Energy Resources, Economics, and Sustainability

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Week – 05

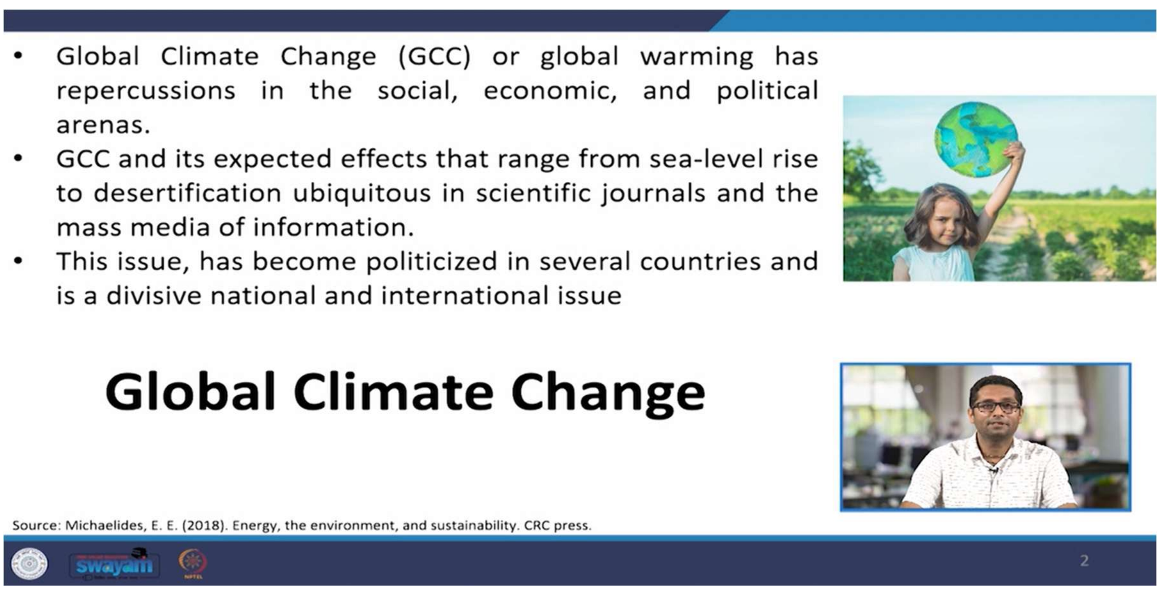
Lecture – 04

Lecture 24 - Global Climate Change

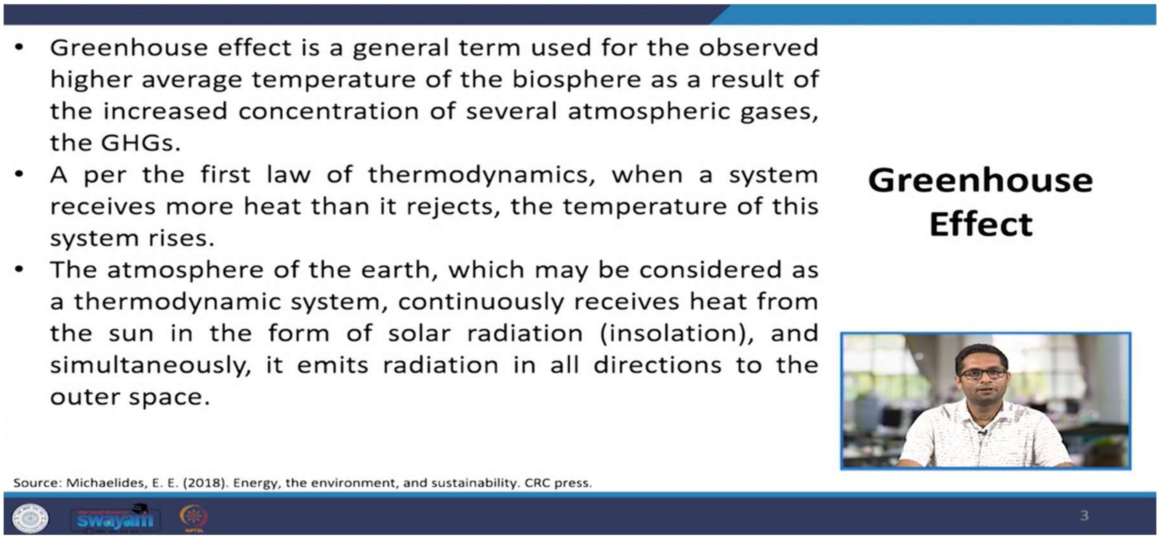
Hello everyone. Welcome to the course Energy Resources, Economics and Sustainability. In the past few classes, we have been discussing the recent advances in the terms of technology that has helped us solve many of the problems that arise through the global energy change or the global energy increase. Those problems were basically the emissions of SO2, lead as well as ozone depletion. We tried to understand how because of technological advancement coming of the communities together, understanding the problem from its root causes, people were able to come up with nice solutions and within a matter of decades, these problems could be solved to a great extent. In today's class, we are going to focus on a much bigger problem that's the global climate change or that of global warming, which I believe all of you would have heard about at some point in your life.

The problem as such has become a big sort of problem or a big issue that has been discussed in a lot of popular medias. We find people discussing the global warming problem, the energy crisis, the climate change problem on different social media platforms, different talk shows and different kinds of newspapers. And they tend to give us all kinds of different opinions. And many of these opinions tend to be coming not from a very scientific point of view.

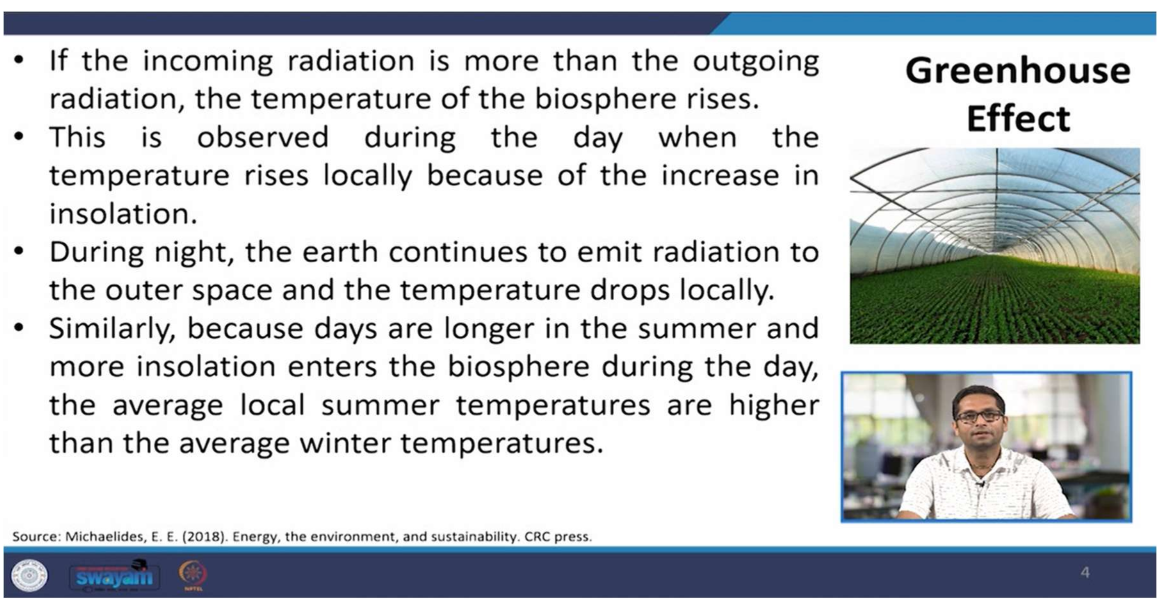
So the aim of today's lecture and the coming few lectures, what we give you a basic understanding, what is the problem of global climate change? How is this problem very different from the problems that we have been encountering in the past that was something related to sulfur oxides or acid rains, lead or ozone depletion? How are the dynamics very different? What is stopping us from having or finding a good solution to climate change? And what could be the possible ways of climate change mitigation? So these are some of the topics that we'll be discussing in the coming few classes. So if I talk about the problem of global climate change, this is also known by different terms like global warming and like climate change, energy crisis. Commonly it is annotated by the term climate change because it gives us a feeling something is changing. Whereas when someone using the word global warming, people don't want to use that because it gives the feeling that something is warming up. That's not a good feeling. Whereas change is something that is a part of a life since millennia and it's not something to be worried about. So people would want to give it a slightly neutral annotation and that is why climate change is a more of a unused term. But if you see the repercussions of this particular problem that we're talking about, it could be in our social lives or economics life, economical life and political life. And there have been political discussions. There have been scientific discussions on this.



