Energy Resources, Economics, and Sustainability

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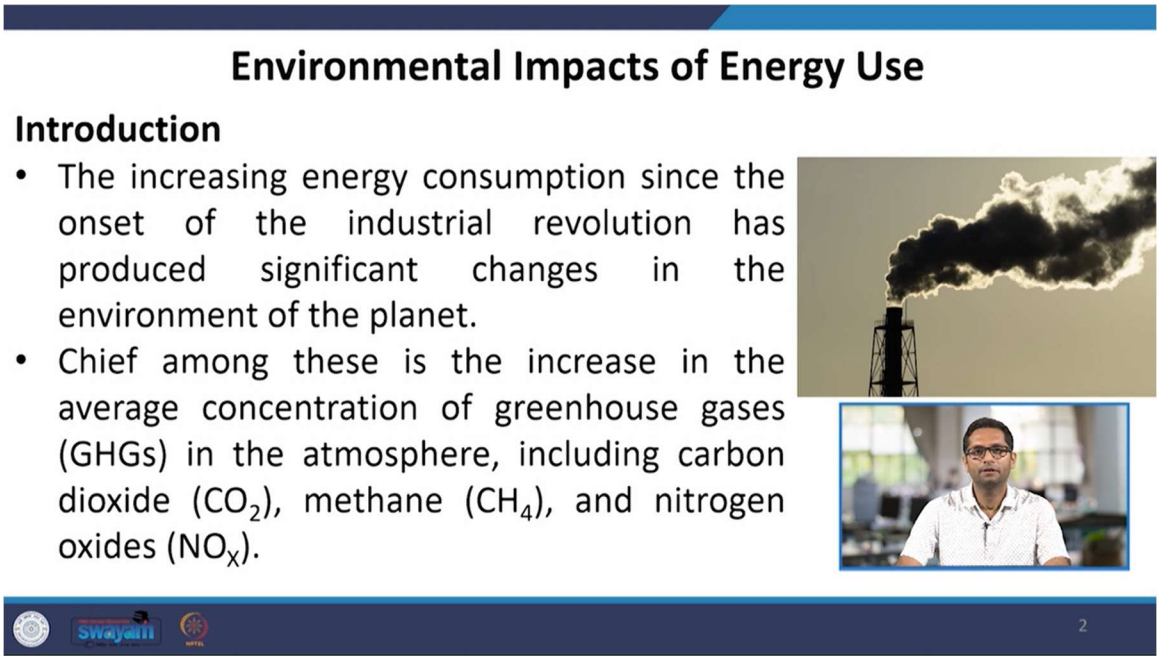
Week – 05

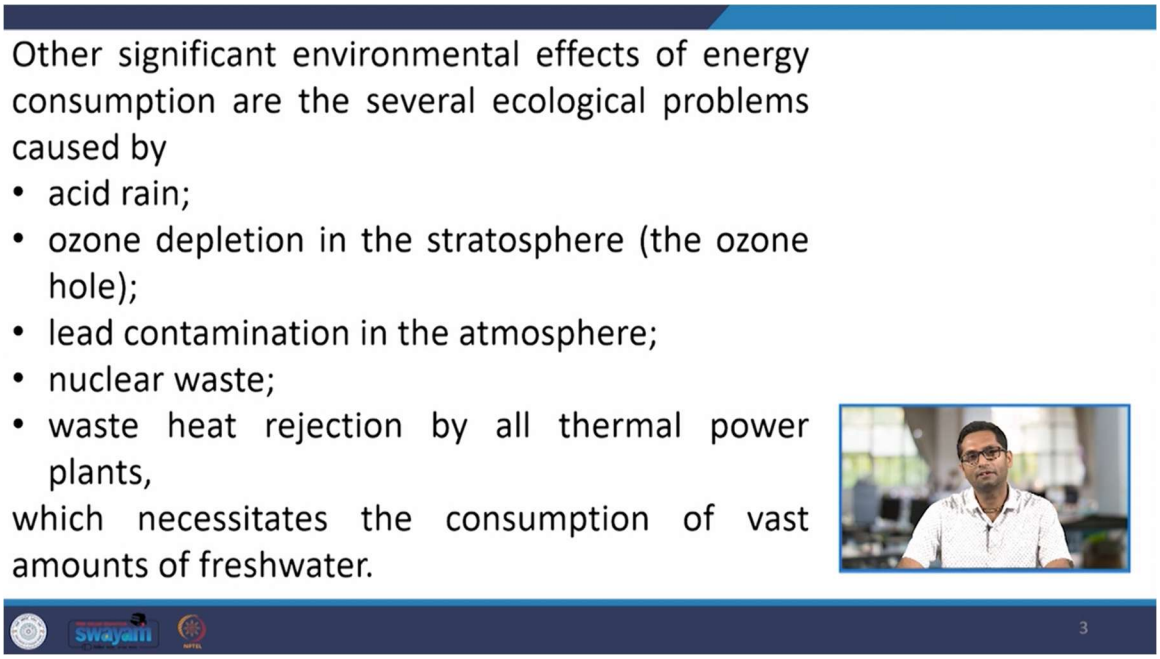
Lecture – 01

Lecture 21 - Energy, Ecology, and Environment

Hello everyone. Welcome to the course Energy Resources, Economics and Sustainability. In the past few classes we have been discussing the profitability as well as the economic effects or the economic matrices of the different energy related processes. Now from this class onward and for the future few classes we will be focusing on the environmental effects of the different energy related pathways. We will try to understand the interplay of different forces in terms of energy, ecology and environment. Most of us are quite familiar that any energy process that we use has had major environmental consequences and this has particularly been true for the fossil fuels which we have been using in the past 200 years or so.



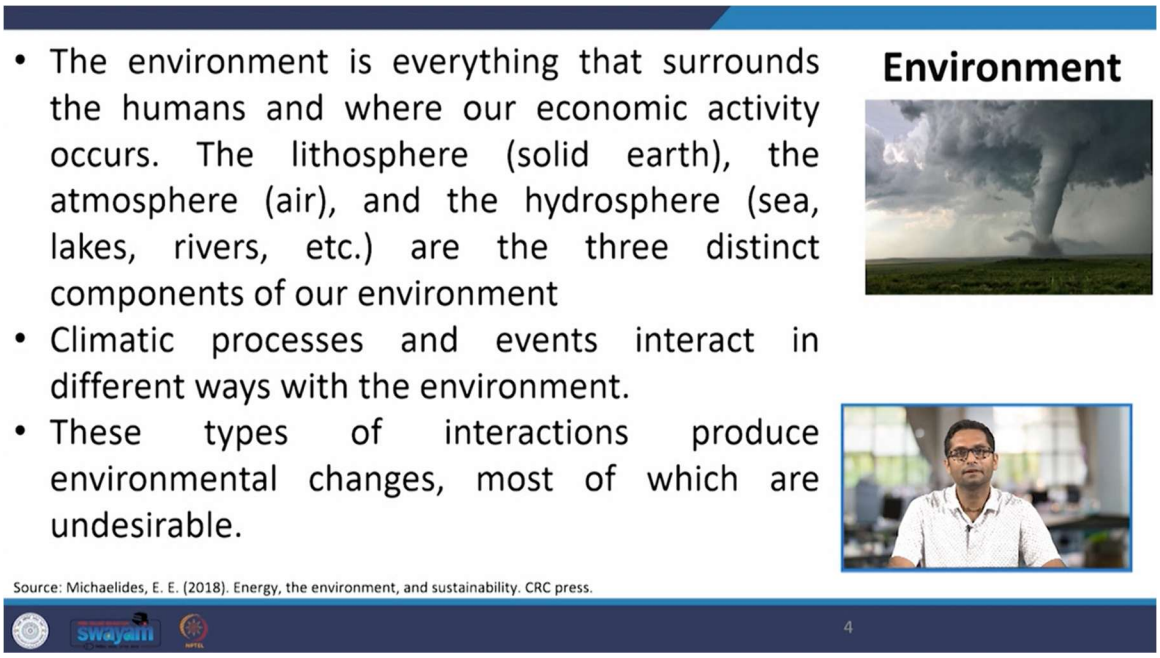
With the onset of the industrial revolution and a great amount of increase in the manufacturing of the products which required a lot of energy for their production, raw material extraction, consumption, this has also been accompanied by a lot of emissions into the atmosphere and the most prominent among the emissions have been the different kinds of greenhouse gas emissions which have been led by carbon dioxide, methane, the NOx emissions and all of these emissions are primarily coming from the combustion of fossil fuels which was to provide energy either in terms of heat or electricity. This has been a major emphasis because the GHG forms a blanket around the earth which have been responsible for a steady increase in the global levels of temperature and these levels of temperature have also been accompanied by different kinds of climate changes which has led to severe weather events which also had impact on the day to day life of humans which is also leading to an increase in sea level rises and these are some of the effects that we are going to study in detail as we proceed further. But apart from the effects of the different energy related production scenarios in terms of GHGs, there have been other effects as well. There have been an effect which could be called the acid precipitation.



