Energy Resources, Economics, and Sustainability

Prof. Pratham Arora

Hydro and Renewable Energy Department

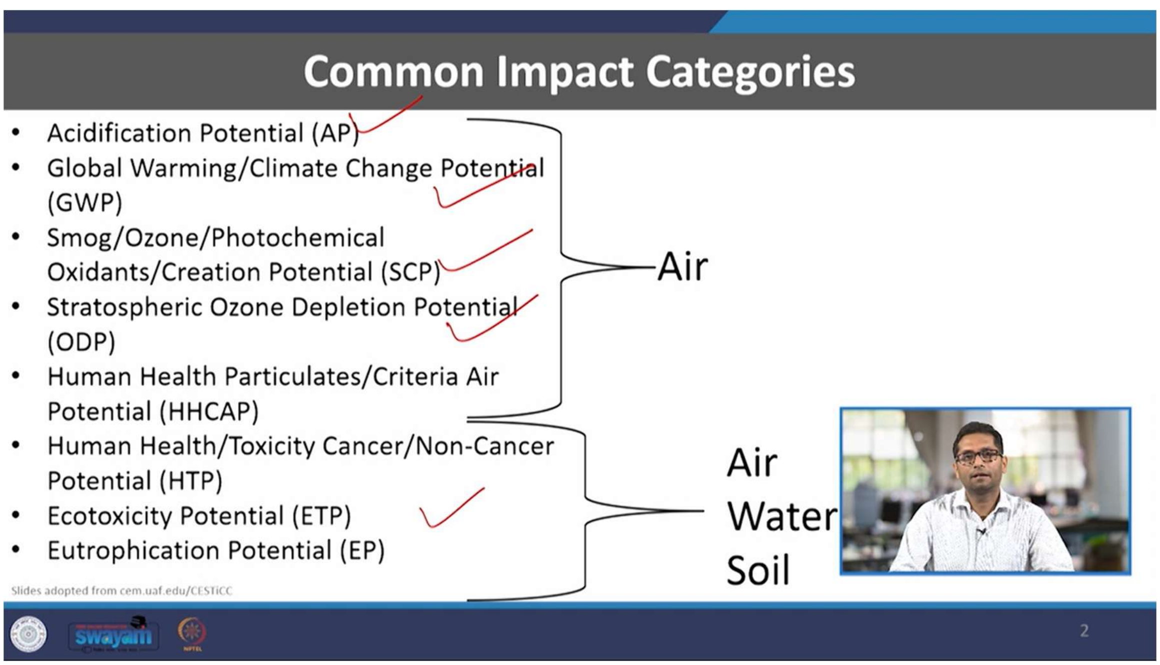
Indian Institute of Technology Roorkee, Roorkee, India

