Energy Resources, Economics, and Sustainability

Prof. Pratham Arora

Hydro and Renewable Energy Department

Indian Institute of Technology Roorkee, Roorkee, India

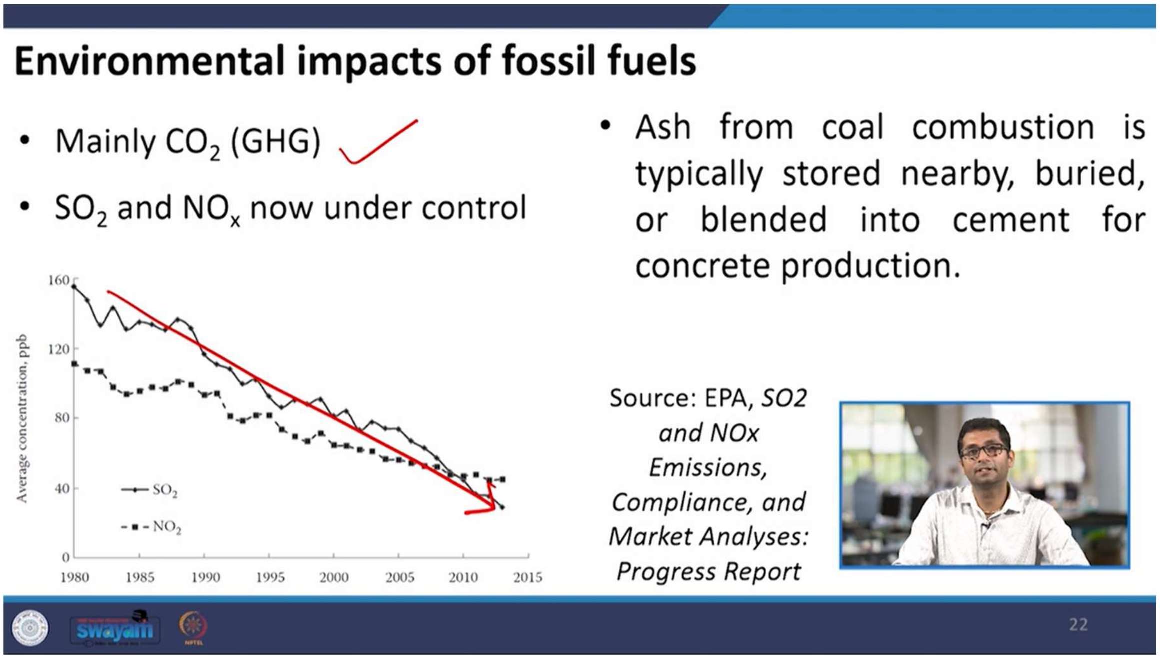
Week – 06

Lecture – 04

Lecture 30 - Environmental Impacts of Different Energy Pathways-I

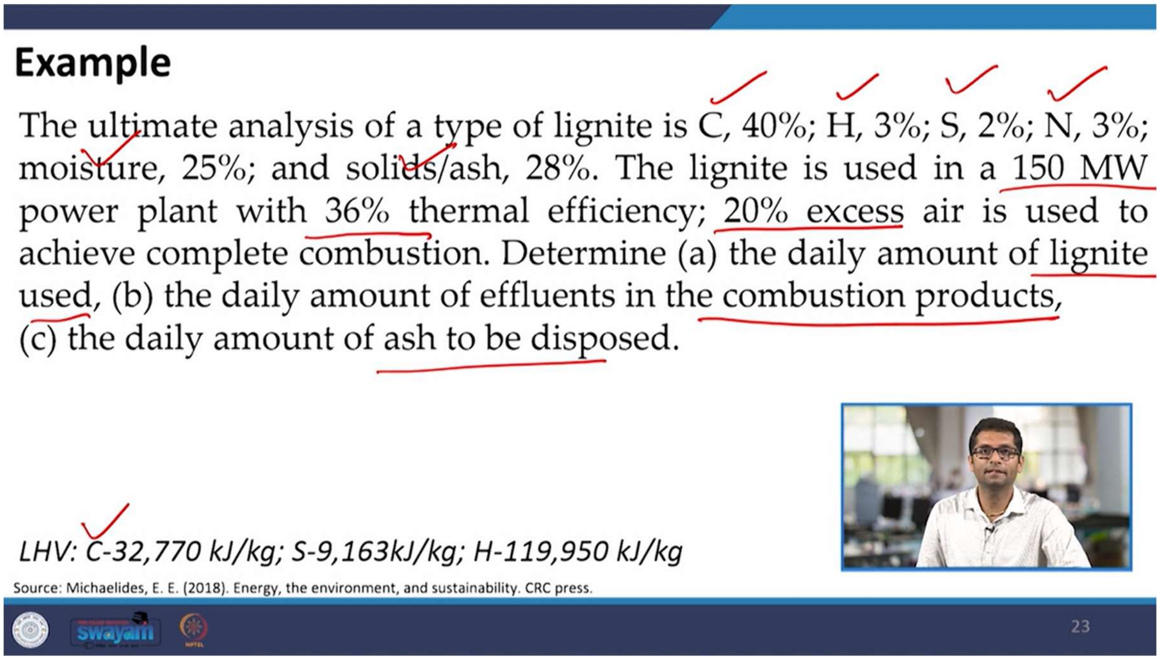
Hello everyone. Welcome to the course Energy Resources, Economics and Sustainability. In the past few classes we have been trying to consider or concentrate on the major problems that could come upon the use of conventional energy processes. We have discussed the problem of the global climate change. In the last class we have tried to focus on the waste disposal that is a big problem from nuclear power plants as well as understood the concept of thermal heat and how that could lead to call for a better understanding of the energy water nexus which is being talked around a lot. The use of any production of energy is linked to the water consumption and we also know that water consumption also has energy consumption linked to it. So this nexus is a very interesting thing to understand and this is something we have discussed in the previous class. Further in today's class we will try to focus on the different environmental impacts that comes from the different energy pathways. We will be discussing both the conventional, non-conventional, renewable and non-renewable. So in today's class the focus is would be more on the conventional or the fossil fuel based resource.

We will try to understand what could the likely impacts of fossil fuels. Of course we have spent a great deal on understanding the climate change problems and the CO2 problem. So we will touch upon that as well but the focus will be more on the other problems that are linked to energy production pathways. So as to provide us a holistic picture it should not happen that in the, with the aim of replacing one energy pathway within another that solves us the climate change problem we are leading to another bigger problem in the future and that is the aim of the current class. So let's go further.