We have seen an increase in acid rains that has been happening in the past. We have had seen the ozone depletion which have led to creation of ozone holes over different parts of the world. The one over Antarctica has been a major case study. There has been a lead-

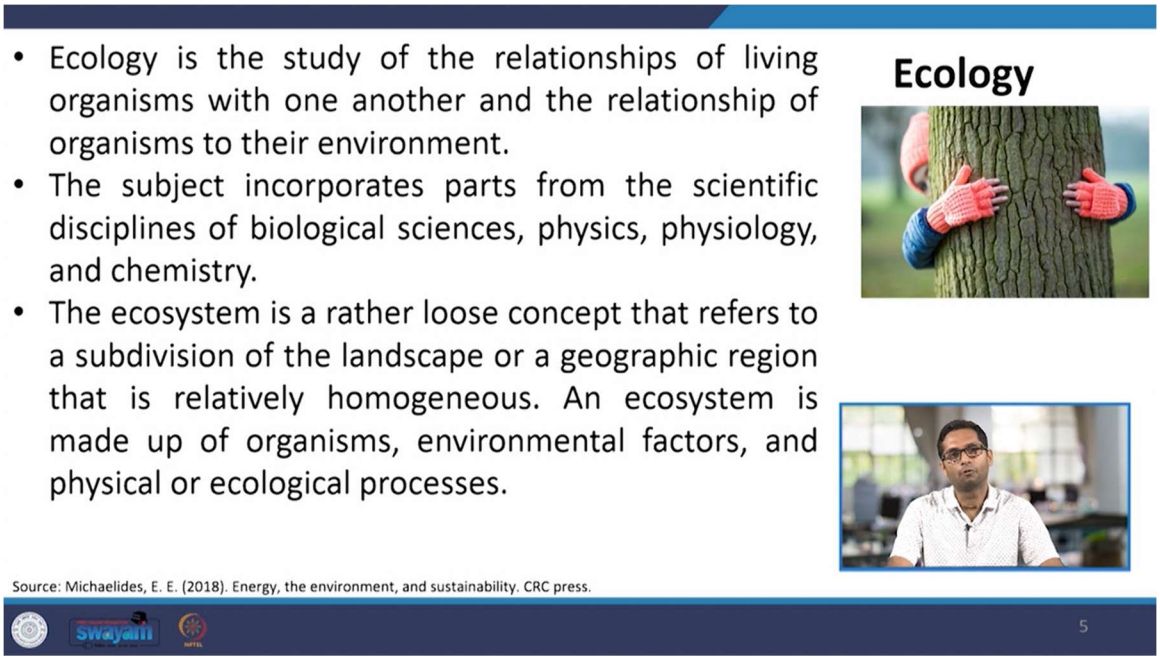
based contamination in the environment, again with the influx of use of more and more fossil fuels. As we have moved towards cleaner fuels in terms of nuclear fuels, they also have a problem of the disposal of the radioactive waste that is generated from these processes.

Further, the thermal plants that use different kinds of fuels also have a good amount of waste heat rejection and which also has severe consequences on the environment. So, it is not that GHGs are the only impact that the world faces because of the increased use of energy. There are other impacts which have been there in the form of acid rains, ozone depletion, lead contamination, nuclear waste, and many others. And these are some things that we will be discussing as we proceed further. It is also important that at this point of time, we understand the basic meanings of the terms that we use in today's life.



Let's start with environment. The environment is defined by everything that surrounds the humans and our economic activity. But it specifically means the non-living world, which includes the lithosphere, the solid earth, the atmosphere, the air, and the hydrosphere, which includes the different kinds of water bodies. The different kinds of climatic processes and events interact among themselves. Take the example for a hurricane or a cyclone.

It will be generated in the atmosphere because of the different kinds of currents. It will pick up the moisture or water from the hydrosphere or the different water bodies. And eventually, it would lead to a lot of destruction on the soil or on the land in terms of the soil changes, and that happens in the lithosphere. So, it is mainly the different kinds of or different aspects of environment interacting among themselves. And they all come in the ambit of atmosphere.



When I talk of a term called ecology, I would also take into account the living organisms that are a part of that system and also the relationship that exists between the living organisms and the environment. So, if I am talking about ecology, it is more to do with the society of organisms, how they have been living and how they have been interacting with the environment. This also brings in the disciplines of biology, physics, physiology, as well as chemistry. And to differentiate, the ecosystem is a rather loose concept. It refers to a subdivision or a small landscape, which is quite homogeneous, but it encapsulates the organisms, the different kinds of environmental factors, and the different kinds of relationships that exist between the organics, organisms and the environment.

It can consist of the water cycles, it can consist of the nutrient cycles, the carbon cycles, the phosphorus cycles, and all those. So, we have seen that the terms environment and ecology are used quite interchangeably, but that is not the case.

- The concept of the ecosystem comprises living organisms, species and populations; soil and water; climate and other physical factors; and physicochemical processes, such as nutrient cycles, energy flow, the carbon cycle, water flow, freezing, and thawing.

Ecology

Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

Whenever we are talking about ecology, we are also talking about different interaction that is happening between the living world as well as the environment. And this also includes the different nutrient cycles that are needed for the sustenance of life, which includes the carbon cycle, the water flow, the different kinds of nutrient cycles, the flow of energy as well. So, when we are talking about the two terms, we need to understand the ecology and the environment are a bit different.