Week – 08

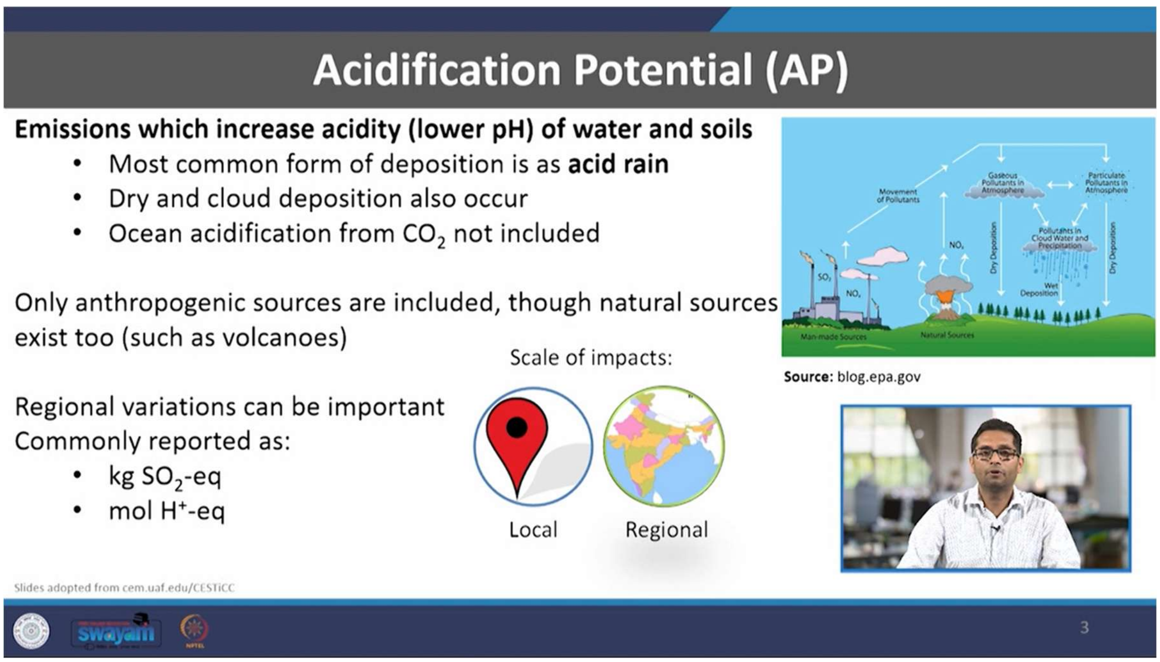
Lecture – 02

Lecture 38 - LCA: Impact Categories

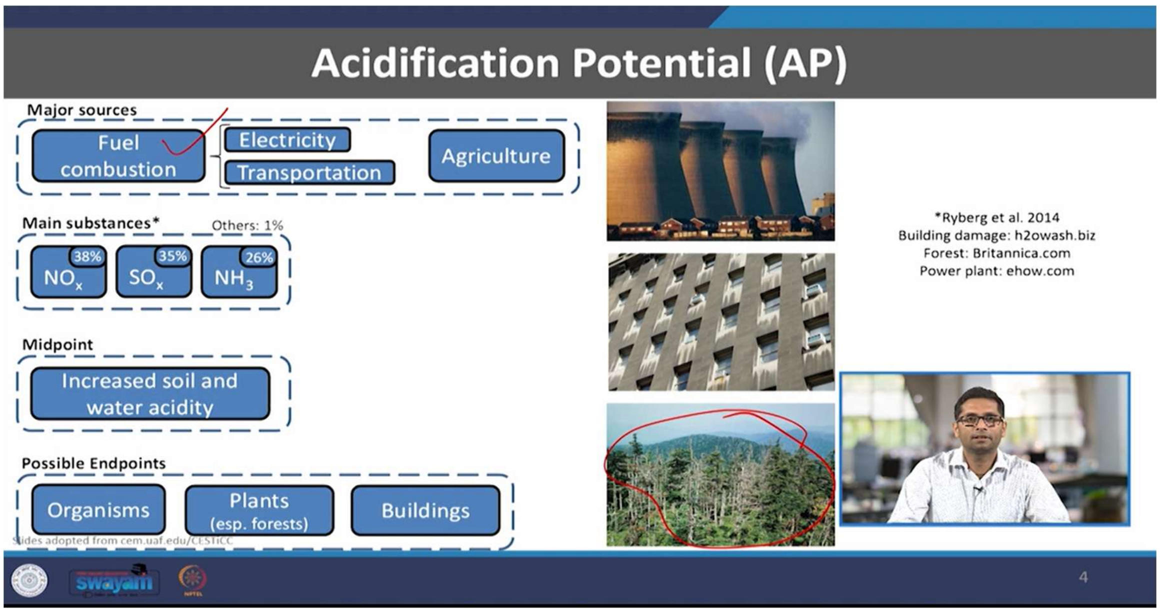
Hello everyone, welcome to the course energy resources, economics and sustainability. In the past few classes, we have been discussing the basics of life cycle assessment. Particularly in the last class, we have been discussing how do we convert the different kinds of emissions into the different impact categories. Carrying on the same discussion, we will try to understand what are the importance of these different impact categories in today's class. What we are going to discuss is what are the major impact categories that you can find in a common LCA study. What do they stand for? How important they are? What are their major contributors? What are the relevant midpoint and endpoint indicators? This is going to be the focus of today's class.