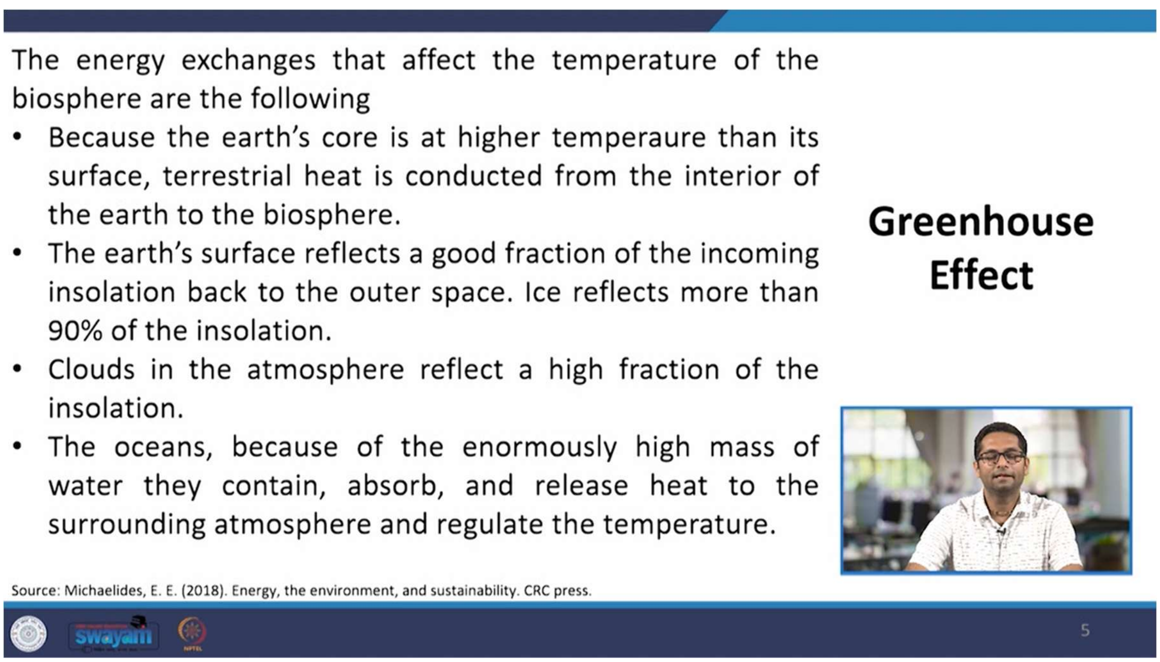
Now everything that we want to do, like what should be linked to sustainability, companies need to focus on sustainability. The students, the projects they are doing want to focus on sustainability. The countries and the policies they are making want the sustainability aspect to win it. So it's a big issue and some of it is politicized and some of it does have scientific backing to it. And what in this class you are going to understand these very facts.



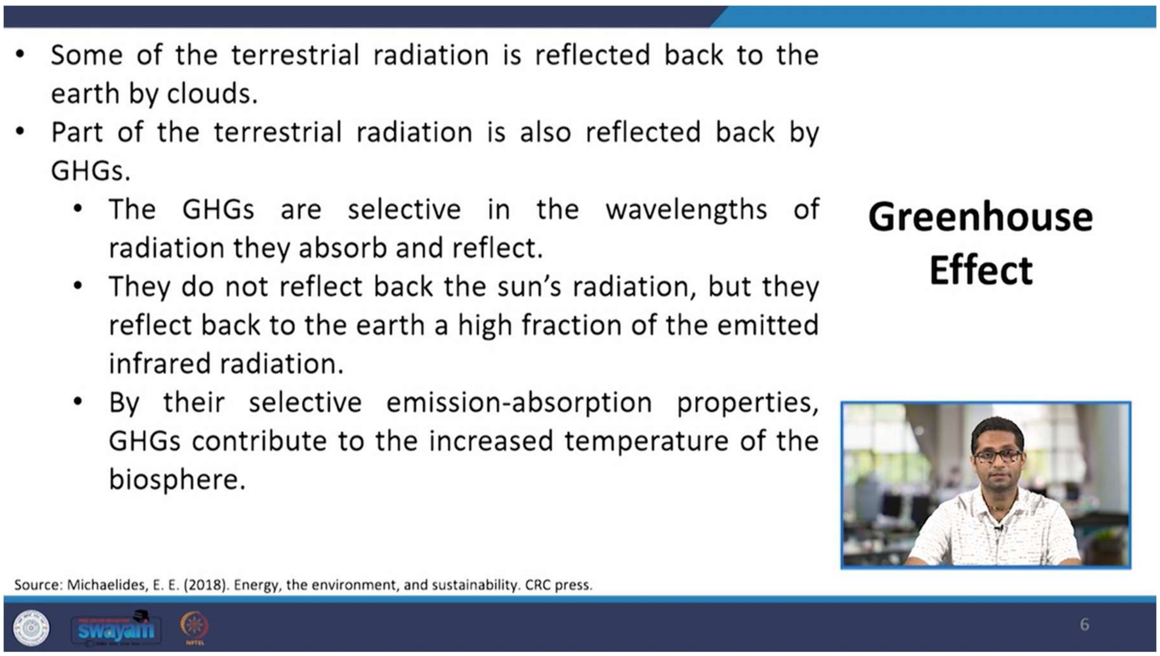
So first let us go ahead with the greenhouse gas effect or the greenhouse gases that have been the center of this major problem that we are talking about. So when we talk about the greenhouse gas effect, this is basically the increasing of the average temperature of the biosphere, which is the atmosphere which we are interacting in on a daily basis. So if we go by the basic laws of thermodynamics, if we consider any system, any control volume, if it is receiving more energy, then it is able to emit the temperature or the energy is going to accumulate and its result will be the temperature of that particular system is going to rise. And this is something that happens with the planet Earth as well. We continuously receive insulation from sun in the form of the solar radiation and the earth also emits a great deal of radiation to the outer space and that happens again 24/7.



So during the day what happens is the insulation from the sun that we receive is much more the radiation than we are or the planet Earth is radiating to the atmosphere outside and something opposite happens during night time in which the radiation from the sun dips greatly whereas the radiation that is coming out from the earth to the atmosphere tends to be more and this is why you would experience that nights are generally cooler than the day times. Something similar also happens during the different seasons in the summers when we have longer days. The insulation that is coming from the sun tends to be more than the radiation that the earth is emitting and that is one of the reasons why summer temperatures tends to be higher than the average winter temperature. So this is a normal thermodynamic phenomena which all of us have been experiencing since many years. But apart from this energy exchange there are also certain other exchanges that happen.