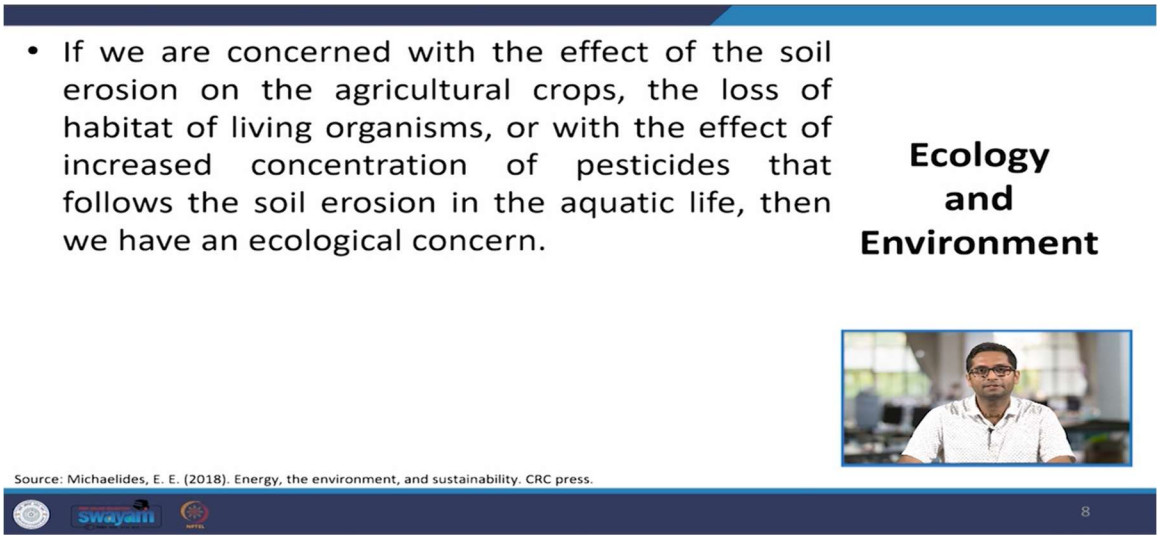
- Although the two are related and are often confused, there is a clear distinction between environmental and ecological changes as well as between environmental and ecological concerns: The ecological concerns always involve effects on ecosystems. For example, a tropical storm will wash a great deal of soil into the sea and will change the coastline of an entire region.
- If we are concerned only with the physical process of the soil erosion, the suspension of sediment in the water, and the subsequent deposition of soil at the bottom of the sea—three purely physical processes—then we have an environmental concern.

Ecology and Environment

Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

\The ecological concerns would involve the effect on ecosystems. Whenever we are talking about like say a tropical storm like a hurricane coming in, it would have an effect on the environment in terms of the great loss to the soil, but it would also change the harvesting pattern of the crop that is happening and that is what would be the effect on the environment. So, the effect that comes into the living world would be termed as ecology and that is precisely the difference between the two, ecology and the

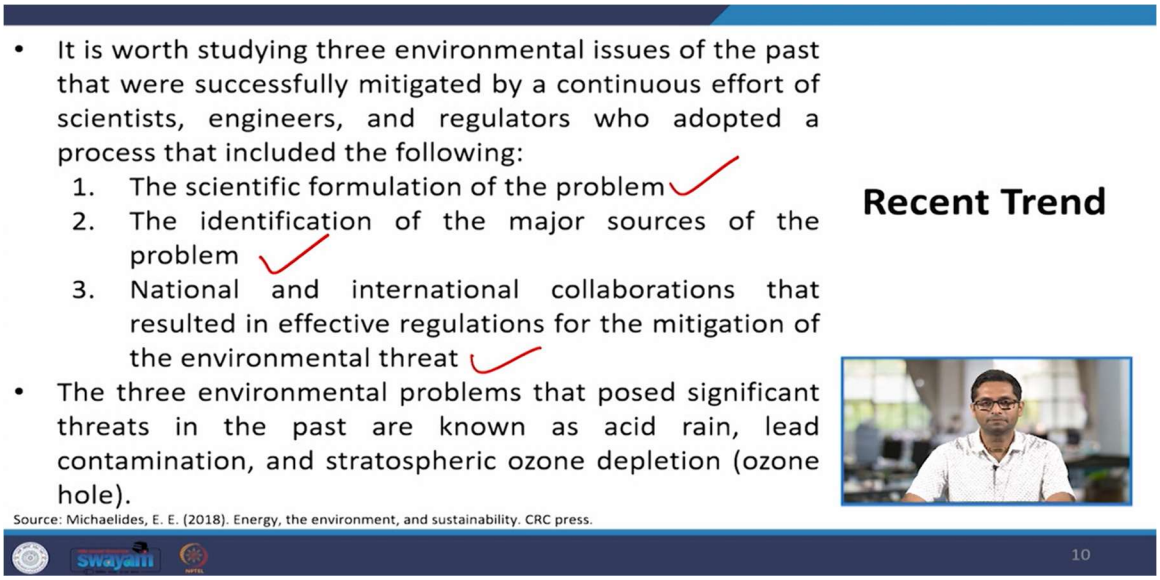
environment. Let us also try to understand the difference in the two terms with the help of another example. Suppose, what we are concerned with is the effect of soil erosion.



So, whenever the soil erosion is happening, that is more of an environmental effect, but when the effect of soil erosion in terms of the growth of the different organisms and as well as the effect of the different kinds of pesticides in terms of its effects on aquatic life is taken into being, it is more of an ecological concern. Another example could be one that was experienced in the past.

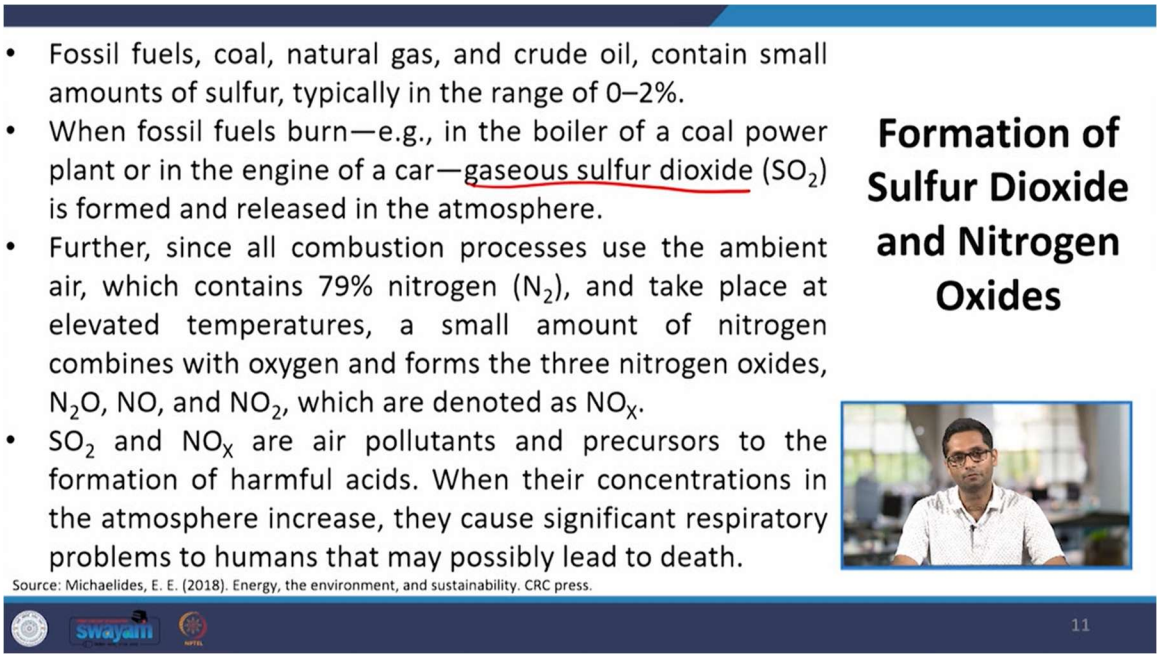
So, this is the Chernobyl disaster, one of the major nuclear disasters that happened in the erstwhile USSR. So, that happened because of the bursting of the steam reactor and that was being used in a nuclear power plant. This led to a release of a lot of radioactive

material into the atmosphere. So, the environmental effect was a lot of radioactive material was contaminating the soil as well as the water bodies nearby. So, that was an environmental effect. But as the time proceeded, a lot of these radioactive materials entered the food chain through the growth of different plants that was using that soil as well as the drinking of water that was contaminated by this radioactive material. And what was later experienced that there were different kinds of deformities that were experienced between the plant life, the animal life as well as the humans that was a direct result of coming in contact with this radioactive material being incorporated into the soil or in the water. So, if you consider the impact that was created on the humans as well as the different kinds of plants as well as animals, what we would be saying would be the effect on the ecology. So, that was more of an ecological effect in terms of the different kinds of diseases that like cancer that were propagated because of this disaster.