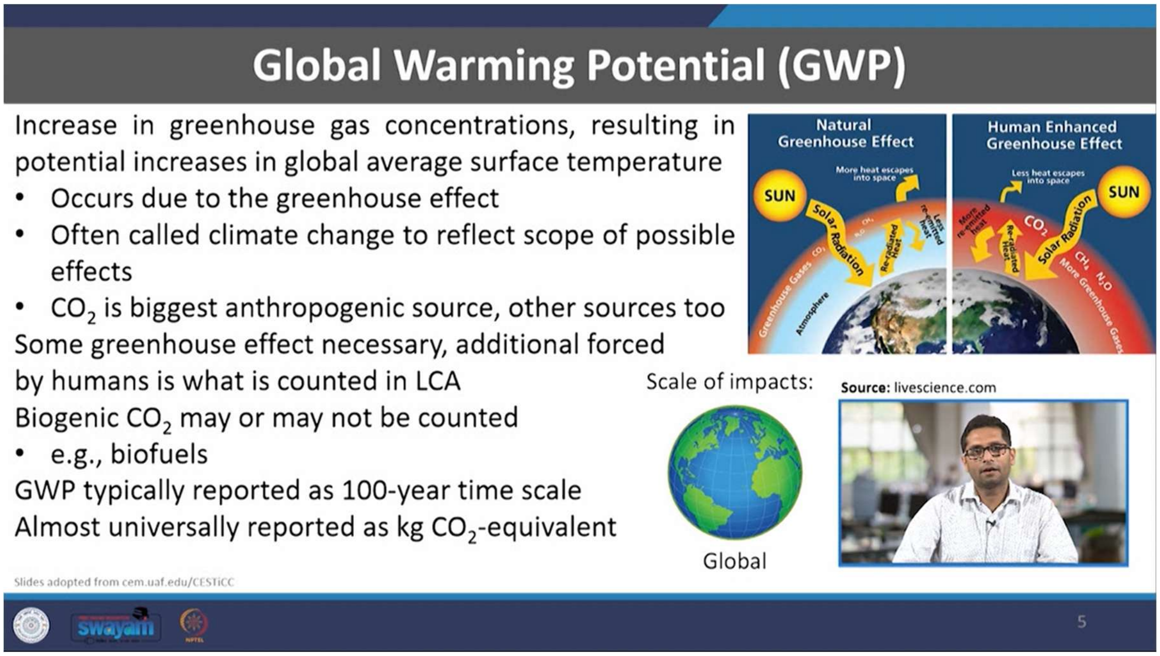
So, if we have to discuss the common impact categories that you will most certainly come across in any life cycle assessment study, here are some. Many of them are related to the air emissions, particularly the global warming which everyone of us talk about. Almost 100% of the LCA studies that you would come across would have this particular impact category which is climate change or global warming. Apart from it, you can come across other impact categories like acidification, photochemical oxidation formation, ozone depletion, as well as the human eco toxicity to be quite often. Now, the above ones are particularly related to the air emissions, whereas the impact categories that you see on the bottom could have the impact on either the soil, water and air. So, we will proceed in understanding some of the impact categories. What are the major causes? What are the relevant midpoint and endpoint indicators? And what could be the different kinds of problems on the environment, the human health and the ecosystems that could come out from these impact categories?



So, let's start with the acidification potential. So, it goes by like the emissions which increase the acidity of water or soil. Basically, as we understand, pH of water is 7 which is considered to be neutral and a pH which is the concentration of H plus ions, like if that is below a certain level, it's considered to be acidic. And normally the soil or the water would turn acidic through the medium of the rains which are acidic in nature. We have understood the concept of acid rain in the previous classes as well. So, normally you would have the SOX and NOX emissions that are coming from different energy related projects or processes. This would cause different kinds of acid precipitation in kinds of acid rain, acid snow. When they enter the water body of the soil, this would decrease the pH and ultimately lead to acidifying of the water as well as the soils. Further, it is not that like the SOX and NOX emitted from anthropogenic processes are the only source of these kinds of emissions. The NOX emissions particularly can also happen from volcanic eruptions. But as we have understood that the LCA methodology is particularly dealing with anthropogenic emissions. So, any emissions of which are coming from natural pathways such as volcanic eruptions are not a part of any LCA regulation. Further, there is another kind of acidification that is ocean acidification that is from the dissolving of the excess CO2 in the water bodies or particularly oceans. And that kind of acidification is not a part of this impact category. So, particularly when I am talking about acidification, it's the SOX and NOX emissions. And if I talk about how they would, the characterization factor would normally be reported in terms of kg of SO2 equivalent or moles of H plus equivalent. The impact, if you want to consider, it would be mostly local or regional in nature because the vapours can travel only to a few hundred kilometres from the place of origin. So, at max, the impact would be regional from the point of source where these emissions are being formed.