One particular exchange or some of the exchanges that are experienced is the earth's core is at a much higher temperature than the surface of the earth and this heat is again is conducted from the interior to the surface of the earth and finally to the atmosphere. Then the earth also reflects a good fraction of the sun's radiation and if you see different types of landscapes would have different radiation capacities and the most radiation capacity could be attributed to that of surfaces that are covered with ice. Ice covered surfaces have the capacity to reflect almost 90% of the insulation that they receive. Further clouds play their own role in blocking the insulation as well as reflecting the insulation that is coming from the sun. Clouds also tend to reflect some of the radiation that is coming from the earth. The oceans again have their vital role. They are huge water bodies, majority of the earth is covered by the water bodies. They can absorb and release a good amount of heat and they also play their role in regulating the temperature of the atmosphere.

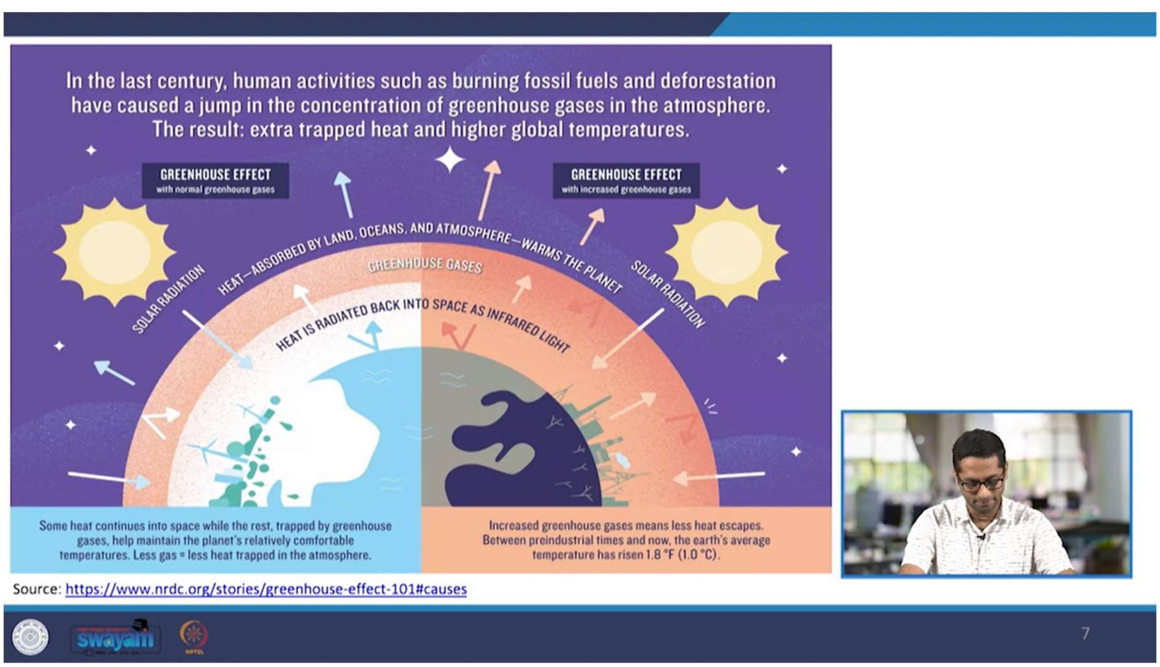


Further we also have the terrestrial radiation get reflecting back to the earth by the clouds and then there is one particular feature the greenhouse gases. The greenhouse gases have one particular feature that they are very selective to what kind of radiations they would want to absorb and what they would want to reflect.

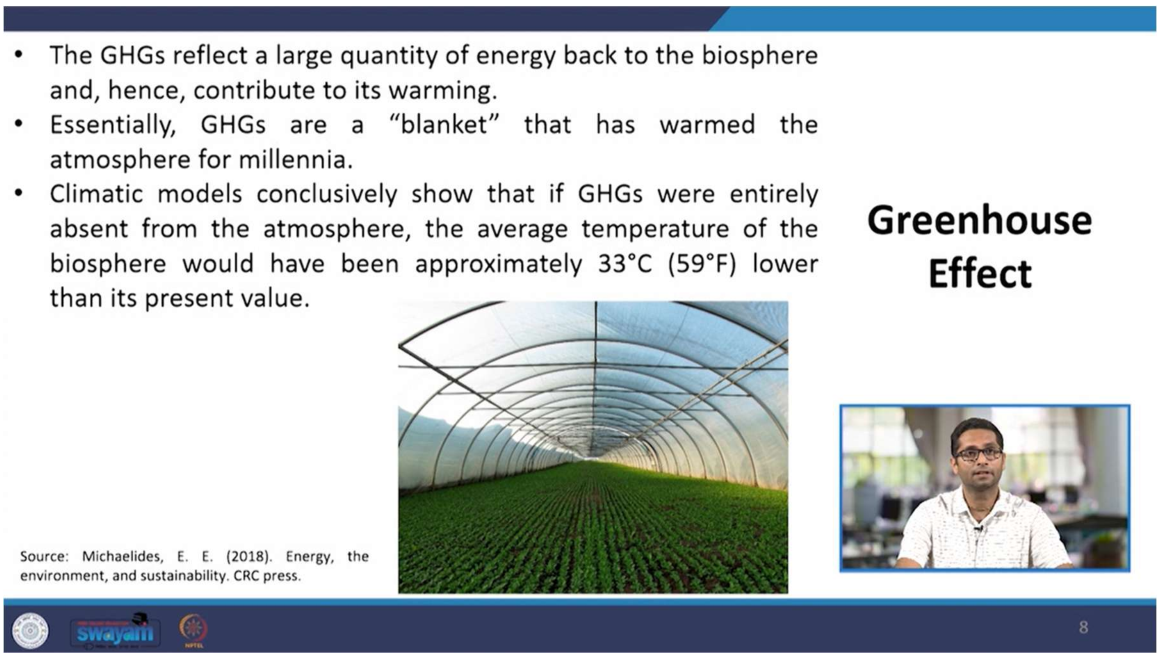
Normally the GHGs are almost transparent to the insulation of the sun which is coming from the sun but they are very active in reflecting the radiation that is coming from the planet earth and that is what makes their role very interesting. They have been like regulating the temperature on the earth since the since the planet came into being. So some might someone might want to question what if there were no GHGs in the atmosphere? Well if there were no greenhouse gases the temperature of the earth has been predicted like it would be 33 degrees lesser than what the average temperature is now today. So if the average temperature that we are coming across around 20 degrees

Celsius if there were no GHGs present in the atmosphere I am talking about just zero GHGs the temperature might be less than minus 10 degrees Celsius which means the life as it is present on earth might not be able to flourish or thrive as it has been doing since thousands of years. So GHG is like a protective layer that is helping build the temperature on earth it is building the temperature that is just optimum for the survival of the life on earth but what happens when there is an increase in GHG it also tends to have increased the reflection of the radiation that is coming from the earth when that happens the temperature of the earth also begins to rise slowly.

