_2 which can make these kinds of processes too prohibitive in the future. So with this we have discussed quite a few areas or a few methodologies which could help us in mitigating the climate change problem but again many of them have their own limitations or drawbacks.

The best ones so far that have been chosen would be the ones related to reduction of energy or producing energy from an alternate source. So either we shift the source of energy to renewables or cleaner source like nuclear or hydro or other thing could be we can go for as much efficiency improvement as possible. If I talk about the other sources they have some major drawbacks and it is not likely to come up in a major way and this is one of the major reasons why everyone is now talking towards going towards renewables because that is expected to be the least resistance path to achieving the net zero targets or reducing the CO_2 levels and achieving a better future for all of us. So with this we end today's lecture and in the next lecture we will try to discuss some of the major international protocols and treaties or the agreements that has been achieved or that have been ratified for solving this problem of global climate change. Thank you.