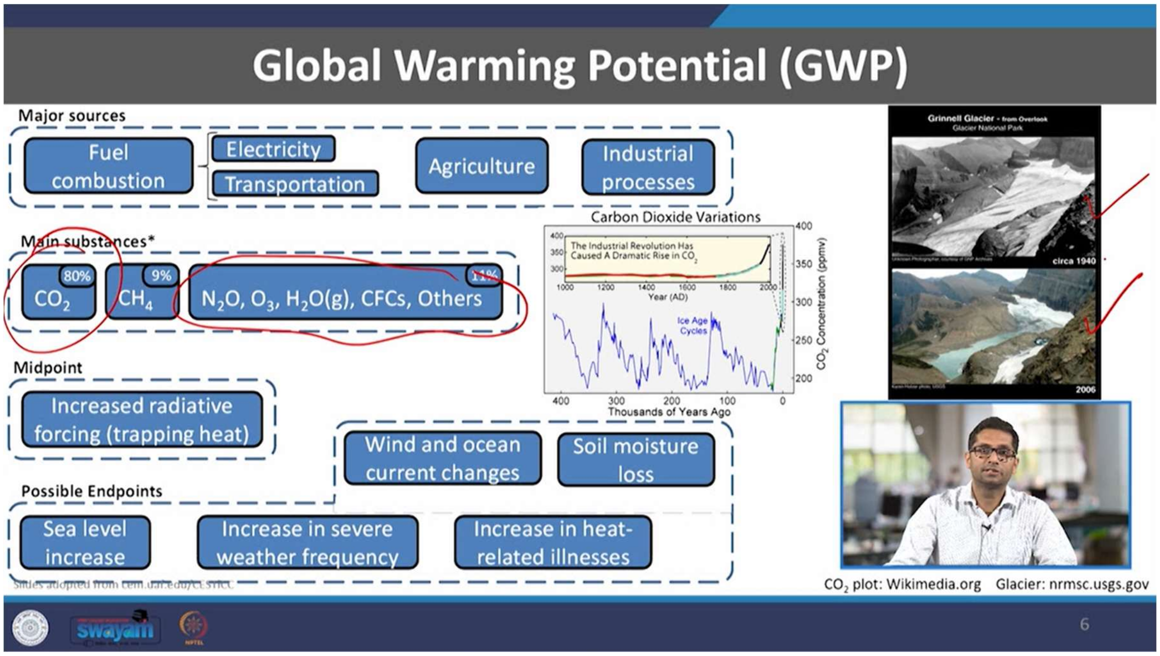


If I consider about the major sources of these impacts, of course, fuel combustion leading to electricity or different modes of transportation is a major source of the SOX and NOX. And further, we can also get considerable emissions from the agricultural sector which comes out in the form of ammonia. And if I talk about the major substances, it's particularly the SOX and the NOX emissions almost equally coming out from the different kinds of fuel combustion. If I talk about the midpoint, it would be the increased acidity of the soil and the water bodies that would be, that happened to be nearby. And if you talk about the endpoints, this would particularly be affecting the different organisms, the plants, as you can see in the picture here, like much of the forest has been destroyed and it would also have a great consequence on the different buildings, particular would be the buildings which have an archaeological value or the heritage buildings which have been there for a couple of hundred of years and people attribute a lot of history to those buildings so they get destroyed. You can see the effect of acid rains on a building like this.