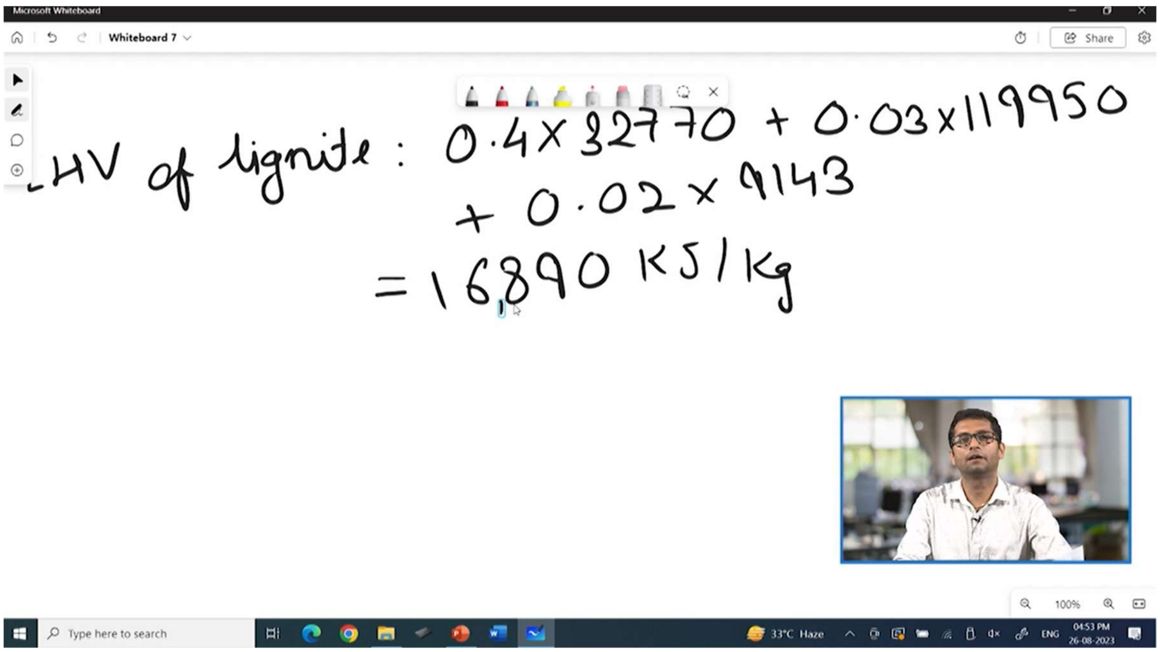
Let's start with the impact of fossil fuels. We all understand that the major impact of fossil fuel has been the CO2 emissions which is a major GHG and the other impacts include the sulfur and the nitrogen emissions which have been basically responsible for the phenomena of acid rains and degradation of the water bodies in different parts of the world. But we have also understand in the previous classes because of the efforts by the different national governments as well as international collaboration. The concentration of sulfur and nitrogen oxides in the atmosphere is consistently coming down in the developed countries. It is still a problem in the developing world and in India the levels are still rising but much of the world has been able to find a solution to these particular issues.

Another issue for the coal based power plants has been the production of ash. Ash is something that is produced in a large quantity in the power plants and the storage as in disposal of this ash has been a big problem. So normally one would store it or bury it in the ground or blend it with some kind of cement. So these are some of the pathways that have been associated. So let us try to understand what would be the production of different kinds of waste that would be accompanied by a conventional power plant.

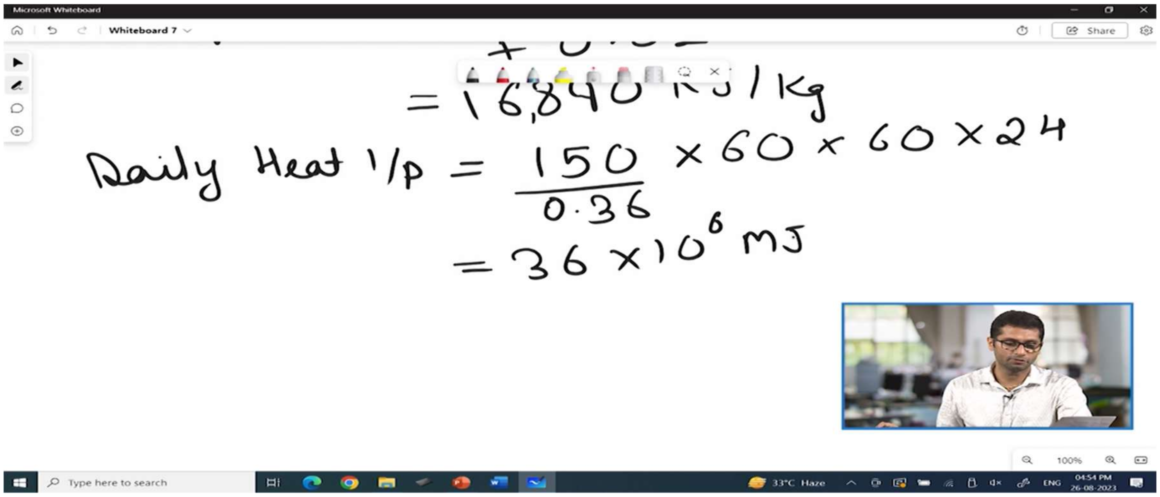


So in this example we will be taking a much more realistic scenario compared to the other examples. In the other examples we have taken a lot of assumptions like we are using very high grade coal in the form of anthracite and there have been not much of the production of residues like ash or solids. So let us take more of a realistic plant and say we are using lignite and not a very high grade coal. In India most of the coal that is available again is not very high grade and we are comparing that let us assume that the coal that we are using in the present case would have almost 40% of carbon, around 3% of hydrogen, 2% sulphur, 3% nitrogen, moisture stays at around 25% and then there would be other unwanted inorganic impurities which forms the ash roughly of 28% which is quite high. Now, This lignite is expected to be used in a 150 megawatt power plant.

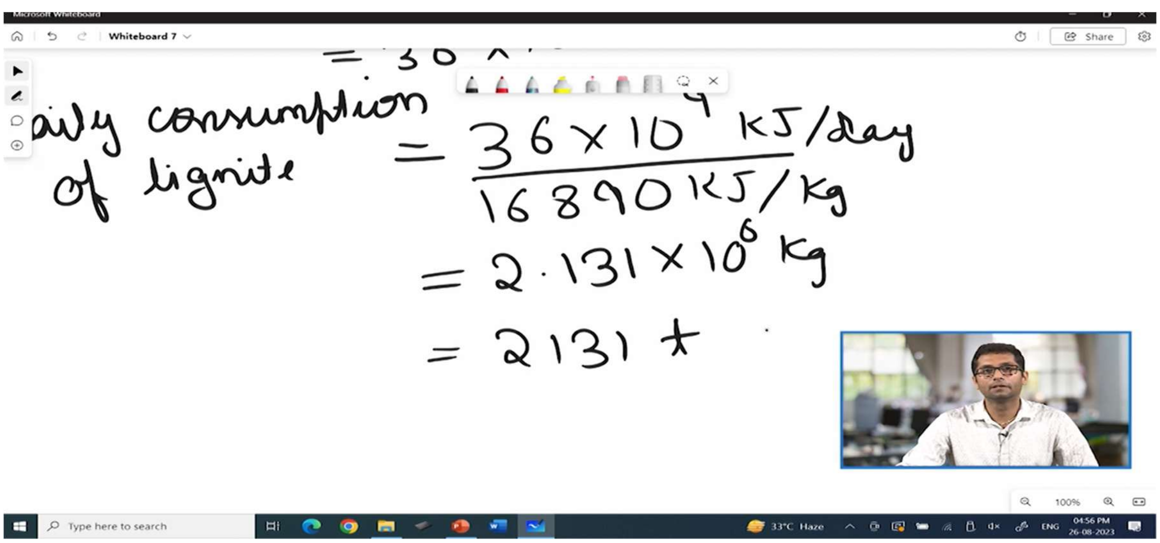
The eficiency has been assumed to be almost 36% and as in the case of any power plant we would not give stoichiometric amount of air or oxygen that is required, we will give some amount of excess air or oxygen and normally it is a convention to give 20% or so excess air to the operation of such a power plant. So let us assume something similar in this case as well that the power plant is running on 20% excess air so whatever would be required stoichiometrically for the complete combustion of this coal I am giving 20% more of the air that is required. So what I would want to determine is the daily amount of lignite that I would be using, then the daily amount of effluents that would be produced from the combustion process and also the daily amount of ash that needs to be disposed. So we would be using the heating values of the different compounds, so I have used the lower heating value of carbon here which is 32,770 around 9,163 for sulphur and around 1,19,950 for hydrogen. So if you see the composition of coal these are the three main chemicals or elements that would be producing energy, carbon, hydrogen and sulphur. Nitrogen would not be producing energy and the same goes with moisture or the solids that are present. So let us go to the white board to understand this in detail.