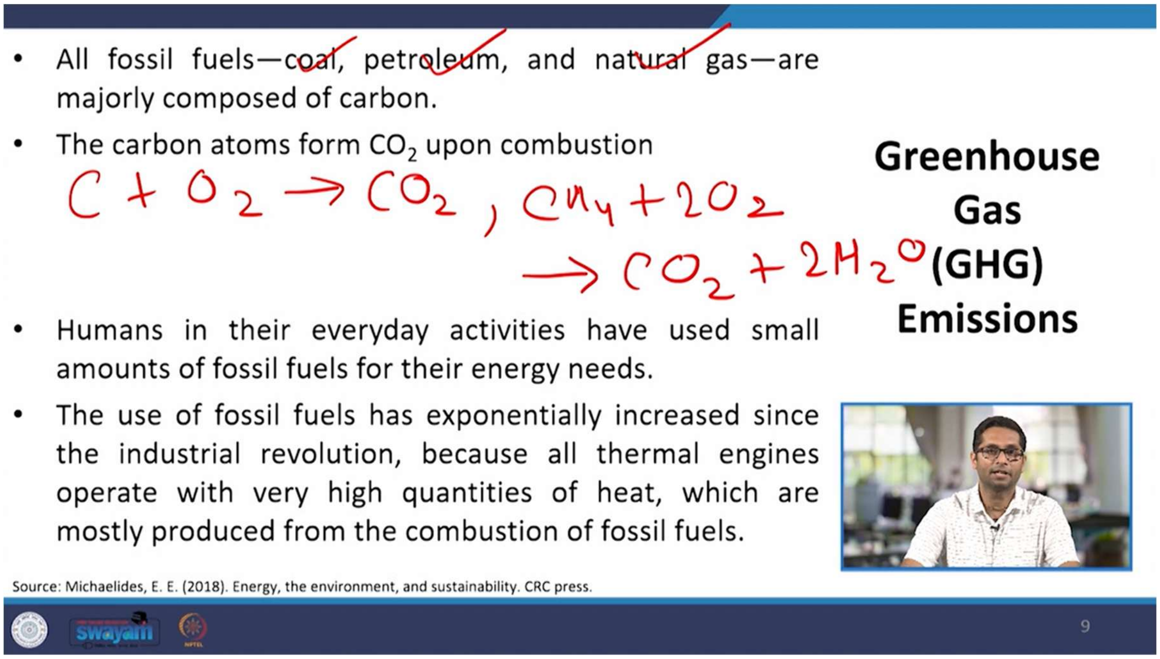
Now the temperature in itself might rise a few degrees Celsius but it effect that it would have could be long term and could last long term as well as the spatial variation could be huge it could lead to great amount of weather disturbances in terms of extreme weather events like cyclones or hurricanes it can also change the weather pattern in terms of the growth season of certain crops. The areas which were very nice for cultivating crops might in future become deserts and the opposite can also happen it might also happen that deserts might be receiving snowfall and these are the kinds of extreme weather events that are led because of temperature change further few respects of temperature range could be the increase in the sea level.



Let us try to understand the same concept with the help of a simple diagram so here in you can see the different types of radiations being coming from the sun and being emitted from the earth so as such there is a nice thermodynamic equilibrium that has been existing for many years but what has happened because of or since the onset of the industrial revolution is that there has been an increase in flux of the GHG gases primarily led by CO2 and this has led to a great amount of reflection of the radiation that is coming from the earth surface which has basically increased the temperature or led to an increase in the average temperature of the planet earth.



Now we understand that the GHGs reflect a great deal of energy back into the biosphere and it's like a blanket that has been warming the earth for millennia and it's not that we can just do away with the GHGs. GHGs are vital for the existence of planet earth but any change or even a small change in the concentration of GHGs in the atmosphere can have great consequences that could lead to economic losses that could lead to environmental losses that could have political implications.

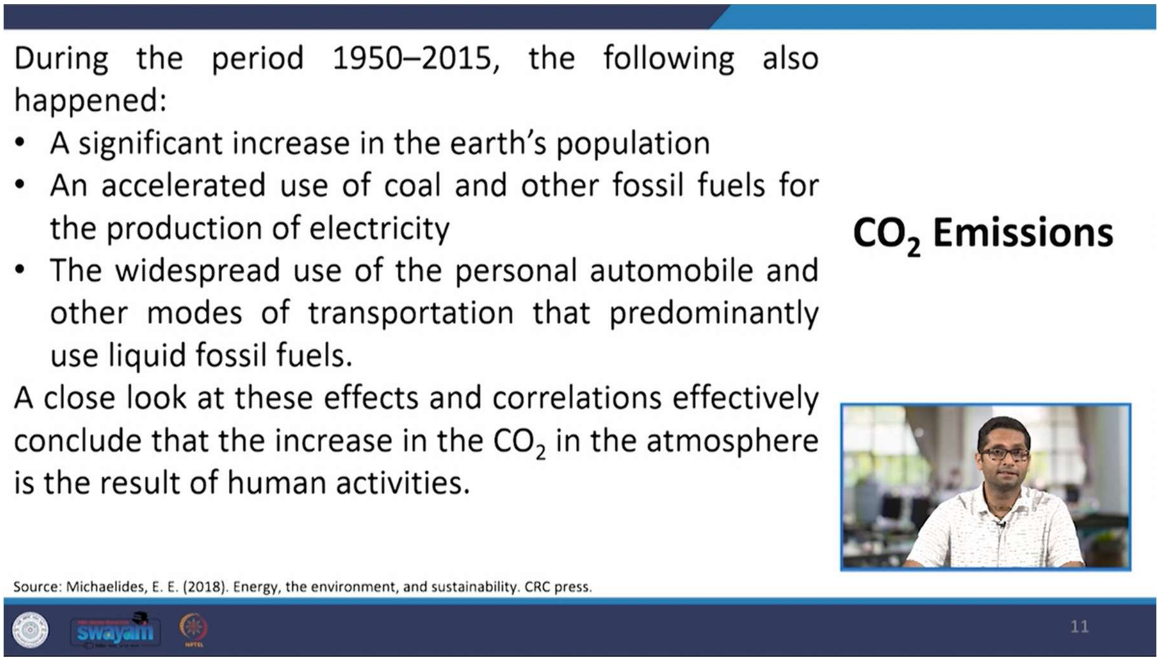


Now a major source of these GHGs is attributed to the increased amount of fossil fuels which could be attributed to coal, petroleum and natural gas. We understand that all the three major fossil fuels are composed of carbon and also some amount of energy is coming from hydrogen. The carbon items whenever they are getting combusted would form CO2. The basic equation we all understand would be the carbon combining with oxygen molecule forming the CO2 or the other pathway could be methane which is a major component in natural gas combining with two molecules of oxygen giving in CO2 plus two molecules of water. These could be some other ways of producing but primary product that we see is the production of carbon dioxide and this is one of the major reasons why there has been an increase in the GHGs primarily led by CO2.

And humans as such have been using these fossil fuels since many years. First it used to be smaller but now with the onset of industrial revolution as well as highly mechanized way of living where the energy consumption has increased manifold we would consume energy for thermal engines, we would consume energy for centralized heating, we consume energy for the transportation, we consume energy for the production of electricity which is primarily coming from the burning of fossil fuels and these fossil fuels irrespective of which fossil fuel you are using called petroleum and natural gas would emit CO2 in the atmosphere. Some fossil fuel like natural gas would be a bit cleaner than coal but the end product primarily remains CO2.

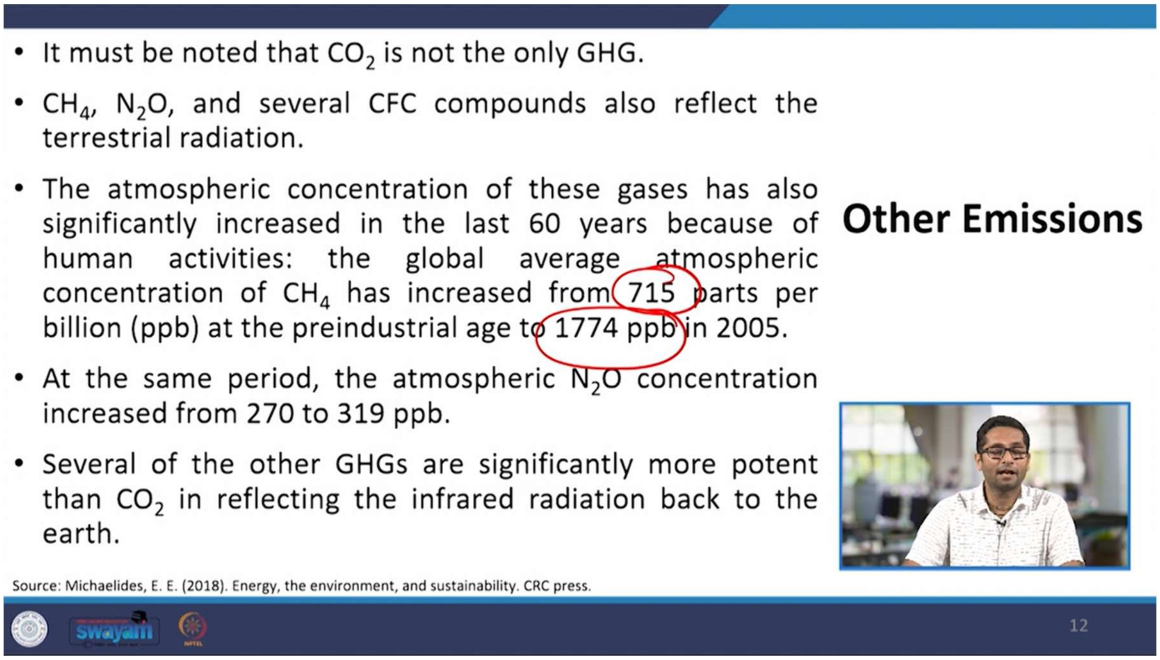
And if you look at the CO2 emissions for the different countries and the globe as such we see they are nicely correlated with the increase in consumption of the fossil fuels and the CO2 is directly correlated to that. We see the major industrialized nations of the world, the US, the European Union, China, UK all have had like a vast increase on CO2 emissions and this is primarily attributed to the increased use of fossil fuels in the past.