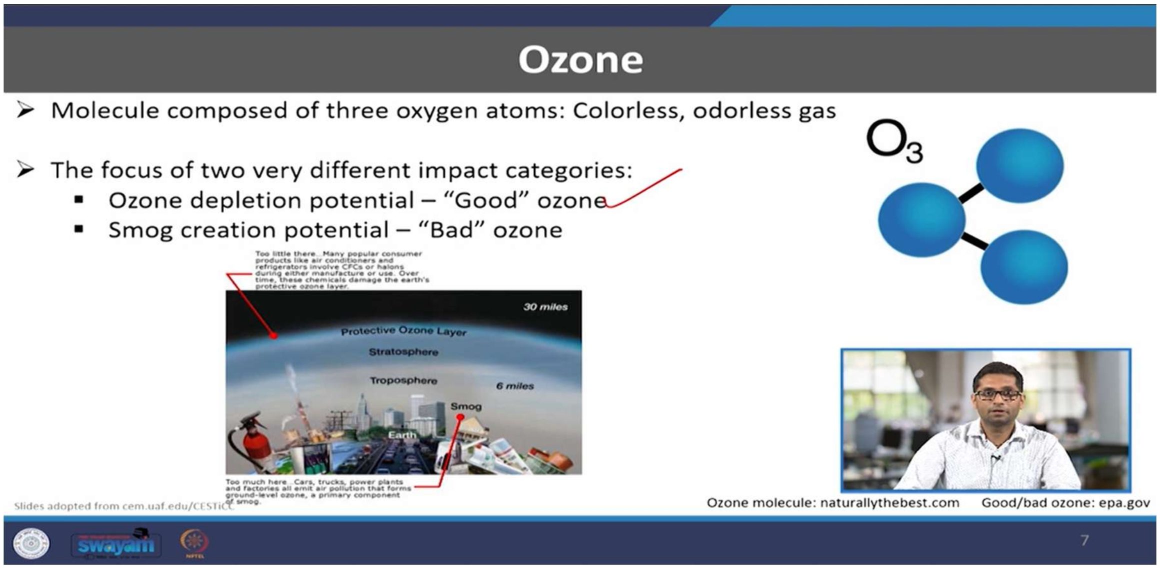
Then another impact category or one of the major impact category that you would come across is the global warming potential which is basically the increase in the greenhouse gas concentration and which would ultimately result in the global average temperature. We have in the past classes understood the phenomena of greenhouse gas effect, how that is affected by the increasing concentration of the different gases like CO2, methane, nitrous oxides and few others. And we also understand that it is not that we can do away with these greenhouse gases altogether, these gases are very important for our survival. But an increase in the concentration of this gas in the atmosphere also does have consequences which are not very good for the future generations. And again we need to understand that CO2 is the biggest emission that is happening from the energy production processes and it is the biggest anthropogenic emission that we have currently. Further there are CO2 emissions that can be considered biogenic in nature. Supposedly the CO2 emissions that come in from the growth of or the use of different kinds of biofuels or bioenergy pathways. So whenever we are having sources of CO2 like this we have to exhibit a question with respect to whether we should include that or not. Because if we go into the depths of the LCA there are certain complexity involved which we won't be discussing but we need to be careful whether we need into account the biogenic CO2 or not because that could affect the results greatly.

Further the emissions that we have in terms of CO2 equivalent in here are also like are temporal in nature because the different molecules of the different gases that we have would have different residence time. There is only a certain amount of time till which these molecules will be exhibiting their greenhouse gas effect and which would vary upon the time scale. So normally acceptable time scale is 100 years time scale for GWP. However you can also get the global growing potentials for 25 years and 500 years and the characterization factors would be somewhat different if you undertake a different time scale. And almost every time you do an LCA you would be reporting the emissions with respect to global warming in kg CO2 equivalent.