Now, let us try to understand the recent trend that has been there. In the future classes, what we are going to pay emphasis are going to be the three major case studies which are related to acid rains, the contamination of lead and ozone depletion that were major environmental issues in the past. By past, I mean around 1980s or 1990s. But because of the continuous efforts by the governments as well as the different kinds of environmental regulatory bodies, these kinds of problems have been solved in the developed world if to say to a very great extent. And what has helped in solving of these problems? It has been the scientific formulation of the problems. They could very well estimate what was the

root cause of the problem, why it was being exaggerated and what were the bottlenecks in solving the problem. Then they could come up with a nice identification of the major sources of the problem. If we can curb the major sources of the problem, it would be very easy to counter the particular emission. And further, there were major national and international collaborations that took place in due time which helped in forming of the international protocols and international treaties that helped bring down or solve these problems to a great extent. And let me repeat what these three problems were. These were basically the acid rains. Acid rains are basically formed because of the fumes of sulfur oxides as well as nitrous oxides that is from the combustion of different kinds of fossil fuels. Lead contamination and one of the major reasons for that was the use of anti-knocking agents for the better utilization of different fuels in the vehicles. And then we also have the stratospheric ozone depletion which was a direct result of the different kinds of CFCs that were released in the environment. So all the three emissions were somewhere or other released to the increase in the energy consumption and production throughout the world. They have been major issues and posed major challenges to the humans or to the ecology in the past. But with the advancement of technology as well as cooperation of the different nations and their populations, a great deal of success has been achieved in these emissions. So let us and we will try to understand these case studies in the future. Now let us start with the formation of sulfur dioxide and the nitrous oxides.



So fossil fuels majorly if you talk about coal, natural gas or crude oil contain small amount of sulfur. This could vary from 0 to 2%. And the coal that we have in India is slightly better in terms of the sulfur content. And because the sulfur is present in the coal or the natural gas, whenever we are burning any kind of fossil fuel, this sulfur would escape to the environment and the most easiest route for escape is the gaseous sulfur dioxide. Further, more almost all the combustion of this fossil fuel takes place with the help of the ambient air.

And we all understand that the majority of air is composed of nitrogen, almost 79% nitrogen, which also takes part into this combustion process and because of the elevated temperatures, this also leads to the production of certain oxides of nitrogen which are combined, commonly termed as NOx but they are basically N2O, NO and NO2, which again have detrimental effect in terms of the contamination of the atmosphere. Some of these gases also have a good global warming potential, others have been a major cause of acid rains. So these SOx and NOx emissions as we call them are the major air pollutants and or precursors that have been released to the atmosphere and this has been mainly because of the increase of energy production in the power plants which was using three main fossil fuels which was the coal, crude and the natural gas. And in the past we have had good amount of fuels being burnt and a lot of these emissions which have been released to the atmosphere. The result has been there have been significantly problems, particularly in the humans.

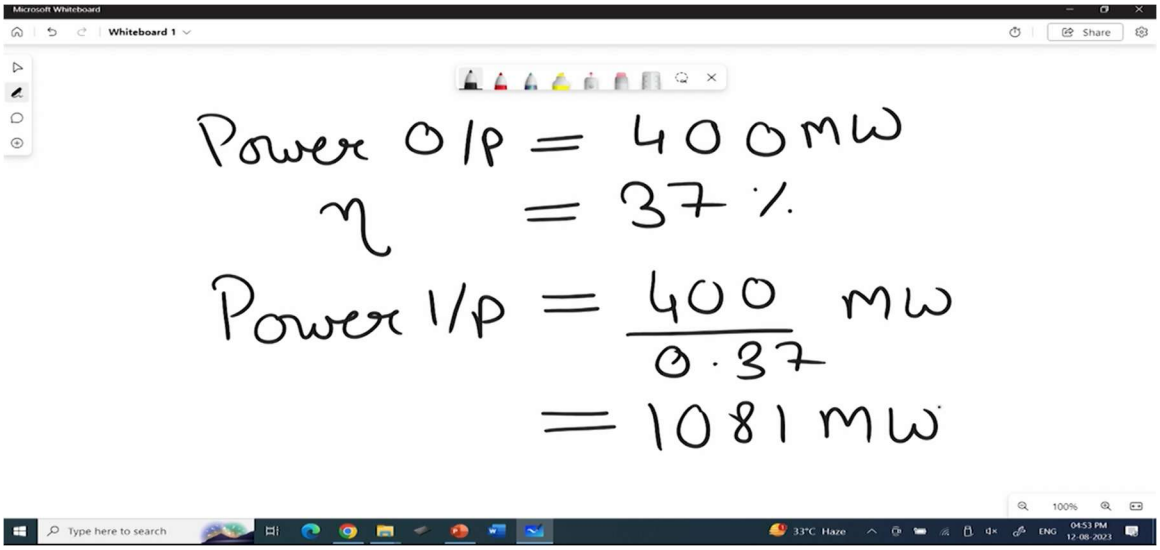
It has affected or caused respiratory problems to humans and in the extreme cases this has also been led to death of certain amount of people as if you remember in the earlier class we have given an estimate that because of the increased emissions in the industrial age, the estimated amount of lives lost has been estimated to vary between 25 million to 40 million people which is again more than the combined amount of casualties that we have lost in World War I and World War II combined. So let us try to estimate like what would be the typical amount of emissions that would be released by a typical power plant that is fed by coal. So let us assume a coal fired power plant, a typical capacity would be 400 megawatt. So this is of the range of the power plant that you are going to find in your neighborhood as well. We are taking a rather typical efficiency of 37% and we are hoping it is burning anthracite which is the high grade coal.