We see countries like US by far are one of the largest emitters of the world which have emitted more than 400 billion tons of CO2 since the 1970s. Of course these figures could be a bit different from the source that you are referring to but the magnitude like would more or less or the comparison of the relative difference would more or less remain the same. And we also see India here rising, the rising in the emissions and it's rising at a very fast rate. Further we can see even the predictions for the future is that like for the next 25 years or so we are going to increase the CO2 levels. And these are very nicely correlated with the onset of industrial revolution as well as the date from which we started using the three main fossil fuels for mass production of energy.



And during the 1950s to 2015 or so of course there was an increase in the fossil fuels that we have been using but there have been also a significant increase in the earth's population. The population also has been rising at a very fast rate in the last 70 years or so. More the population, more are the energy needs and this has also further accelerated the use of fossil fuels. Further there have been much more use of the fossil fuels than the way before. People would want to own their own automobiles, people would want to use as much as electricity as they can which was not the case a few years back.

So if you also look in our lives probably 20 years back we were not using as much energy as we are using today. Further as compared to other countries India is using just a very small portion of the energy on a per capita basis. This is something that we have discussed in the initial lectures. And if you look closely we see that the CO2 in the atmosphere is primarily attributed to the human activities. Of course there have been discussions that the CO2 emissions could be coming from other sources but if one was to go through the data it shouldn't take much difficulty to correlate the increase in CO2 that has been happening in the past and the increase in the US activities. Primarily the anthropogenic activities with respect to the increase in the energy production. Also it also needs to be understood that CO2 is not the only GHG.



Now a greenhouse gas is something that would basically come up with a greenhouse gas effect which means it is able to reflect a great portion of the radiation that is coming from the earth surface where it doesn't cause any problem to the solar insulation that is entering the earth. So CO2 is one of the gas that is most abundant but there are other gases primarily examples could be methane, N2O and several of the chlorofluorocarbons which also have very huge GHG potential. Further it also needs to be understood that it is not only the CO2 levels that are rising it has also these gases, the other gases which are much more potent than CO2 have also been rising in terms of the concentration in the atmosphere in the past 50 or so.

Just for the sake of example if we consider the increase in the level of methane so in the last 60 years it has increased from like 715 ppb parts per billion to almost more than double of around 1774 ppb in the year 2005. Something similar has been observed for the concentration of N2O which again has been increasing its level from 270 ppb to 319 ppb and there have been several other GHGs which were coming from the CFCs which were causing ozone depletion as well and again there were certain gases that were having very less ozone depletion potential but again a very high GHG. So the refrigerants that were used in the past in air conditioning also have very potent GHGs.

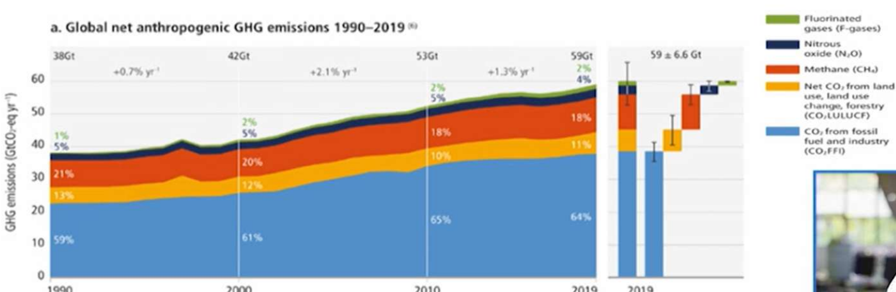
Substance	Relative Potency per Unit Volume (and Unit Mole)	Relative Potency per Unit Mass
CO_2	1	1
Methane, CH_4	21	58
Nitrogen oxide, N_2O	206	206
Refrigerant-12	1,580	5,750
Refrigerant-114	1,830	4,710
Refrigerant-134a	9,570	4,530
Refrigerant-142b	10,200	4,130

Potency of GHGs in Reflecting the Terrestrial Radiation, Relative to CO_2

Source: Fisher, D., Hales, C., Wang, WC. et al. Model calculations of the relative effects of CFCs and their replacements on global warming. Nature 344, 513–516 (1990). https://doi.org/10.1038/344513a0

You can see the basic difference between the potency of the different GHGs with the help of this table that is in front of you. CO2 is often attributed as the base gas which is expected to have the GHG potential or the global warming potential of 1. If we consider a gas like methane it is 20 times more potent than CO2 and if we go for other gases like N2O the level could be 206, other refrigerants which might not have very high ozone potential but it could be having a very great GHG potential in terms of maybe 10,000 times or 9,000 times that of CO2. We will be discussing these things in much more detail when we go to understanding LCA but this is just to give you an understanding there are other gases which might be emitted in a very small amount but if you consider the relative potency that could be thousands of times much more than that of CO2.

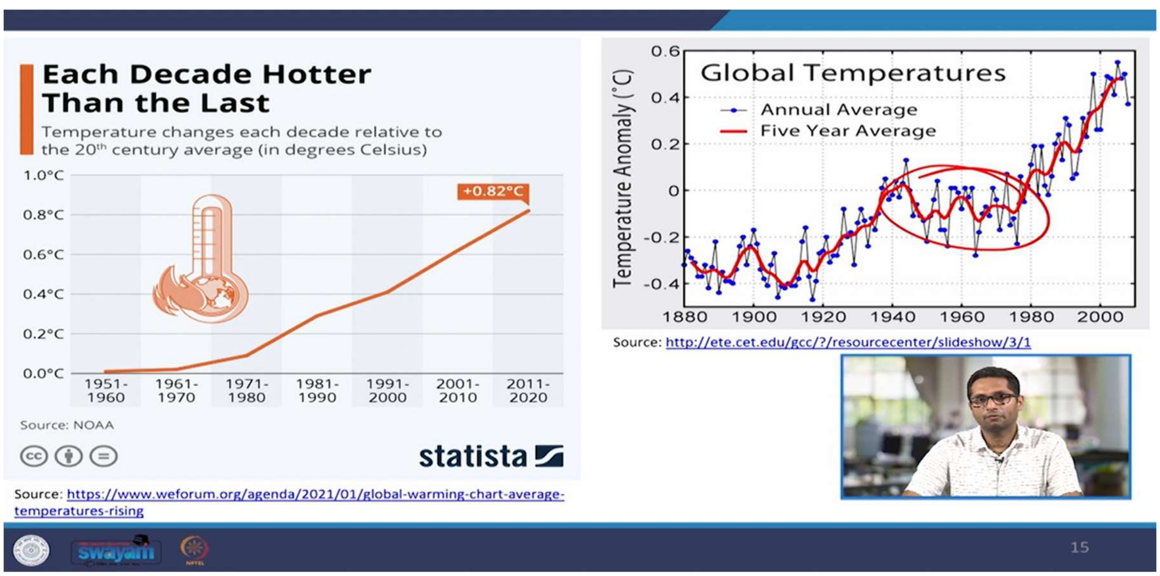
F-Gases (HFCs, PFCs and SF6) contributed about 2% to anthropogenic GHG (greenhouse gases) emissions in 2019, about the same percentage as in 2000 and 2010, although F-gas emissions have increased considerably due to the replacement of Ozone Depleting Substances by HFCs. Average annual GHG emissions during 2010-2019 were higher than in any previous decade, but the rate of growth between 2010 and 2019 was lower than that between 2000 and 2009.