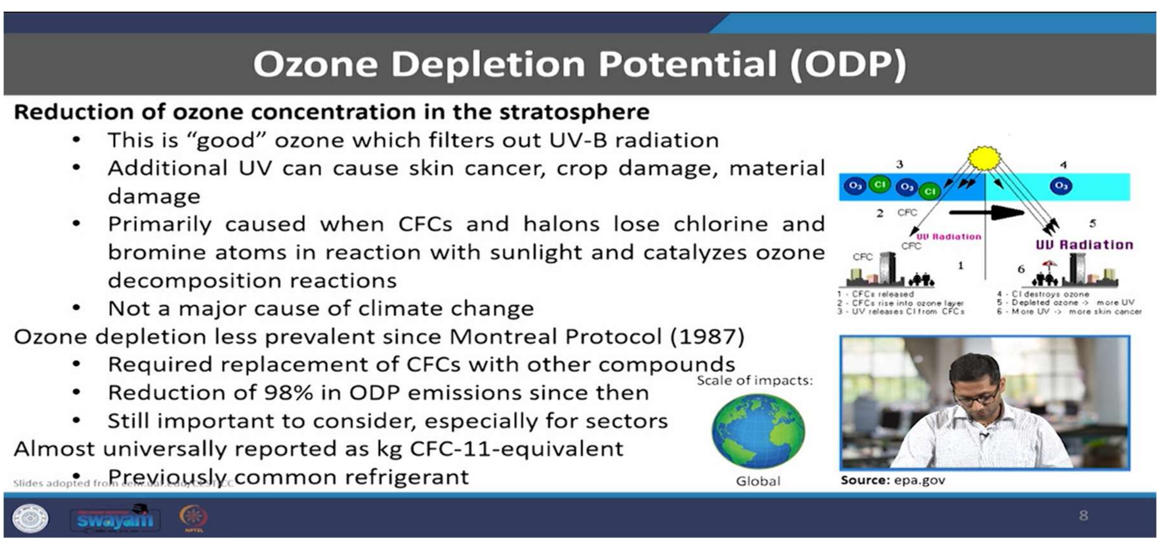


Further if you talk about the major sources it's again the fuel combustion which leads to electricity production and transportation and again a great deal of industrial processes and further we also have agriculture contributing to the methane emissions which can come from the degradation of the different kinds of farm waste as well as from the kettle that is employed there. But as we have discussed in the past class the major source of this global warming would be the CO2 emissions which basically account for more than 70% of the total emissions. Then we also have some emissions coming from the other gases like the nitrous oxides other F gases as well as the CFCs which also have related to the different refrigerants. If I talk about the midpoint indicators in here it would be the increased radiative forcing which basically means how much heat we are releasing as compared to the heat that we have trapped. So an increased radiative heating forcing basically points that we are capturing good amount of heat.

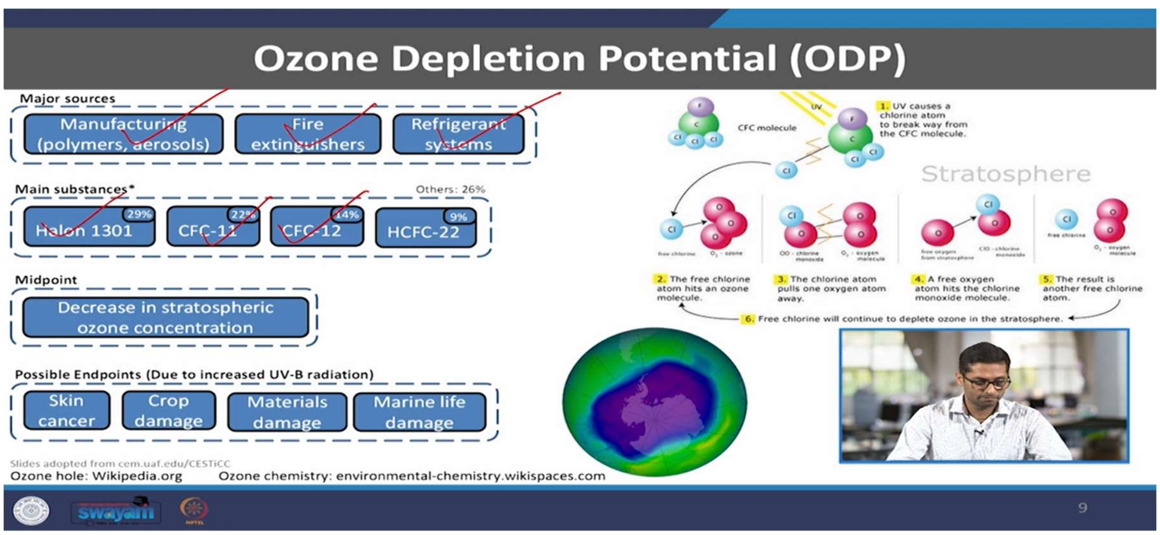
Going towards the end point the different phenomena that we can experience is the level of the sea would be rising we can have an increased frequency of the extreme weather events then there could be changes in the wind and the ocean current changes the soil moisture loss might be seen and then there would be an increase in the heat related illnesses. Further you can see an effect like you can see how the glacier profile would have changed in the last 60 to 70 years and this effect has been attributed to that of climate change which is coming from the different kinds of emissions for greenhouse gases.