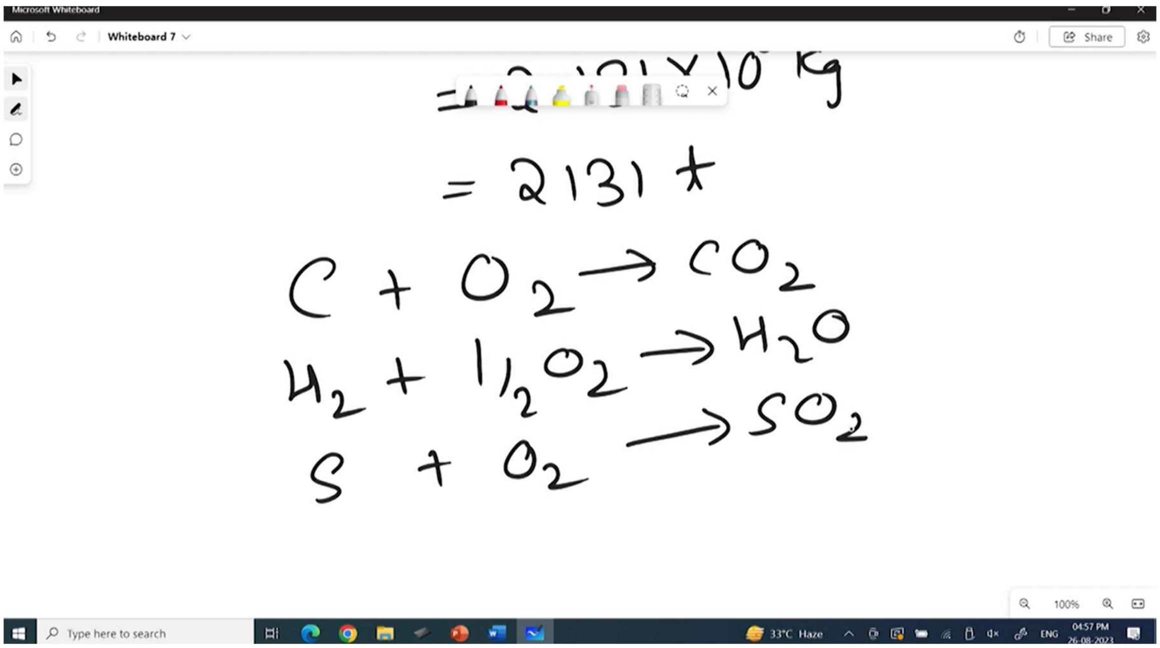
So first thing that we have to take would be calculating the lower heating value of lignite which is the fuel which we would be using. So I can calculate that, I know that 40% of the lignite is carbon and I multiply it with the lower heating value of coal which is 32770 and then I also know that around 0.03% is hydrogen and I multiply that with the lower heating value of hydrogen which is 1,19,950 plus some amount of sulphur which is 0.02 and multiplying with the lower heating value of sulphur. Adding the three values together gives me the lower heating value of lignite which comes out to be almost 16,890 kJ of energy per kg of lignite. So just compare that with the earlier examples, in the earlier examples we have been taking the range of around 27,000, 29,000 or 31,000 for anthracite based coal. So if you go for a low grade coal the heating value is something that needs to be understood, it is quite lesser.



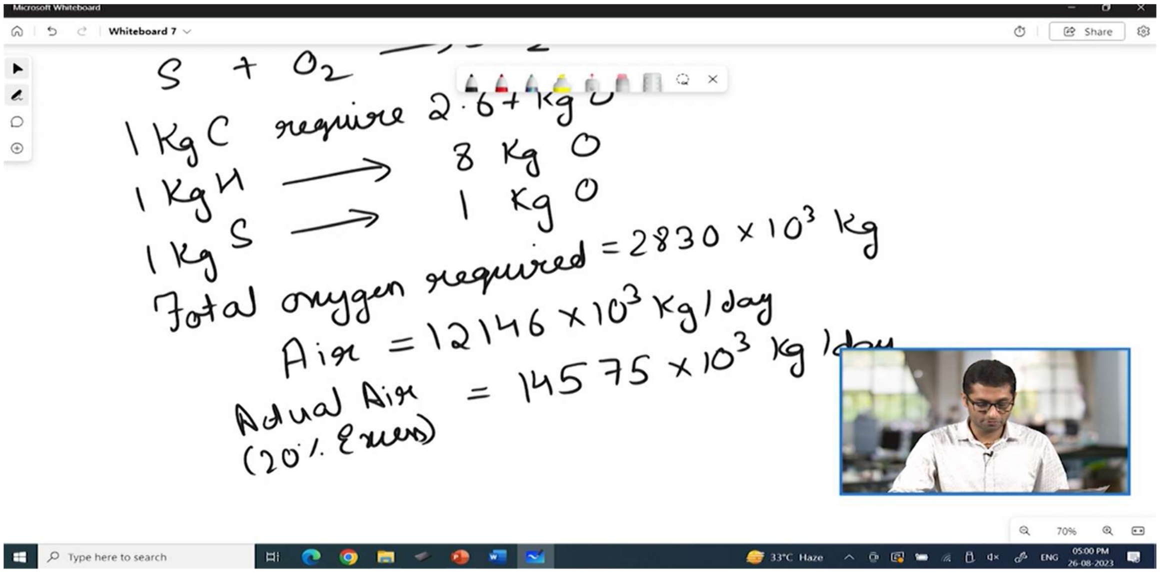
So with this if I calculate the daily heat requirement for the plant, the daily heat input that would be required by this plant, so it is 150 MW plant, the efficiency of the plant that I am assuming is 36%, so I am dividing this by 0.36 and this gives me the total input that would be required in terms of power and I multiply that with 60 seconds into 60 minutes into 24 hours and this basically gives me the daily requirement of heat that would be required for production of almost 150 MW of electricity in a 1 MW of electricity and this would come around to be 36 into 10 to power 6 mega joules of heat, this is what would be required.



Now if I go with the daily consumption of coal, so this all heat is coming by the consumption of coal, so let me calculate the daily consumption of this lignite, this would be nothing but dividing this initial heat capacity which is 36 into 10 to power 9 kilojoules, I have changed the units in here and dividing that with the calorific value or the lower heating value of lignite which is 16890 kilojoules, so this is the amount of requirement per day, yeah so this is the requirement per day and so what and this is the heating per kg, so it comes out at 2.131 into 10 to power 6 kgs of coal that would be required on a daily level or I can also say it is almost 2131 tons of lignite that is required on a daily level, so if you see that is a huge amount of coal that would be required for this again a rather typical coal based power plant.