Source: https://www.fluorocarbons.org/news/ipcc-report-low-gwp-refrigerants-including-hfos-can-contribute-to-climate-change-mitigation/

Further if we consider how the total GHG gases have been varying in terms of CO2 equivalent. So if I equate all the gases in terms of the equal amount of CO2 we can see that in the past or till very recently 2019 almost 64% of the GHG emissions were directly attributed to CO2 emissions. And another 11% could be coming from the land use change.

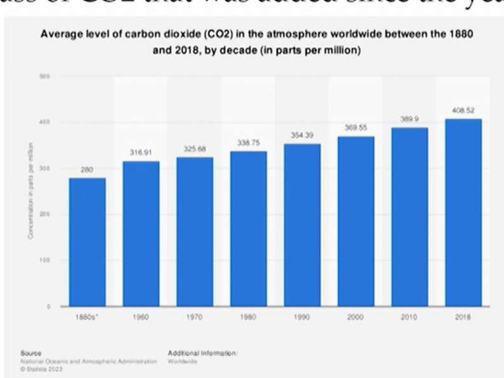
Then methane is another big greenhouse gas that is responsible for roughly 18 to 20% of the total GHG gases. We also have the N2O which is coming around 5% and then we have the different CFCs which are also referred to as the F-gases causing around 1 to 2% of the total or forming the total of GHG emissions. So it needs to be understand that a majority of the CO2 emissions or the GHG emissions are coming from direct emissions of CO2 and that is one of the reasons why everyone is talking about the carbon emissions and also CO2 is attributed as a base gas and all the gases are converted or reflected in terms of CO2 equivalent. So how many kgs of CO2 equivalent that gas would is basically is reflecting effectively. But again CO2 remains one of the major gas that needs to be understood, that needs to be tackled and the concentration of which needs to be brought down.



Also it has been found that this increase in CO2 has also been very nicely correlated to the increase in temperature of the world. So the average temperature of the globe or of the earth has been steadily rising. So if we consider the temperature rise between in the last 70 years or so it has been roughly around 1 degree Celsius or so. And people would also be saying that of course this temperature rises have been happening in the past as well to some sense but if we see the total rise such kind of phenomena is not experienced or cannot be related to the past. It is something that is very nicely correlated to increase of the GHG emissions. Further there might be some studies who would say that if you look at the annual average we see certain periods where the temperature has been rising as well. So if you see the graph on the right hand side you see there have been a few blocks of here when there have been stagnation in the global temperature or almost of certain depth. So if you see this the area between 1940s to 1970s the global temperature was almost stagnant or it was slightly reducing as well. So people might come up with theories like this like there have been periods of stagnation as well. But if we consider the temperature rise for the last 150 years or so we can say that there has been a definite rise in the temperature. There have been like there have been regions or like there have been time spans when it has been stagnating. But if you see the overall it has been increasing and this is something of a worrying phenomena. If we take a 5 year average which is a much better estimation or to understand the temperature of the planet earth it has been continuously rising since the last 150 years or so. Further this is a very complex phenomena that has been correlated with weather phenomena like El Nino, La Nina which are basically related to the way the movement of oceans or the water bodies are considered and also like how the vegetation and weather is occurring has a lot of effect on it. But if you see the overall effect it leads to one conclusion that the temperature has been significantly and steadily rising in the past.

Example

It is estimated that if all the air in the atmosphere were under standard conditions (1 atm pressure and 298 K), its volume would be approximately 6×10^{18} m^3. Estimate the mass of CO2 that was added since the year 1880.



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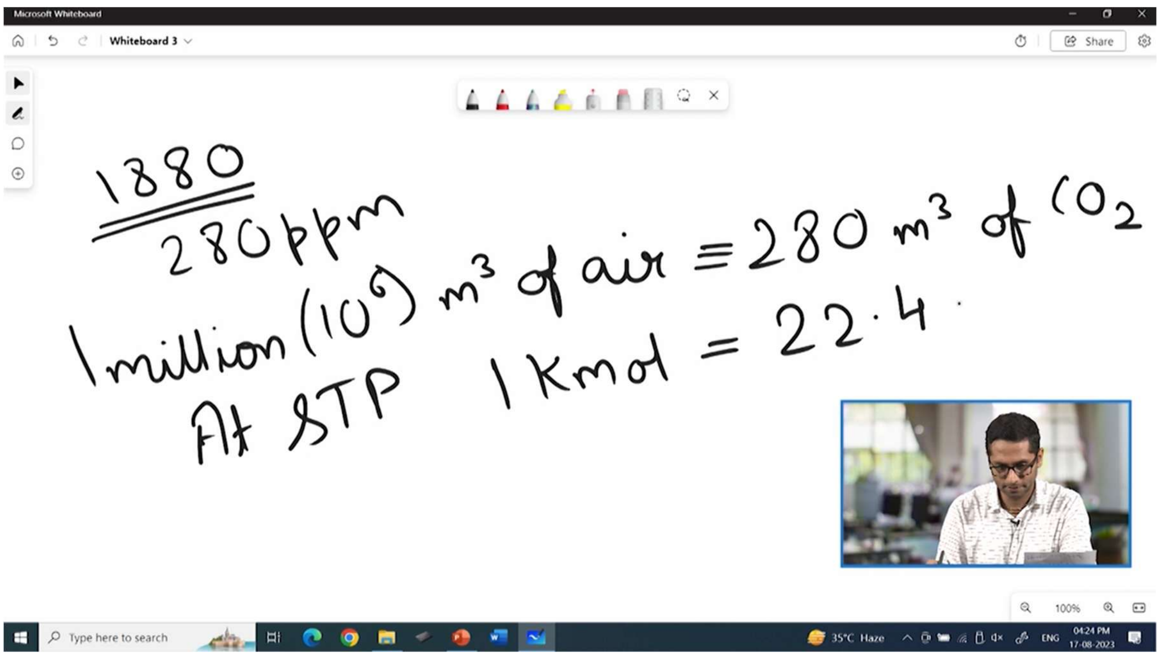
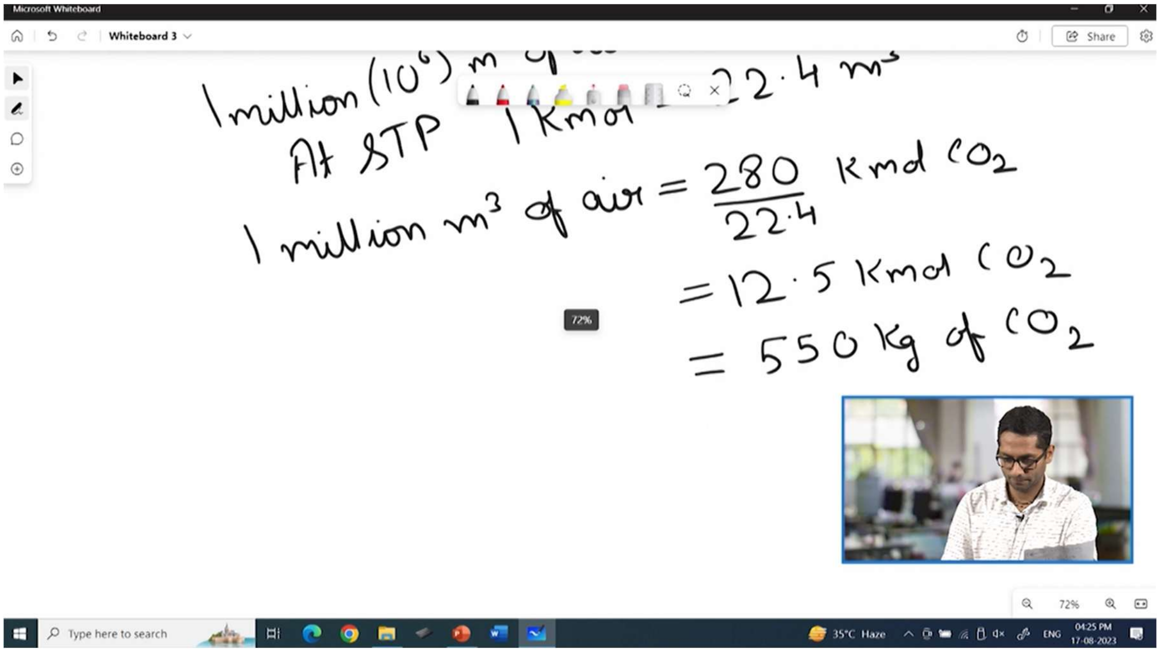
Let us also try to estimate the amount of CO2 that would have been emitted by the planet earth in the last 150 years or so. So we have a nice data about how the concentration of the CO2 in the atmosphere has been increasing from around 280 ppm that was there in the industrial area or like the start of on the onset of industrial area to the present around 400 plus ppm. So the CO2 concentration has been increasing at a steady rate and it used to be around 280 ppm and currently it is around more than 400 ppm and you can see that in the graph. Also the volume of the atmosphere can be approximately approximated by around 6 into 10 to the power 18 meter cube and this is at 1 atm and 298 Kelvin. Similar calculation we did in the first class of this course as well. If we were to estimate the mass of CO2 that would have been added since 1980s let us try to do this calculation. So let us move to the whiteboard for this.