Example:

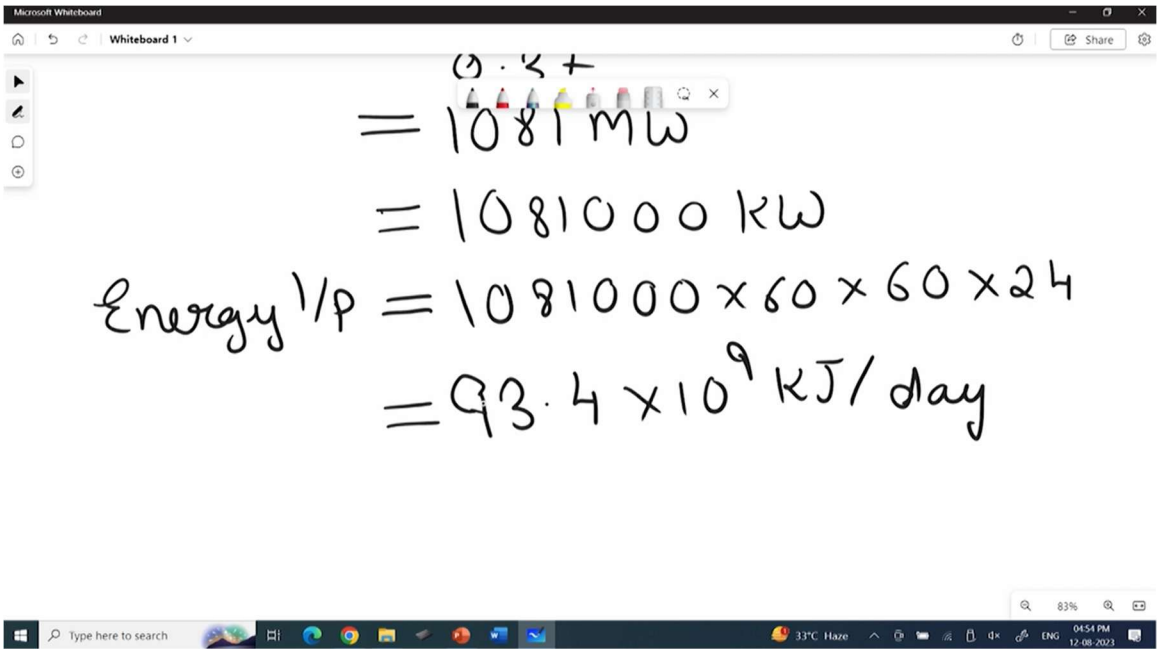
A 400 MW power plant has thermal efficiency 37% and burns anthracite, which has a heat content 29,000 kJ/kg and contains 1.2% sulfur by weight. This anthracite contains 94% carbon by weight. It is estimated that during the combustion process, NO_2 is also formed at the rate 0.02% of the formation rate of CO_2. Determine the amounts of CO_2, SO_2, and NO_2 produced by this power plant per day, per week, and per year.

In India most of the coal that is available is of not very high grade so the emissions that are attributed are somewhat higher but let us say that these emissions are coming from the combustion of the best quality of coal that is available. I am also taking a calorific value of coal of around 29000 kilojoules per kg. We also are assuming that this coal would have almost 1.2% of sulphur by weight. This anthracite contains a 94% carbon by weight is another assumption.

Coal as we understood or as we have also seen in the earlier classes is composed majorly of carbon, hydrogen and oxygen. The hydrogen and the oxygen amount being very less and a majority almost more than 90% of coal would be carbon. If you are taking a low grade coal like bituminous or lesser grade the amount of carbon would be somewhat lesser. And then it is also estimated that the NO2 formation is at the rate of around 0.02% of the formation of CO2. Now given these amount of like these assumptions let us try to estimate the amount of CO2, SO2 and NO2 that would be released by this typical power plant over in one day, one week and one year. So let us go towards the white board and let us try to understand this calculation. So if I talk about the power output from the power plant this is roughly 400 megawatt. I know the efficiency of the power plant is roughly 37% and if I would have to take the input power which is basically coming from the anthracite coal this would be nothing but 400 divided by 0.37 or the efficiency in terms of megawatt.

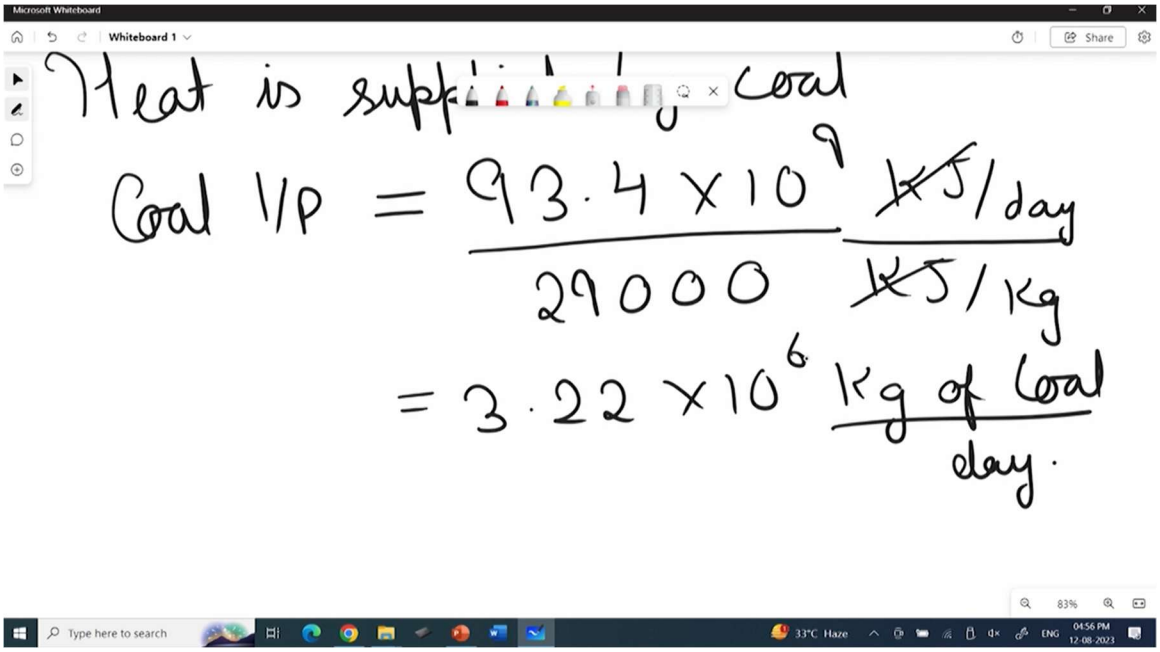


If I do this calculation the number would come around to be around 1081 megawatt or if I want to say it like it would be 1081000 kilowatt.

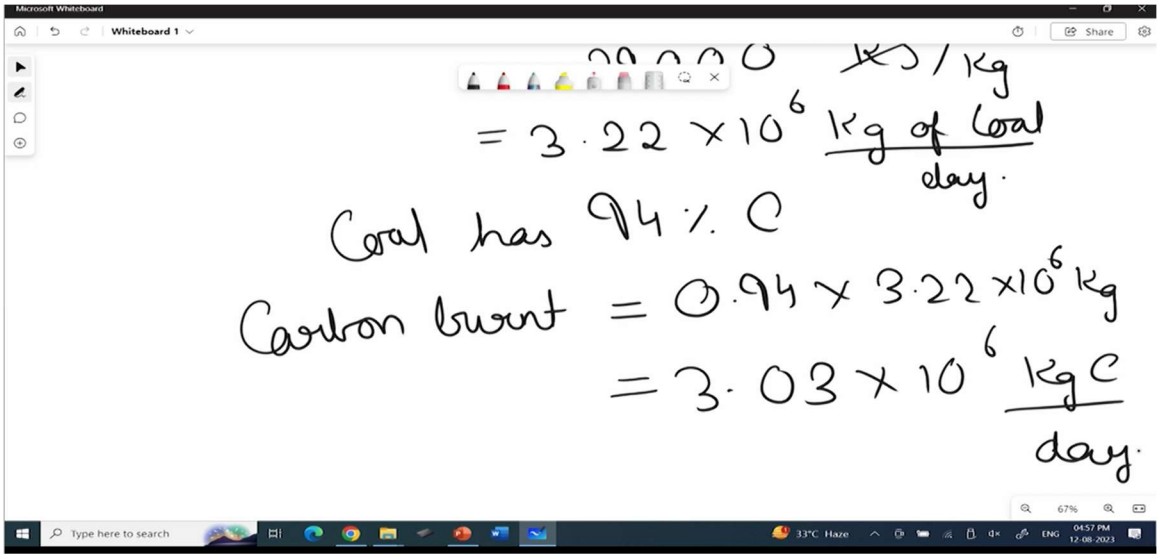


But this is a unit of power and not that of energy so this is the energy consumed per second so the unit of watt is basically joules per second. So if I would want to understand the energy input in terms of the daily use I am talking about the energy that would be used on a daily basis so this would be this power in terms of kilowatt multiplied by 60 seconds into 60 minutes and into 24 hours and this would give me the daily amount of energy that is required and multiply the three things or the four things this would be the