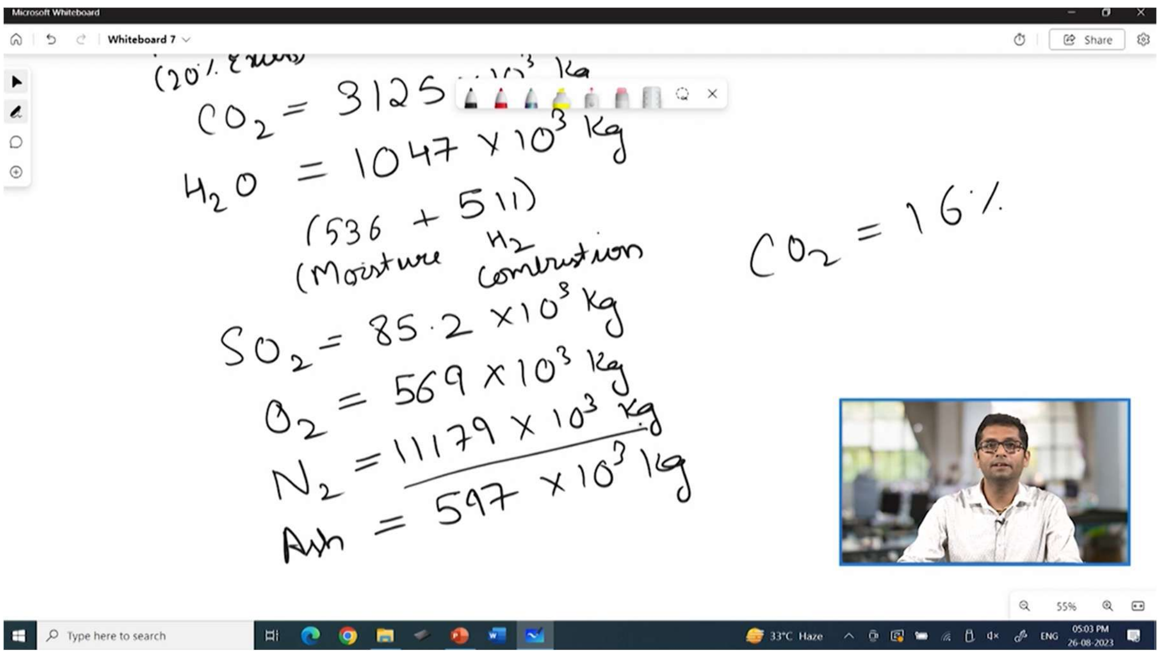
Now we can also, we also know the composition of the coal, so basically 1 kg of coal would have almost 40% of carbon and point around 3% of hydrogen, 2% of sulphur and moisture as well as the ash is known to us and we also know that through the difference to isometric equations like the carbon is going to react with oxygen producing CO2, hydrogen is reacting with half molecule of O2 giving in water, sulphur would be reacting with oxygen and producing SO2, so I would not go into much of the details of the reaction because we have been discussing these in the previous classes and if anyone is interested you can do the calculations again the principle remains the same.



So we have basically understood that 1 kg of carbon if that was to be combusted it would require almost 2.67 kg of oxygen this is again coming from the above equation, in the similar way we know that 1 kg of hydrogen would require almost 8 kgs of oxygen and 1 kg of sulphur would require 1 kg of oxygen because the molecular weight remains the same. So based upon this equations and based upon the total quantity of coal that we would be consuming on a daily level we can estimate the amount of air that would be required for this power plant and so if I go with, if I provide you total numbers, the total oxygen required would be almost 2830 x 10 to the power 3 kgs. So but in the power plants you would not be feeding it with oxygen directly normally it would be the air that is going in and we understand that air normally contains 23.3% of oxygen by weight I am talking about the weight and not the volume if I consider volume it would be 20.98% but around 23% of oxygen goes in in air in terms of the weight.

So the air that I would be requiring would come out to be 12146 x 10 to the power 3 kgs again this is something we are taking about the daily level so this is the amount of air that would be required per day and if you remember the question we have assuming that the air that we are supplying is in 20% excess. So if I am talking about the air, the actual air that would be supplied and that is in 20% excess this would come out to be around 14575 x 10 to the power 3 kgs per day. So this is the amount of air that you would be supplying and based upon this calculation you can also estimate the amount of different chemicals that is created. So all the carbon would be converted into CO2 as we have seen in the earlier case all the hydrogen would be converted into water and there would be 2 source of water in the output product one water that is being coming from the combustion of hydrogen and the other one is the inherent moisture that is there on roughly around 20% or so. Then we would have sulphur getting converted again into sulphur dioxide and then we have oxygen that we are providing an extra which would be coming in unchanged and further we would have the nitrogen coming in the nitrogen that is present in the coal could be expected to be converted into nitrogen.

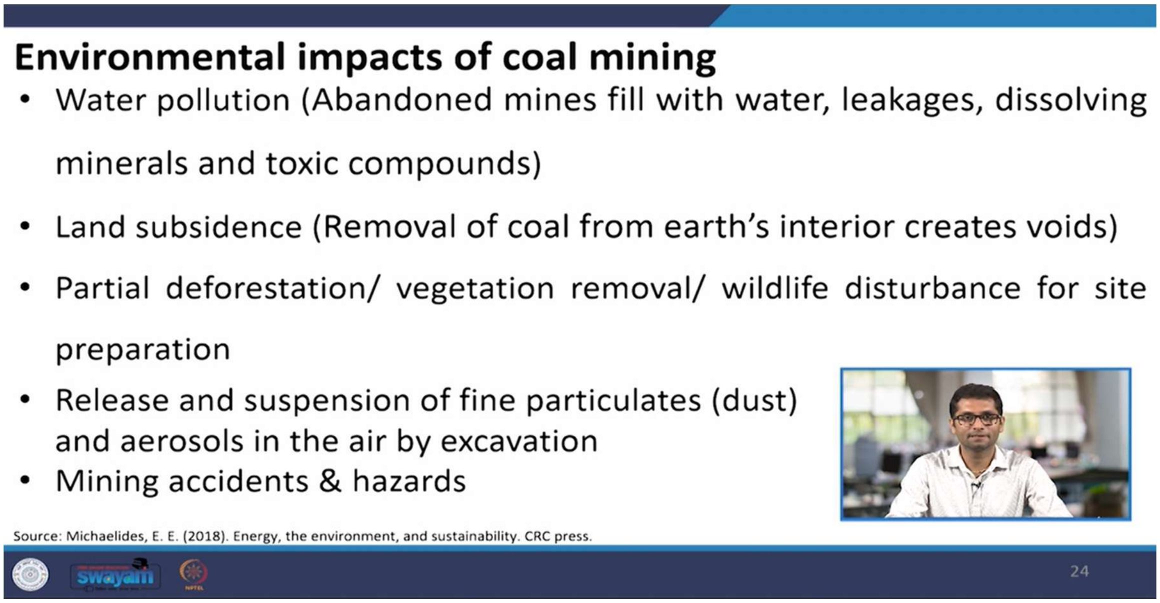
The other pathway it can convert into NO2 but in this example we can consider that it is being converted only into nitrogen gas and finally the ash. So I again would not go into the mass balance of all the elements which I believe the students can do on their own.