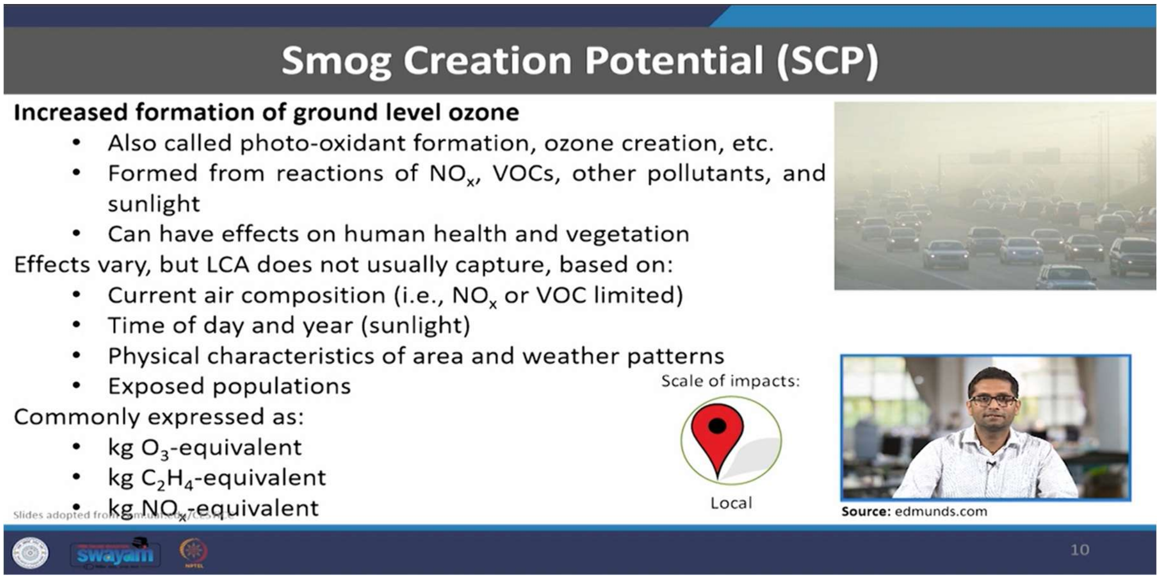
Another major emission would be ozone. Now the ozone is the same molecule the O3 molecule which is having three atoms of oxygen bound together and this basically leads to two different kinds of impacts. One is the ozone depletion potential which is the depletion of the good ozone that is found in the stratosphere. So we have discussed the different layers of the atmosphere in the initial few classes and we know that like beyond the troposphere which is on the sea level we have the stratosphere and in that stratosphere we have some something called as the ozone layer which is responsible for capturing the UV radiation that come from the sun and the system as the good ozone. Then there is also something called as the bad ozone which is found at the land level or the sea level and which is coming out from the different kinds of emissions from the different fuels that are burned in the transportation and that can cause a lot of diseases and that is what we term as bad ozone. So let us try to understand the two kinds of impact categories that are related to this ozone emissions.



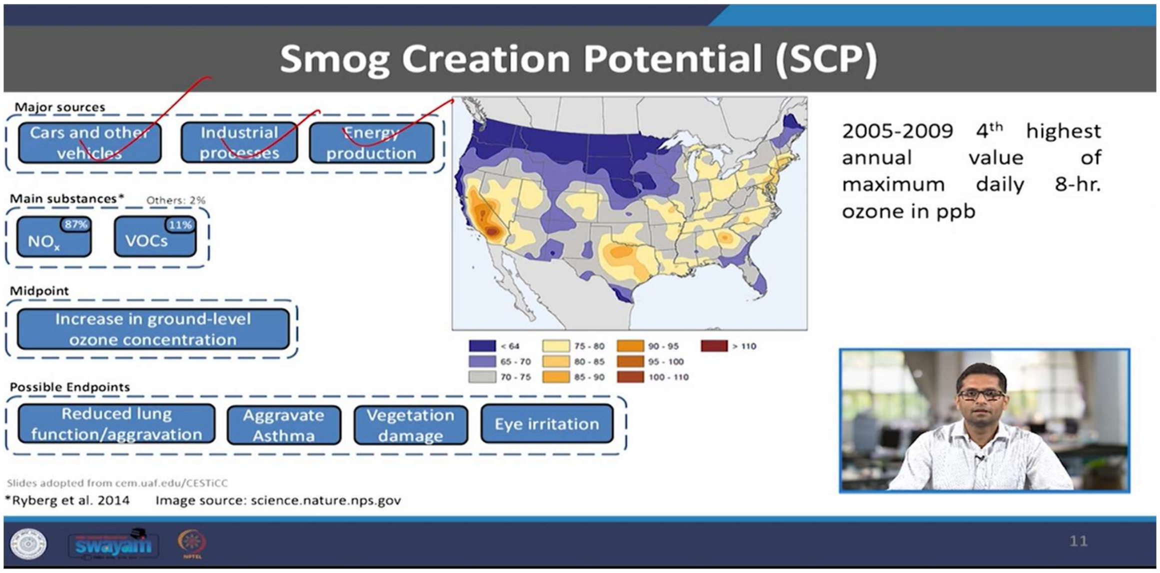
So the first one would be termed as the ozone depletion potential and it is basically deal with the good ozone which we found in the stratosphere. So this good ozone is responsible for basically absorbing the UV radiations that come from the sun and stop or maybe like it removes the damage that could be caused by this UV radiation in the form of skin cancer, crop damage or material damage and the concentration of this ozone is basically decreased by the emissions of CFCs and halons which are basically chlorine and bromine combining compound and a major source of this emission have been refrigerants in the past. But as we have discussed in the previous classes because of the Montreal protocol and later on the Kigali agreement much of this problem has been solved so there has been almost 98% of the reduction in the ozone depletion potential of the different kinds of emission that were happening. But still it is an important impact that should be considered and we should not be ignoring it. And normally these kinds of impact would be reported in terms of Kgs of CFC 11 equivalent. So chlorofluorocarbons 11 was one of the major refrigerants that have been used in the past and that is what has been used as a basis and particularly this particular emission has been global in nature and the impacts are global and it is for everyone to like if there are emissions it basically impacts the complete earth.