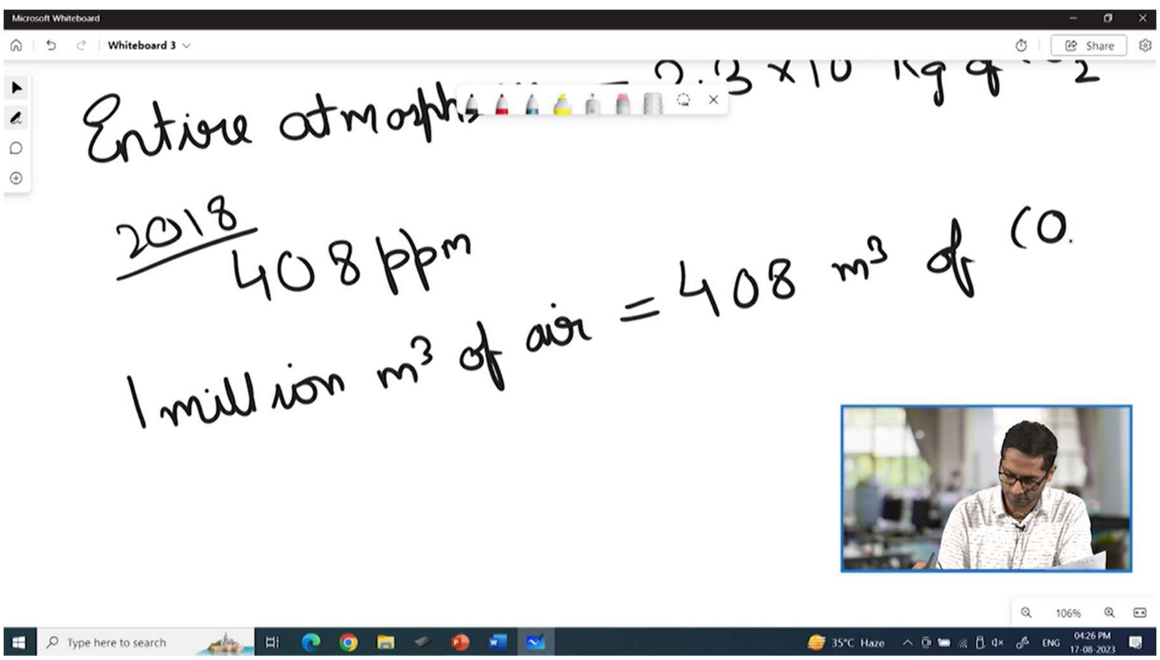


So let us consider the year 1880 and that is near when the industrial revolution started or near the start. So at that time the CO2 concentration was almost 280 ppm. It basically means 1 million or 10 to power 6 meter cube of air would have 280 meter cube of CO2.

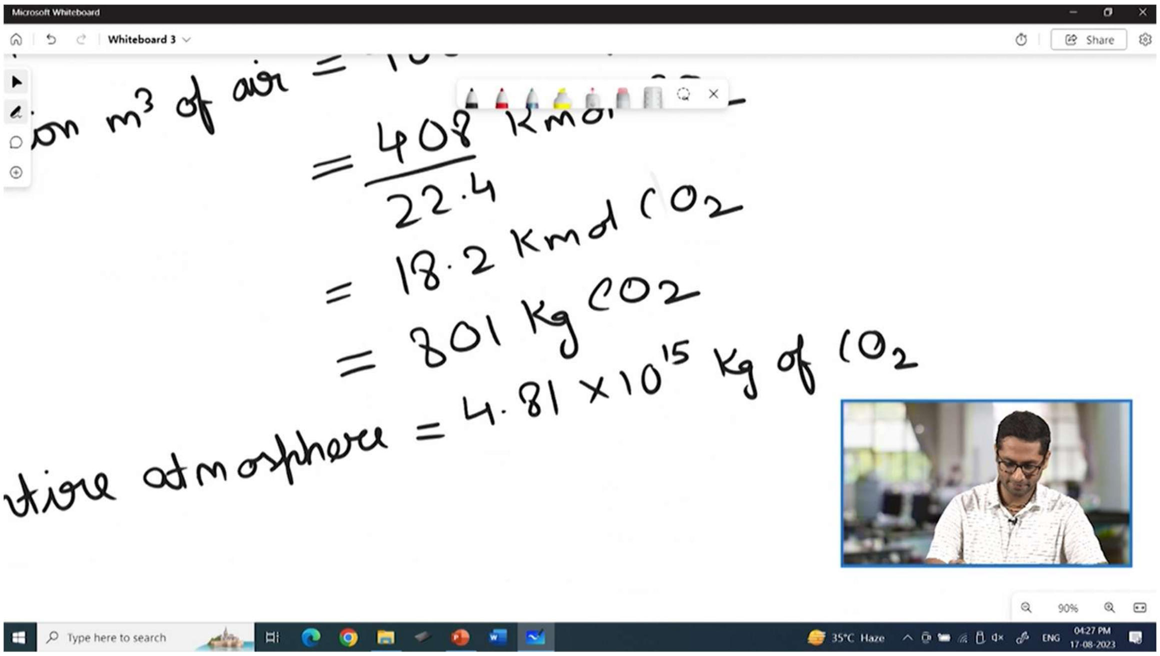
So one part per every 1 million parts of air. So if there were 1 million parts of meter cube of air the volume of CO2 in that air would be around 280 meter cube. You also understand that at STP 1 kilo mole is equal to 22.4 meter cube or 1 mole is equal to 22.4 liters and this is something we all have studied in the past as well.