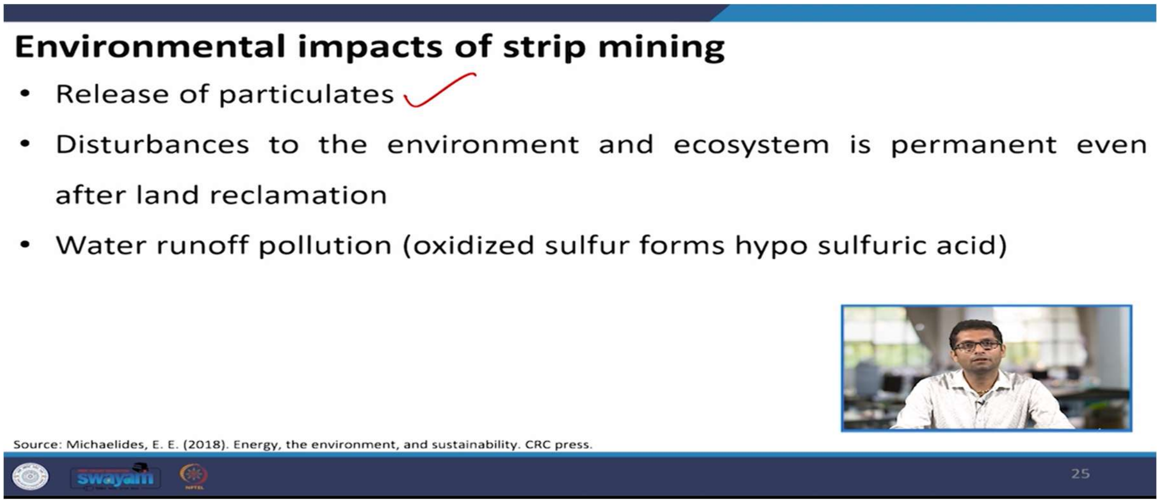
I will give you the final answers so the CO2 that should come out from this particular operation would be of the order of 3125 into 10 to power 3 kgs. So this is the amount of CO2 that you can expect to be produced. We are already aware of the carbon that is there so one mole of carbon will combine with one mole of oxygen giving in one mole of CO2 and you can estimate this value. Coming for the hydrogen the total amount sorry the water that is formed the water that will be formed would be of the order of 1047 into 10 to power 3 kgs and as I told you before water would be coming from two different sources. One would be the moisture which would be 536 and this is the amount of water that is basically the moisture and plus we would have also water coming in from the conversion of hydrogen or combustion of hydrogen and this is from the hydrogen combustion. So total amount of water that is produced around 1047 tons per day. Sulphur dioxide is coming entirely from the combustion of sulphur and that would be of the order of 85.2 into 10 to power 3 kgs or tons.

Oxygen is basically coming out from the excess oxygen that we are providing. So we are providing in 20% excess air which consists of the oxygen as well and this oxygen comes in unreacted and this would be of the order of 569 into 10 to power 3 kgs. Then we would also have nitrogen coming in so most of the nitrogen that goes in as air comes out unreacted and further we would have some amount of nitrogen that is being formed because of the nitrogen that is there in the coal and this would be forming the largest component of the flue gases almost 11179 into 10 to power 3 kgs and further the amount of ash that would be produced on a daily level would be almost 497 into 10 to power 3 kgs or almost 600 tons a day which is a huge amount and that is the reason why most of the coal plants if you visit them are normally surrounded by empty fields where the ash is dumped and most of them are swampy regions which are useless for any other use and that is again a great amount of environmental degradation that is happening. And another thing you would notice here that if you see the amount of CO2 in the flue gas it is not very high. So on the mass basis if you see the CO2 is just 16% of the total gas which is not very concentrated.

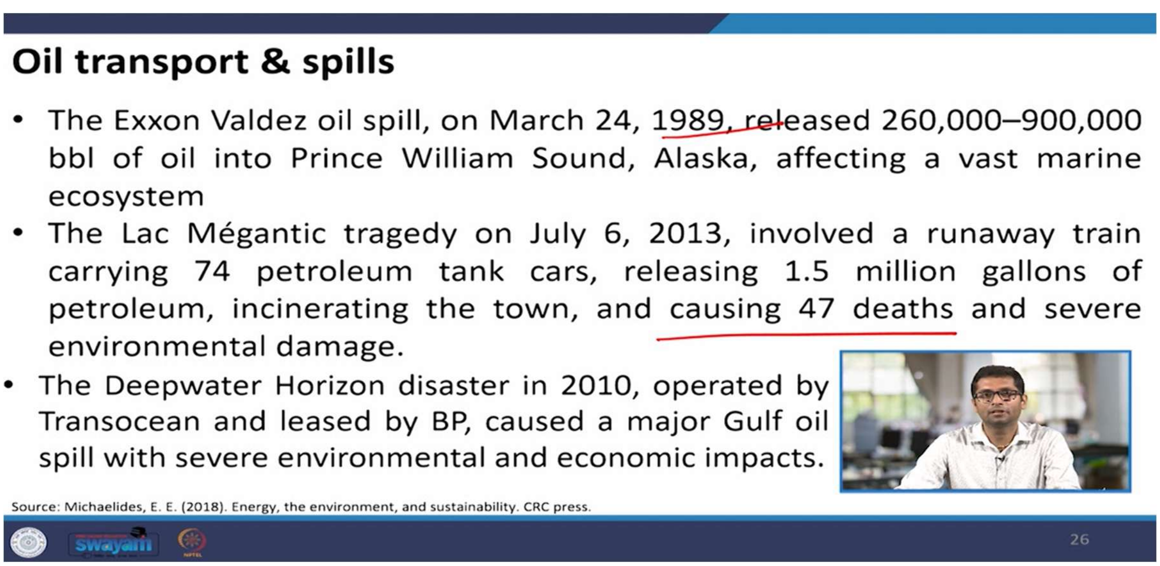
So if we hear people talking about that CO2 could be readily captured from a coal based power plant it has its own problem associated with it because the concentration of the CO2 the amount of CO2 in the exit gas is not very high. Primarily it is composed of nitrogen which is the largest component and capturing CO2 from the post combustion flue gases is again an issue where the concentration of CO2 is not very high. And also there are talks of about transporting this CO2 to other places where they could be used. Again this is a major issue because why would you want to transport a gas total amount of gas where the CO2 concentration is just 16%. So this provides us an important insight that all the CO2 is released at a very big level from a power plant the concentration at which the CO2 is released is not very high.



So let us go back to the slides and discuss some more issues with respect to the fossil fuels. Some other issues that are associated with the coal mining so is that like the water pollution the coal after it is being extracted the mines are normally abandoned and with time they fill with water there are water leakages and these water leakages basically degrade the water and the water if it enters the different water cycles or the underground water tables it has toxic effect on the nearby population. So that is a big issue that has been faced by people who live in the vicinity of the coal mines. Further because you have been digging the mines in the earth's surface you are removing a great amount of coal there is also a problem of land subsidence that could be experienced. Further for creating of a large amount of mines you would have to deforest a lot amount of land which again could have its implications on the wildlife that might be accommodated in that particular land or if that land has been used for farming or agriculture. Further the combustion of coal in the power plants also releases a good amount of fine particles PM2.5 or PM10 which basically if inhaled by the human population can cause a great deal of breathing problems and it has been experienced by people who have been working in the mines like they and so that is another issue that is not much talked about. Further because of the harsh conditions these mines are very susceptible to accidents and hazards that has been happening in the past as well. A lot of people tend to have not so good experience working in the mines and considering that in the past like most of the mines were using manual labour the accidents were even more.