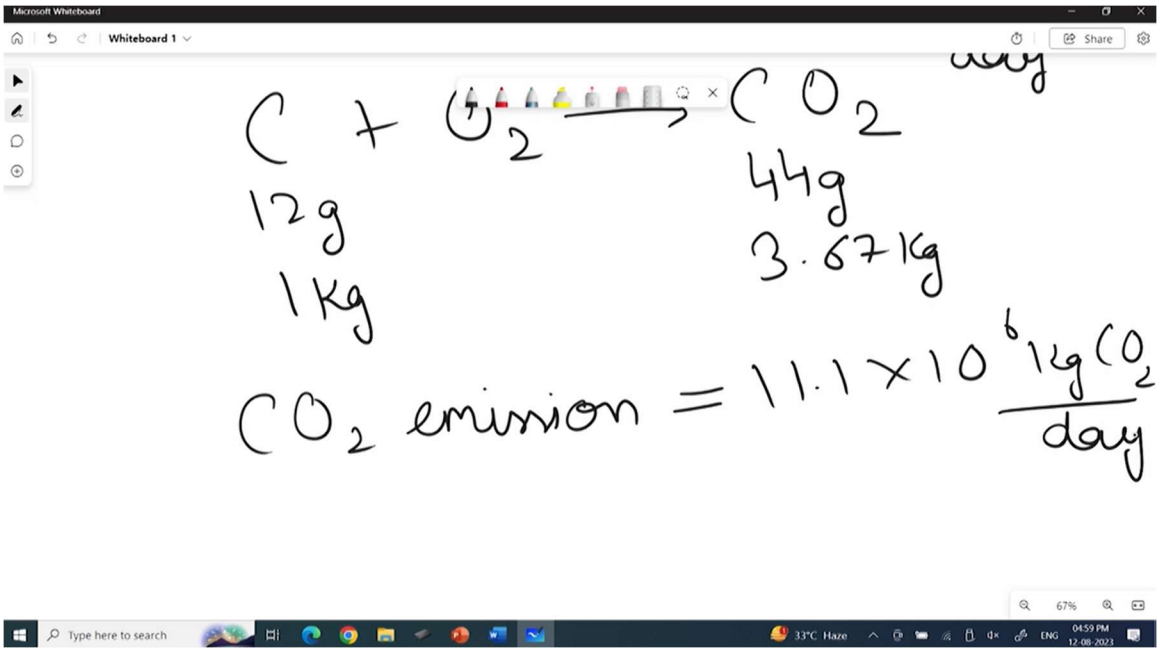
total energy which is 93.4 into 10 to power 9 kilojoules of energy that would be needed per day and this energy is basically coming from coal.



So this is the energy input that I have been looking for. This heat is supplied by coal the input energy and we know the calorific value of coal which have been listed to be around 29000 kilojoules per kg. So what I would do is like if I have to calculate the amount of coal input it would be this energy that I would need which is 93.4 into 10 to power 9 which was in terms of kilojoules per day and I would divide that with the calorific value of coal which is anthracite in this case so this is basically kilojoules per day and this value is kilojoules per kg this kilojoule kilojoule cancels out and the result of this would be around 3.22 into 10 to power 6 kg of anthracite coal and this is coming on a daily level. So what I would be consuming I will be consuming around 3.22 into 10 to power 6 kgs of coal over around 3220 tons of coal per day for this rather typical coal fired plant and if you consider this amount of plant that is operating and if you would consider the amount of coal you would have seen this coal carrying trains are pretty long and further coal supply chain is a major source of revenue for Indian railways as well because huge amount of coal needs to be transported from the mines to the power plants where they are used at a very huge level. So this is just to give you an estimate that you would be using almost 3000 tons of coal per day for a rather typical coal based power plant.

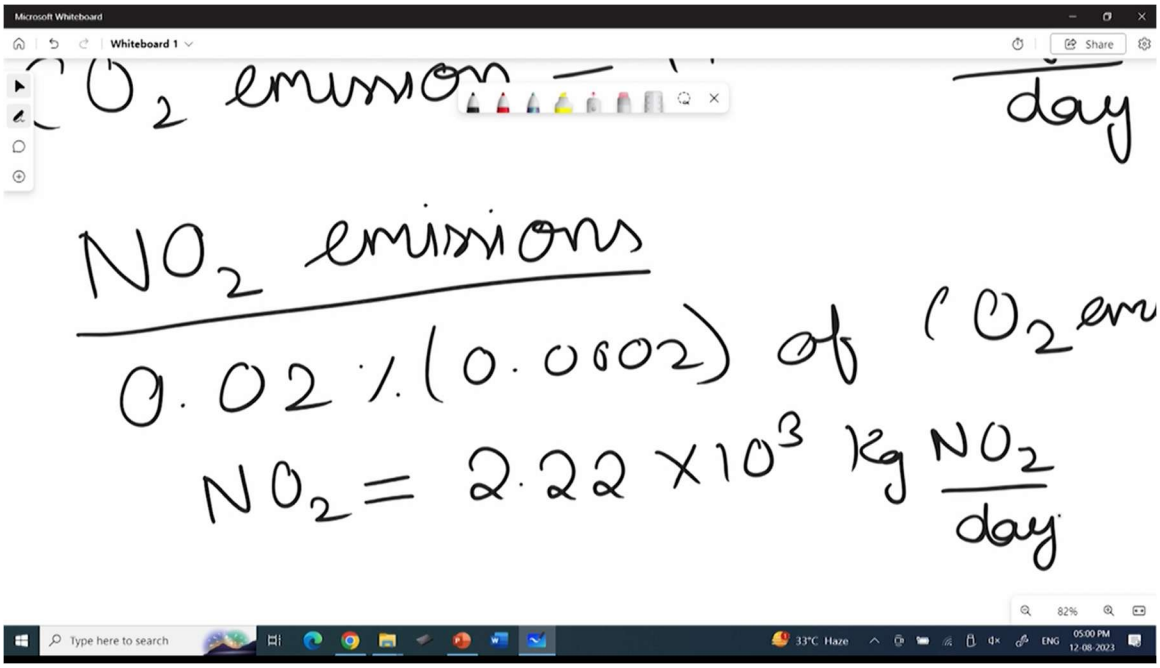


Further we have estimated that coal would have 94% carbon content. So the amount of carbon that would be burnt per day would be equal to 0.94 into 3.22 into 10 to power 6 kgs. And this would come around to be 3.03 into 10 to power 6 kgs of carbon that is consumed per day.