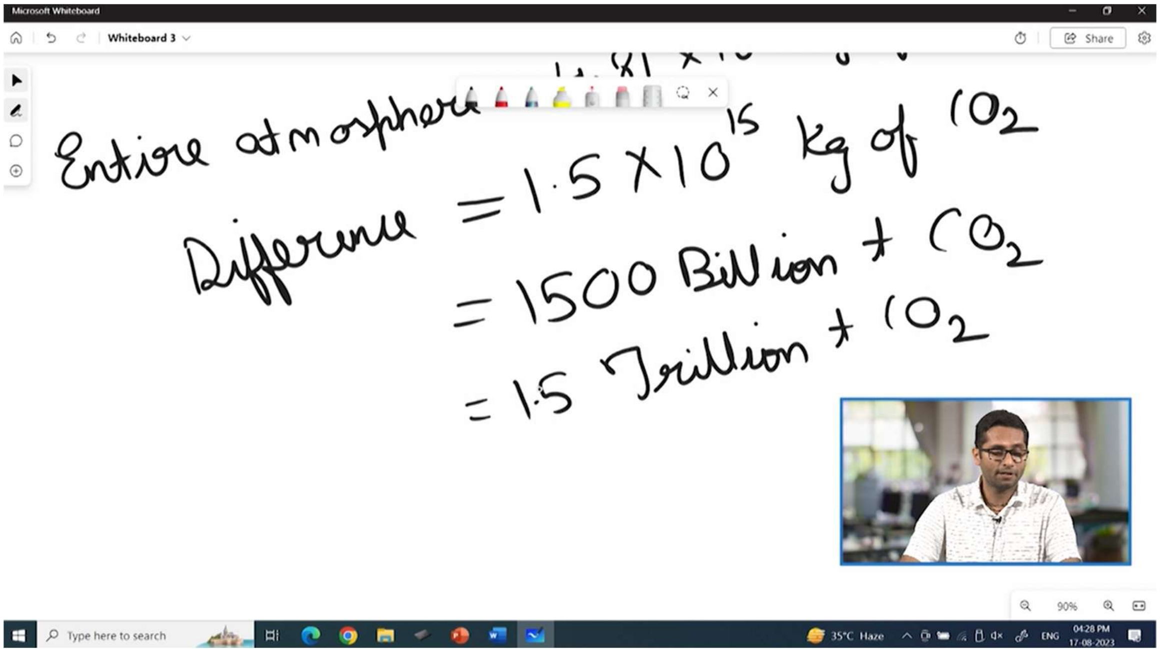
So if there was 1 million meter cube of air it meant there were 280 divided by 22.4 kilo moles of CO2 that were present and if you do this calculation this would be roughly 12.5 kilo moles of CO2. We know the molecular weight of CO2 which is 44 multiply with that and this would come around to be around 550 kgs of CO2 per 1 million meter cube of air.



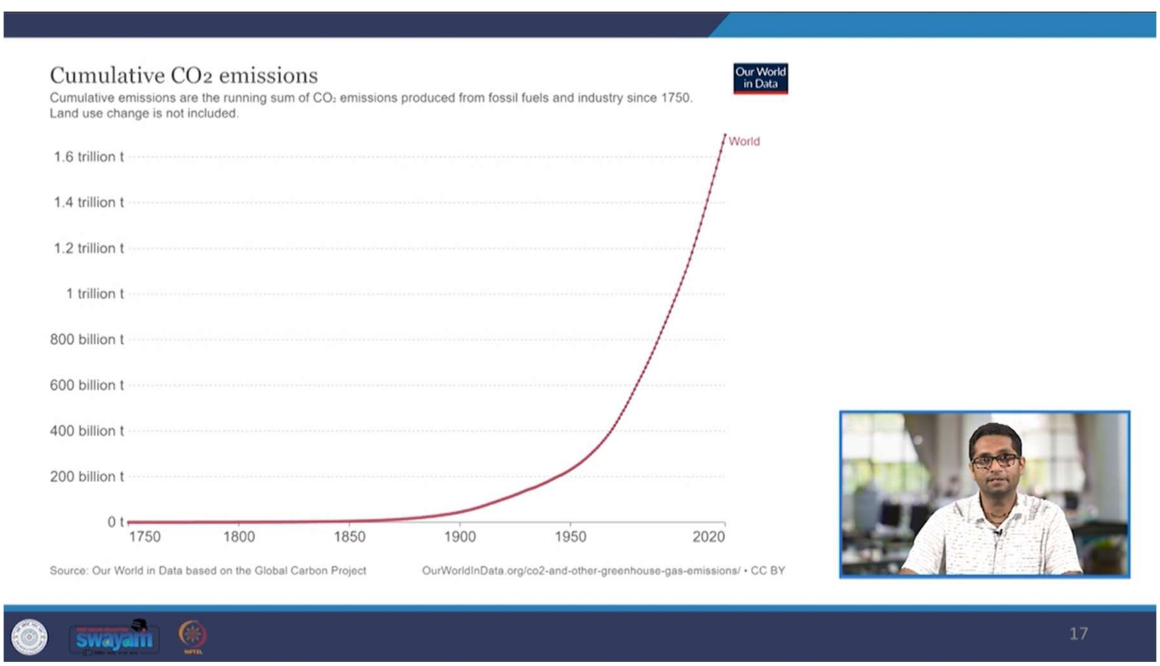
We also know that the entire atmosphere can be approximated as 6 into 10 to power 18 meter cube and so if I talk about the entire atmosphere I just multiply that factor and this would come around to be roughly 3.3 into 10 to power 15 kgs of CO2. So this was the amount of CO2 that was there at the onset of the industrial revolution. Now fast forward it to the recent history in the year 2018. We know the concentration is almost 408 ppm. If we consider the data today it might be slightly more than that. So we know that this is equivalent to like 1 million meter cube of air is equivalent to 408 meter cube of CO2.



So if I see that I can divide this again by the factor of 22.4 to give me kilo moles of CO2. This would roughly come around to be 18.2 and further I can multiply with the molecular weight of CO2 and this would come around to be 801 kgs of CO2 and this is for 1 million meter cube of atmosphere. And if I was to talk about the entire atmosphere and I multiply that with the volume of the atmosphere and this value would come around to be roughly 4.81 into 10 to power 15 kgs of CO2. So there is no doubt that the absolute amount of CO2 in terms of kgs has been increasing. So earlier when it was around 3.3 into 10 to power 5 kgs and now it is 4.81 into 10 to power15 kgs of CO2.



I can take the difference of the two and this would come around to be roughly 1.5 into 10 to power 15 kgs of CO2 or I can also say roughly around 1500 billion tons of CO2 or I can also say 1.5 trillion tons of CO2. So this is the tons of CO2 that has been emitted by the anthropogenic activities that has been extra since this whole set of industrial evolution. If we go back to the slides and we try to see the cumulative CO2 emissions since the past we see that like the figure is quite close to what has been in reality as well.



So it is around 1.6 trillion tons of CO_2 that has been emitted on a cumulative level and different countries have their own emission profiles some have been emitting less some have been emitting more but overall there has been a lot of emissions of this particular gas that has been going into the atmosphere and this very well correlates with the increase in the fuel uses in terms of fossil fuels, coal, oil and natural gas in the industries as well as the industry energy production industries. So we understand that these kinds of industries have been a major source of CO_2 and this has also been correlated with the increase on CO_2 and this CO_2 again correlates very nicely with the temperature rise as well as the phenomena of global warming or the climate change which is responsible for harsh weather events. So with this or in this class we have tried to get some basic understanding of the concept of global climate change. In the future classes we are going to understand this concept even in more depth and we are going to discuss what are the ways in which we can mitigate or what could be the key methodologies for mitigating this problem of global climate change. With this we end today's class. Thank you.