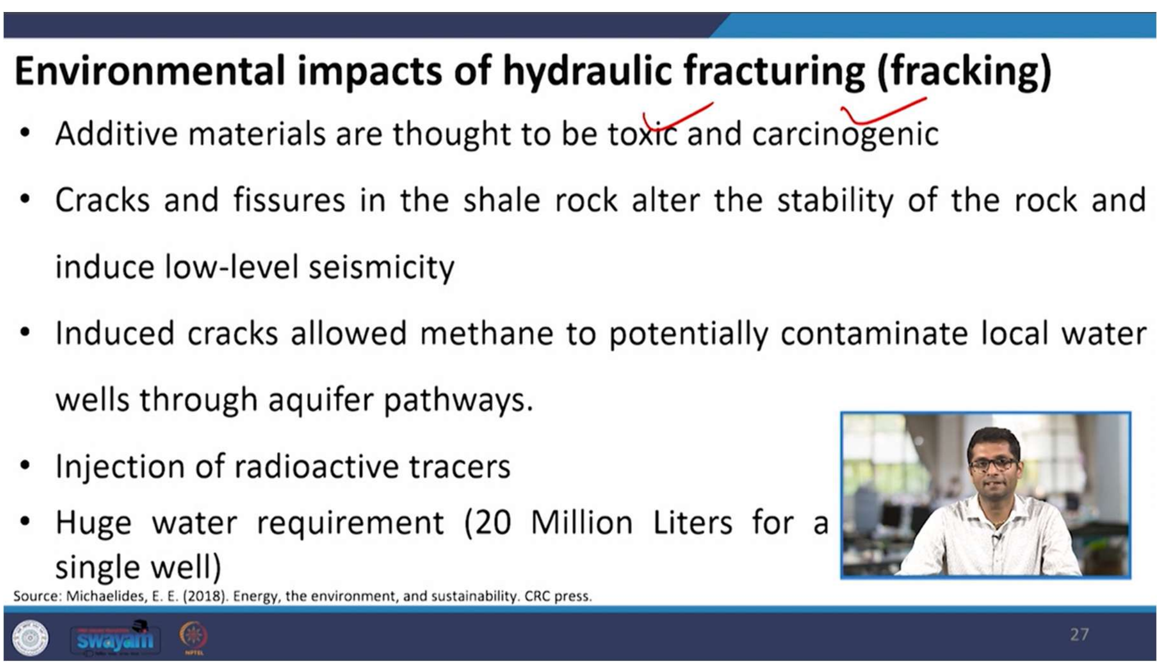


Solution that has been now been proposed is the use of strip mining where it's like the mines are being exposed layer by layer so that the accidents are as low as possible but still we would have the release of particulates that would be happening to the environment and that causes a lot of problem to the people who would be inhaling these kinds of particles and living in the vicinity. Further we understand that the disturbance to the environment and the ecosystems is almost permanent even after you go for a land reclamation that's not 100% of the time and the land tends to be spoiled and water pollution and water runoff is again a big issue specifically for the mines which would have a significant sulphur content. So if this sulphur enters into the water tables and then reaches the population who might be using this water for different portable purposes it could have serious problems.



Then if we talk about another major source of energy which is the crude it is susceptible to a lot of transportation and spills. We have seen in the earlier classes the first few classes that there is a huge mismatch among the countries who would be consuming and who would be producing this oil which calls for a huge amount of transportation of this crude that happens through the sea through big big tankers and we have been hearing about the cases of oil spills. Few major ones have been listed here there was a major oil spill in the year 89 which is also called as the Exxon Welders oil spill.

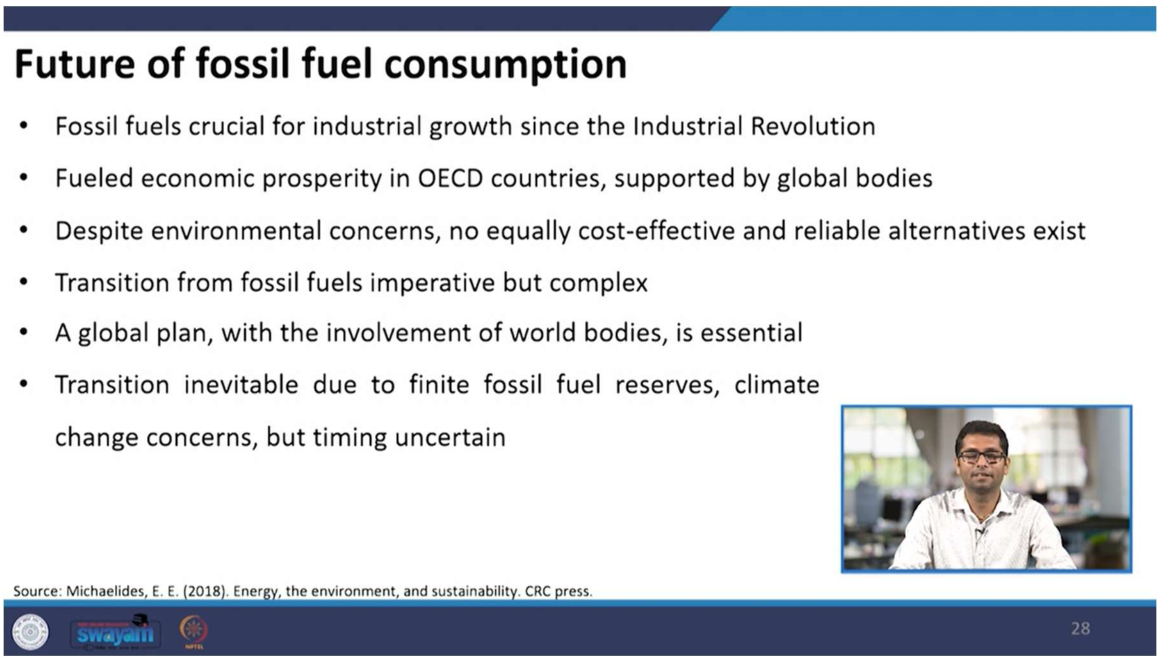
It was the Exxon Welders vessel which basically spilled almost around 9 million barrels of oil into the sorry not 9 million it's like 9 lakh barrels of oil into Alaska and it affected a great deal of marine life. Further there was another tragedy that happened recently in the past which is called the Lac megantic tragedy wherein again there was a train carrying a lot of petroleum products and that had met an accident causing a lot of spill of the oil on the land and also causing significant deaths like it led to almost 47 deaths in the area. A similar thing happened by the oil spill by the BP it's also known as the Deepwater Horizon disaster that happened in the year 2010 and wherein it led to a release of great amount of again like oil and causing a great deal of impact on the local ecosystems as well as the neighboring beaches where this oil might be reaching.



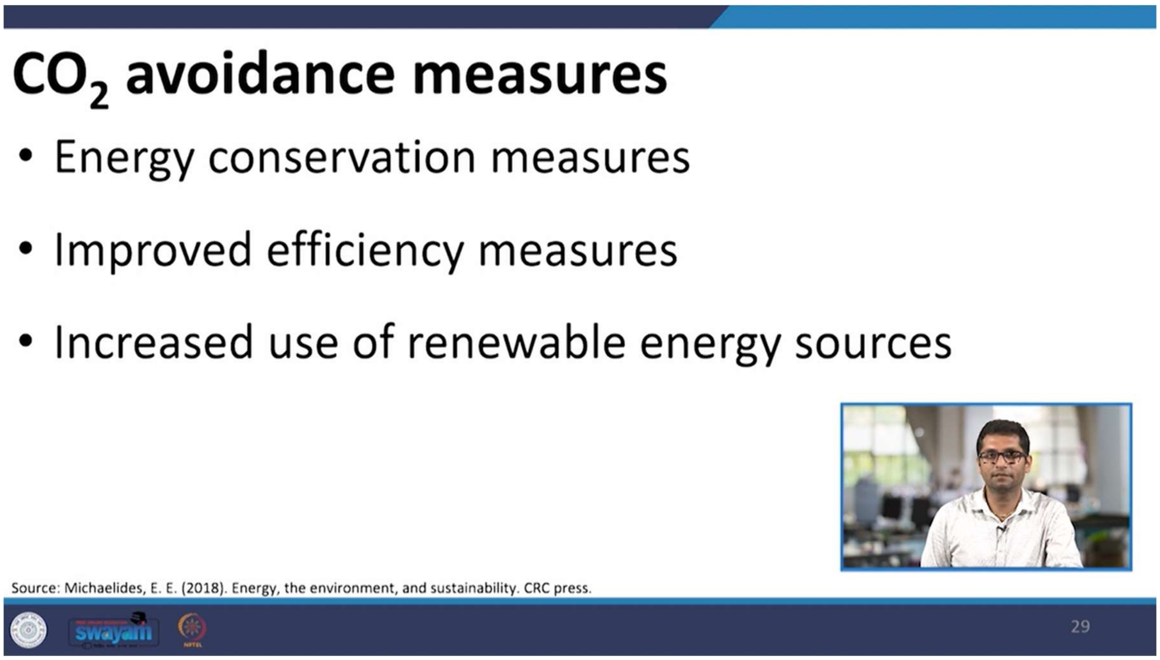
So and as the technology is progressing we have also seen that people are going towards better technologies for extracting oil and gas and this is specifically true for the Americas where like a hydraulic fracking is one of the major technologies that is being adopted. So fracking is one of the latest technologies that helps us increase the productivity of oil or extract oil and gas from the areas where it was not found to be possible in the earlier but again with the increase of this technology there are also certain kind of apprehensions that are coming.