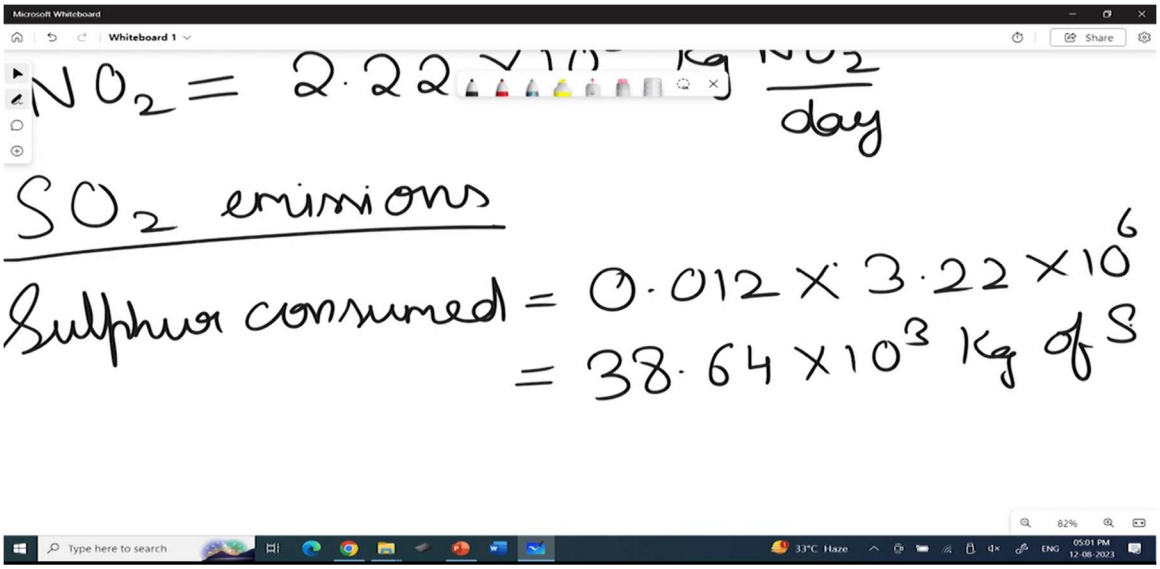
Now we know that a major source of CO2 from the combustion of this coal would be carbon that is in it and we know the simple equation like one mole of carbon will combine with one mole of oxygen and give you one mole of CO2. If you go with the combustion kinetics or the combustion mechanism that is a fairly complex system with

more than 200 reactions taking place but the underlying reaction would be one mole of carbon combining with one mole of oxygen and producing one mole of CO2. Or we can also have 12 grams of carbon which will be reacting by 36 gram of oxygen and producing almost 44 grams of CO2. However in terms of kg if I am consuming 1 kg of carbon this would lead to the production of 3.67 kgs of CO2. So we can use the same analysis to estimate the amount of CO2 that would be generated by the combustion of the carbon that we have estimated earlier. So if I multiply this with the factor of 3.67 because 1 kg of carbon is giving me 3.67 kgs of CO2 and this is precisely the reaction that is occurring. So the amount of CO2 emission that is happening would come around to be 11.1 into 10 to the power 6 kgs of CO2 per day. So this is the amount of CO2 that you would be releasing on a daily level. Now compare that with the NO2 emissions.

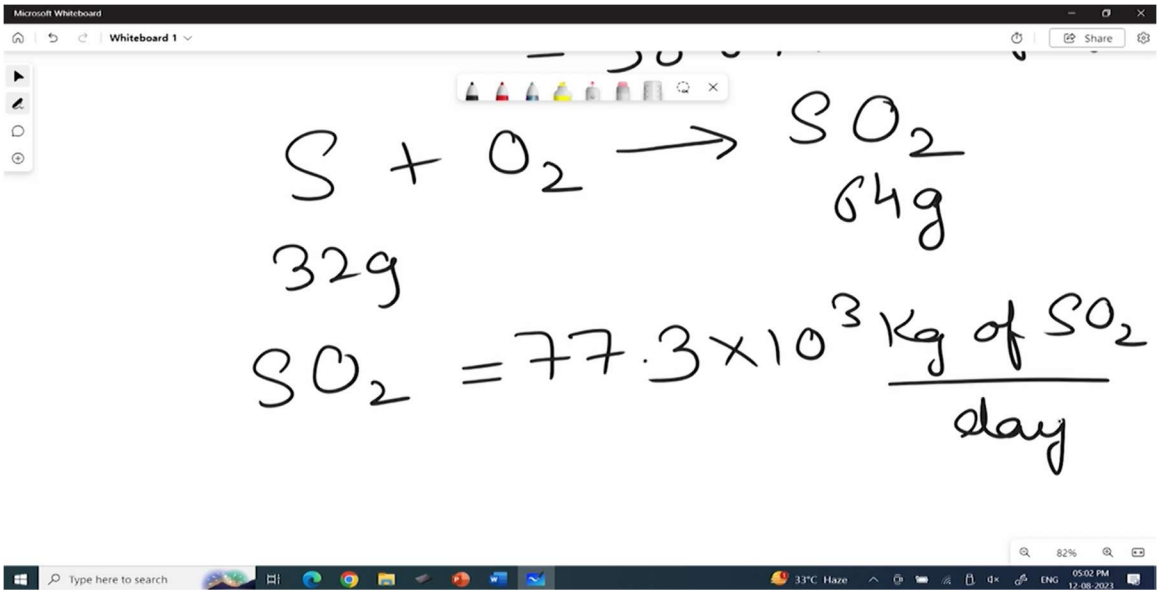


So let us try to estimate the NO2 emissions as well. And the NO2 emissions are basically 0.02% or this would be 0.0002 of the amount of CO2. So this is a fairly simple calculation. So we can just multiply the factor of 0.0002 and the NO2 emissions will come out to be around 2.22 into 10 to the power 3 kgs of NO2 per day. Something similar could be said for the SO2 emissions. So we now understand that from the assumptions that the coal that we were consuming had around 1.2% of sulphur and this would be consumed for production of sulphur. So the amount of sulphur that would be getting

consumed or this would be sulphur consumed. This would be equal to 0.012 which is the percentage of sulphur into the amount of coal that is being utilized.