One of the major apprehensions is that like a lot of fracking basically involves pumping a lot of water into these shale rock formations which help in bringing out the oil and the gas and because of this they also use a lot of additive materials and many of these additive materials which are proprietary items and for which the formulas are not disclosed are there is a perception that they might be toxic or carcinogenic in nature. Then the cracks or the fissures that are made in the shale rock in order to extract the different fossil fuels also induce a low level of seismicity which might affect the people who are living on the ground above these formations and also there is a like anticipation that there could be a methane leakage and that can contain or contaminate the water wells or the water aquifers that lie above these coal fields so that is again a major apprehension. Again like to measure the amount of the fossil fuels that are left in the mines normally they are doing a tracer analysis where they would inject a radioactive tracer and note down its concentration at the onset and the final concentration to make an estimate like what could be the effective amount of fossil fuels that could be remaining in a particular formation and so that could have its own consequences. A major consequence that is being talked about is the huge water requirement. So for a single well normally it would require about 20 million litres of water and that is something that is being debated a lot like does it make sense to use a lot of water that is injected at high pressures so as to make capital gains and that is another water energy nexus that needs to be understood.

Further another major controversy that has been erupted is like is because of the property rights like who basically is responsible for the different effects. So normally the mines would be owned by different companies but on the floor there would be farms, there would be ranches or there could be different kinds of economic activities going on. So because of the result of these kinds of operations that are happening beyond beneath the land there could be a low level seismicity or there could be emissions of methane that are occurring. So people are almost debating that who would be responsible for these kinds of emissions because the suffering population would be the one who are living on the land whereas the money earning people or the people who would be making an economic incentive are the one who would be digging the land and extracting these resources. So who would be held responsible for these kinds of operations is one of the areas of debate.



Then it is also almost discussed like what could be really the future of fossil fuel consumption. In the past we have understood that a whole lot of economic development in the major countries which are the part of OECD or the organization of economic cooperation development is supported by the fossil fuel based industry. A lot of their effluents is being owed to the use of fossil fuel and they have been efficiently using that for many centuries now and despite all the environmental concerns there have been net zero targets, there have been different agreements into place but again the progress if you have to quantify there is no unanimity that we are proceeding in the right direction and with the right speed. So one thing we need to understand that transition from fossil fuels is almost certain but it is again a very complex problem at hand like it is not one pathway could be said like this is the pathway from the change in fossil fuels to other types of fuels because every country would have to have its own pathway and this would involve a lot of complex situation we would have and geopolitics we would have the local economies we would have a lot of regulations coming in but we need to understand that this transition is inevitable because ultimately the fossil fuel reserves are limited and climate change concerns are a reality but how fast that happens remains to be uncertain.



Let us also try to discuss the alternates and what could be okay we also need to understand that something that is very closely linked to the use of fossil fuels is the avoidance of CO2 because that is one of the major reasons for the global climate change and one of the major reasons that have been attributed for solving or the low-hanging fruits would be the energy conservation measures which means reduce the amount of energy that is being consumed by people as such improve energy efficiency if you cannot reduce the energy consumption at least try to efficiently use the energy that you are using make the processes much more efficient use much more efficient plants and finally go towards renewable energy sources of energy which are expected to have much lesser carbon footprints as compared to the counterparts but it's not that the other sources of energy would not have any other consequences and we also need to understand that different types of pathways could have or different mitigation measures could have different kinds of CO2 avoidance.

CO_2 avoidance of some common fuels

Fuel	CO_2 avoidance (kg)
1 kg of carbon	3.67
1 gal of gasoline/diesel	8.71
1 L of gasoline/diesel	2.32
1 m^3 of methane at STP	2.40
1 m^3 of CO at STP	4.20
100 ft^3 of propane at STP	15.28
1 t of anthracite (90% C)	3,300
1 L (0.789 kg) of ethyl alcohol	0.75

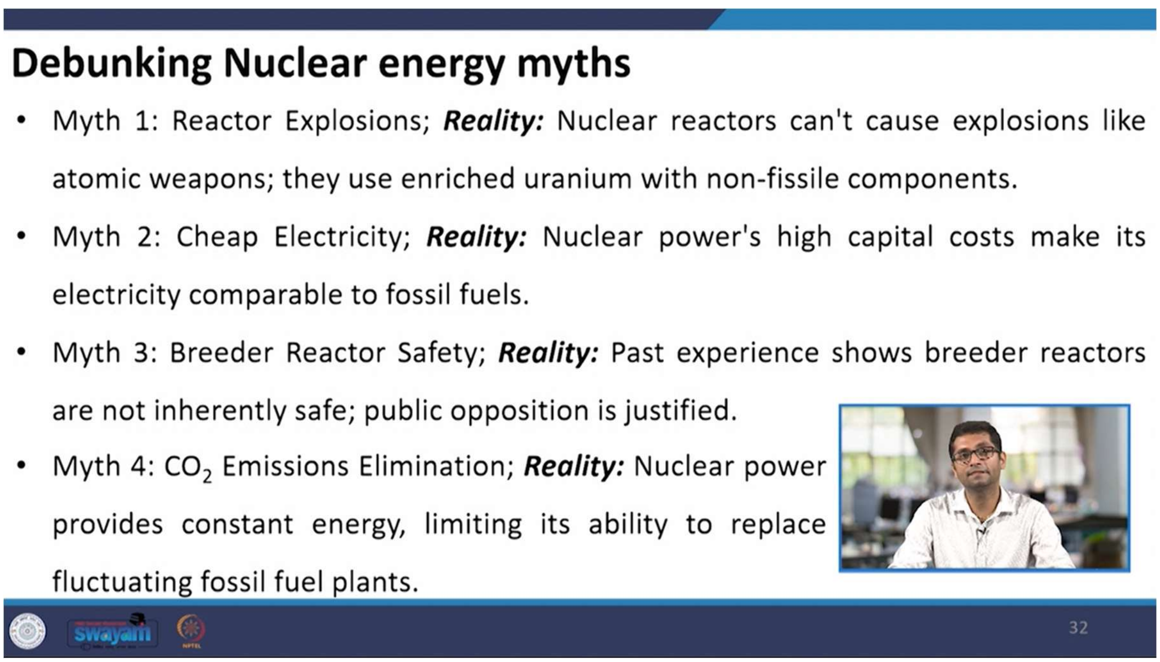
Source: Michaelides, E. E. (2018). Energy, the environment, and sustainability. CRC press.

So here for the reference it is given like if you say 1 kg of carbon the CO2 that is avoided is 3.67 that's nothing but multiplying by 44 and dividing by 12. Further if you reduce 1 gallon of gasoline or 1 liter of gasoline the reduction could be almost around 2.32 kgs at the same time if you are saving 1 ton of anthracite it could be much more savings so it needs to be understood like what particular action is going to save how much amount of CO2 so that the emphasis could be paid on the actions which have the maximum result in return and this is something that needs to be understood as well.

Environmental impacts of Nuclear energy

- Radioactive nuclear fuel poses health risks for miners and workers.
- Deep-earth mines increase health risks, while surface mines are considered safer.
- Protective measures, like masks, are crucial during mining and processing.
- Handling nuclear fuel requires strict safety protocols and automation.
- Temporary nuclear waste storage has moderate environmental concerns.
- Permanent disposal is less risky due to lower radioactivity and secure facilities.

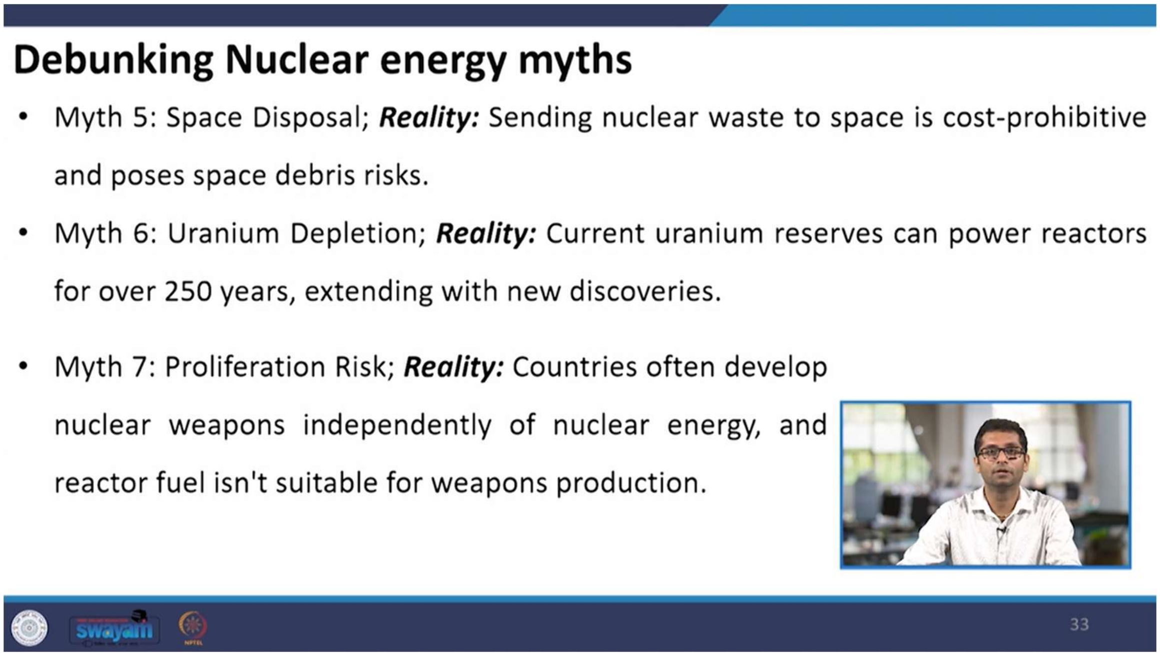
Also we need to understand that even if you go towards other sources of energy and they are not going to be a boon they would have other issues as well and this is what we will be discussing as well. So suppose if you take the case of nuclear energy of course it is poised that a clean source of energy it doesn't have CO2 emissions that are occurring at the plant so far so true but also the radioactive material that is produced as a by-product or that radioactive material that is produced during the extraction of high grade uranium also has a great deal of health risk for the miners and the workers so the uranium that is normally extracted from the mines normally has a concentration of 0.5% to 2% which needs to be concentrated to be used as a fuel in the reactors. Then the deep earth mines which are normally for like used for extraction have their own health risks. We also need to understand that nuclear fuel requires a lot of safety protocols and automation because any spill or any kind of leakage could have serious consequences. We already discussed about the nuclear storage about the temporary and the permanent disposal these are the big issues which needs to be taken care of.



Let us also try to understand some of the myths that are related to nuclear energy. So people are a bit apprehensive that they have seen like how the cities of Hiroshima and Nagasaki was almost completely destroyed at the end of the second world war. Can there be a similar explosion in the nuclear reactors that are used to produce energy in the vicinity of a town? Well the clear answer to that is no because the amount of concentration that is used in the nuclear plants is very less as compared to that used in the nuclear bombs so it's not expected that the explosion that is going to happen would be comparable to somewhere that has been reported for atomic weapons because the amount of uranium that is used is quite different. But nevertheless there is a danger that might come from an accident from a nuclear power plant as we have discussed in the past but the level would be no way comparable to that that was seen in the terms of atomic weapons. Further it is often said that nuclear electricity could be one of the cheapest forms of electricity because it doesn't have any much expensive fuel going into it.

Well we need to understand the nuclear plants because of its high level of automation and the safety requirements have very high capex and because of which the electricity produced from a nuclear power plant is somewhat comparable to fossil fuels. So it's not that if you're using nuclear power plants the electricity would be any cheaper than fossil fuels. Then people are a bit concerned about the breeder reactor safety as well they seem to say that the breeder reactors are much more safe than the earlier reactors say or the FBR reactor the fast breeder reactors. Well the past experiences have shown that all of the nuclear reactors have some amount of problems and have their own safety risks so it can't be said like one particular reactor is completely safe there is a possibility of accident in any reactor that you would be using. Then again there's a myth that the co2 emission there would be no co2 emissions that would be coming from a nuclear reactor.

Well that is true in the sense that there would be no co2 emissions but we need to understand that nuclear power plants would be providing us constant energy which means they cannot be rammed up and down to meet the consumption levels and if we see that the consumption levels of the population vary on a daily level on a monthly level on an yearly level. So nuclear power plants are not designed to make that so nuclear powers can form as a base load but to meet the changing requirements or dynamic power requirements you would need some amount of electricity to be produced from other sources and presently there would be coal and natural gas and they would have co2 emissions.



Further people are also talking about the space disposal and we have also discussed that it nearly costs around 25 000 dollars for sending one kg of material to the outer space and this makes the cost prohibitive for such an expedition. Further it is also sometimes said that the uranium deposits on the earth are going to deplete fast and we might not be able to produce nuclear energy in the future. If you go with the present deposits that are available for the different kinds of radioactive material we can be sure that we have enough fuel available for the next 250 years or so and if we also take into one of new discoveries or new reserves that could be found it could easily extend to 600 to 700 years.

So the availability of fuels for production of nuclear power is not much of a concern and there is also a Crowley Federation risk that has been doing rounds. People are of the apprehension that if you provide nuclear power technology to countries they might be able to make their own nuclear weapons. Well if you see the history that most of the countries that have been developing their own nuclear weapons was before they were using nuclear energy for energy production purposes and further there have been a lot of countries which produce nuclear energy but have do not have nuclear weapons and one of the reasons is because the fuel that is used in nuclear power plants is much different from the one used for weapons production. But further it cannot be denied that the technology transfer might lead to some of the knowledge improvement that might help in the weapons development. But the two things are often unlinked and we have examples to justify them.

With this we have tried to understand some of the myths and the realities with respect to the nuclear fuel as well as we also try to understand the different kinds of problems associated with the conventional forms of energy coming from both fossil and nuclear energy. In the next class we will try to focus more on the problems that are associated with the production of renewable sources of energy. With that we end today's class. Thank you.