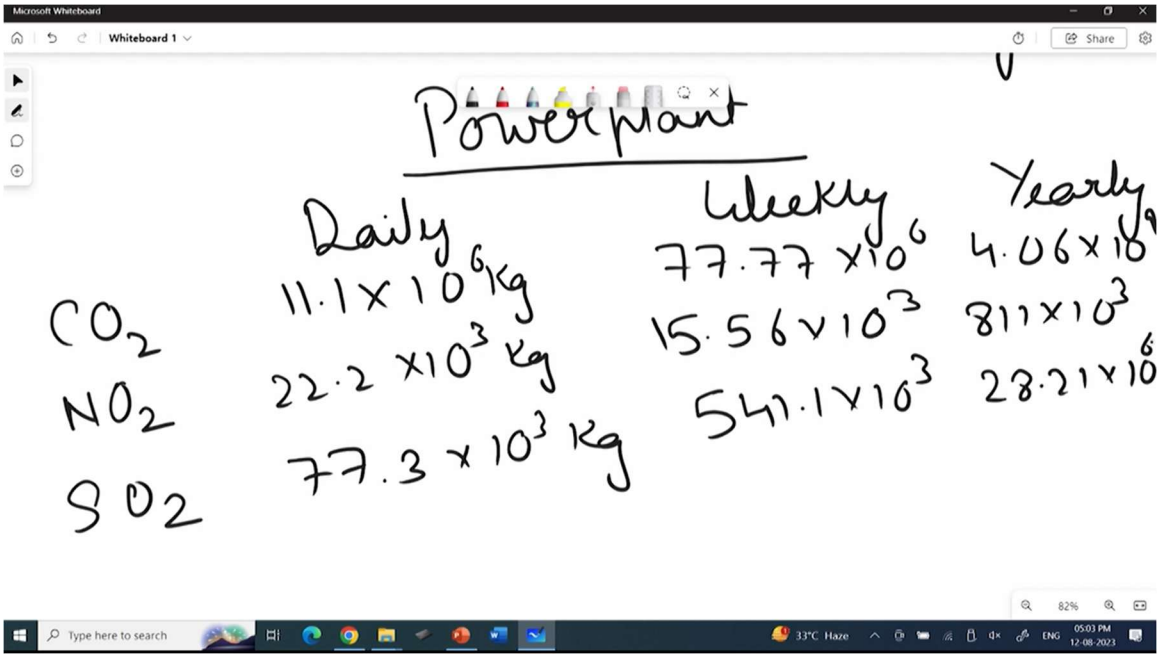


So this would be 3, we have already calculated the amount of coal utilized 3.22 into 10 to the power 6 and this value would come around to be 38.64 into 10 to the power 3 kg of sulphur that is consumed.



Again we can have a simple equation for the production of SO2 which is sulphur reacting with oxygen for 1 mole of oxygen producing 1 mole of SO2. This is basically 32 grams of sulphur combining with another 32 grams of oxygen and producing 64 grams of SO2. Again we can have a similar or 1 kg of sulphur will be producing 2 kgs of SO2 and so the

total SO2 emissions from this particular process would come around to be 77.3 into 10 to the power 3 kgs of SO2 per day. So if I look at the emissions on a daily, weekly and an yearly level I can make a table.



If I can just have this power plant and we can have the emissions daily, weekly and yearly level and we can start with the CO2 levels. So the CO2 emissions would be 11.1 into 10 to the power 6 kgs. On a weekly it would be just a multiplication as 77.77 into 10 to the power 6 and so also in kgs and for an yearly this will be 4.06 into 10 to the power 9. Something similar could be said for NO2. This would be around 22.2 into 10 to the power 3 again in kgs. All the values are here in kgs. 15.56 into 10 to the power 3 and 811 into 10 to the power 3 kgs in here. For the SO2 we can have the values of around 77.3 into 10 to the power 3 kgs. On a weekly level this would be 541.1 into 10 to the power 3 and then around 28.21 into 10 to the power 6. So you can see the most amount of gas released from a power plant would of course be carbon, CO2 because that is what forms majority of the coal as well. But we also have significant of NO2 and SO2 emissions that are happening. So this was just to give you an understanding of the quantum of the different harmful gases that are released by a typical power plant.

- This rather typical coal power plant of 400 MW of electricity capacity produces more than 4 million t of CO_2. In 2014, the entire world produced $23{,}816 \times 10^9$ kWh, of which 40.8% were produced from coal combustion, with an estimated release of 11,271 million t of CO_2. The total anthropogenic CO_2 production exceeded 32,300 million t.
- This reflects the problem with the global CO_2 emissions: too much of this dangerous gas is produced from the several anthropogenic activities, and all of it is released in the atmosphere.

Reflection

Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

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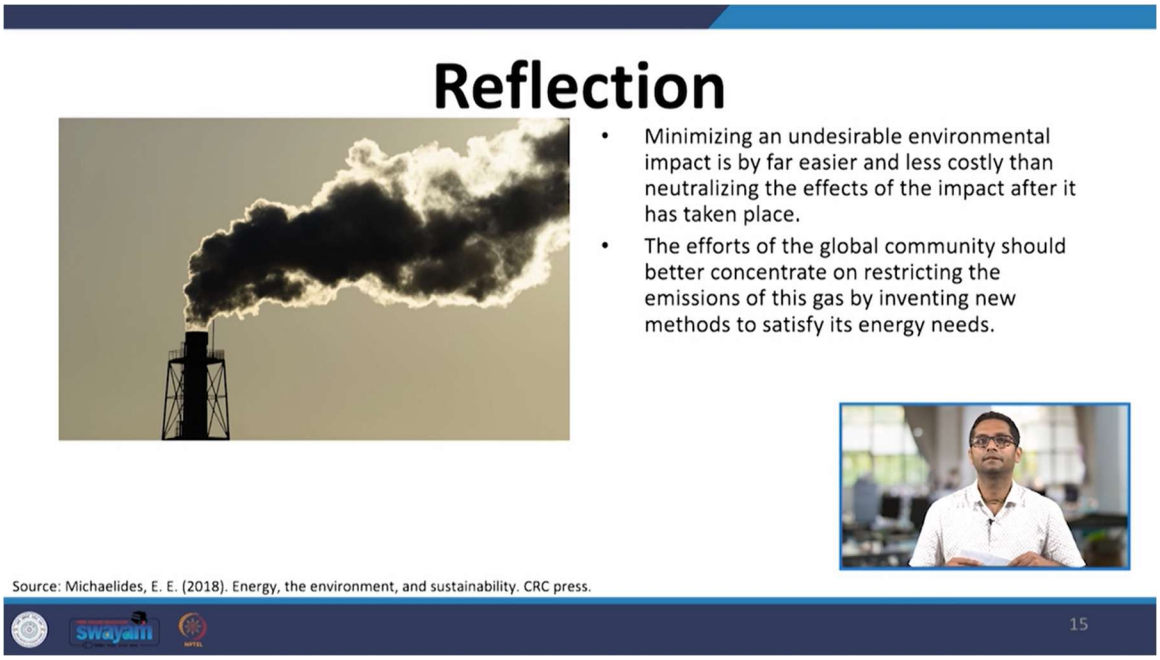
If we go back to the slides, maybe we can come to a reflection that this is a fairly typical power plant of 400 MW capacity and it is producing almost 4 million tons of CO2 on an yearly level. And further if we consider the electricity production in the year 2014 almost a decade back, we would see that there was almost 23816 into 10 to the power 9 or billion kilowatt hour of electricity produced and almost 40% of this electricity was coming for coal combustion or coal power plants. And the majority of these power plants are in India or China as well as Australia.

And it is estimated that the combined power plants which were run by coal were releasing around 11,000 million tons of carbon dioxide into the atmosphere. And the total anthropogenic CO2 emissions exceeded around 32,000 million tons. Well, the calculation was done to just make you understand that a fairly typical power plant was releasing a huge amount of gas into the atmosphere. And this is why the interlinking of energy consumption, the energy production pathways and the environment is very important to understand. Because a lot of this gas is released to the atmosphere at a fairly high level.



And also we would want to minimize the level of these gases. So once it is released in the atmosphere it becomes very difficult to capture the gases. A better way would be to come up with some alternate sources of this production of energy which is much more or which doesn't have much of the degrading effects on the environment. With this we will take a break for today's class and starting the next class we will try to understand the effect of some of the major gases which is the SOX and the NOX and how their emissions have been particularly increasing in the past and how the problem of SOX and NOX have been tackled to a great extent. With this we end today's class. Thank you.