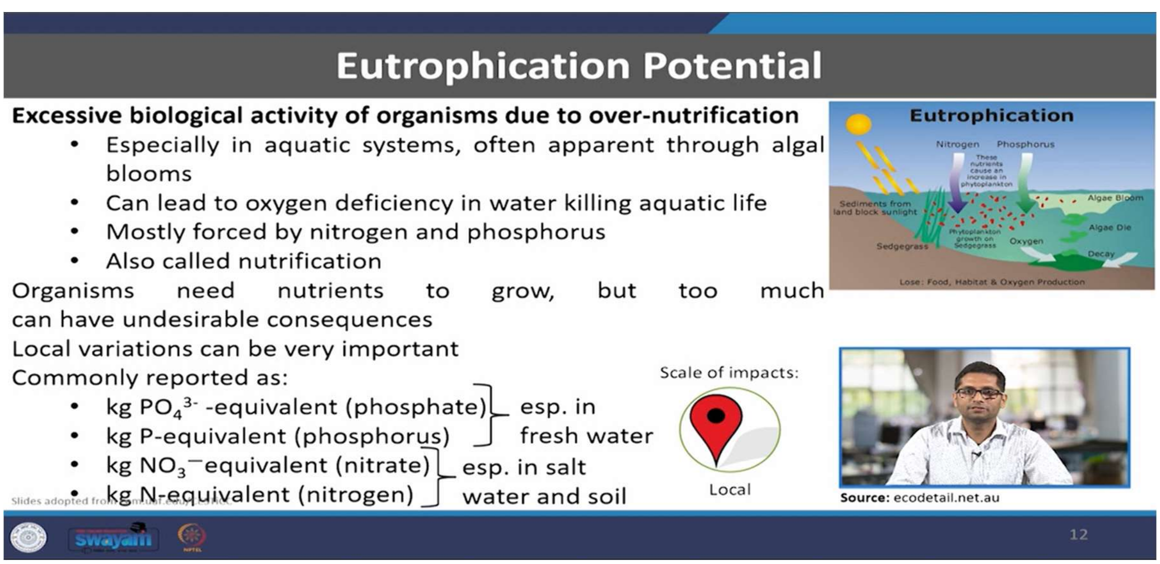
If I talk about the major sources of emissions of course they have been the manufacturing of the different aerosols, the fire extinguishers which use halons as well as the refrigerant systems including air conditioning. So if you talk about the chemicals there are the different chemicals you find CFC 11 here on a similar CFC 12 the different halons are used in the fire extinguishers. So these chemicals when they reach the stratosphere the chlorine on the bromine ions in this react with the O3 molecule break it down and make different chemicals. And if I talk about the midpoint indicator this is specifically the decrease in the concentration of the stratospheric ozone and if I talk about the end point it's basically increase in the occurrence of diseases such as skin cancer and increase crop damage maybe materials damage, damage to the marine life.



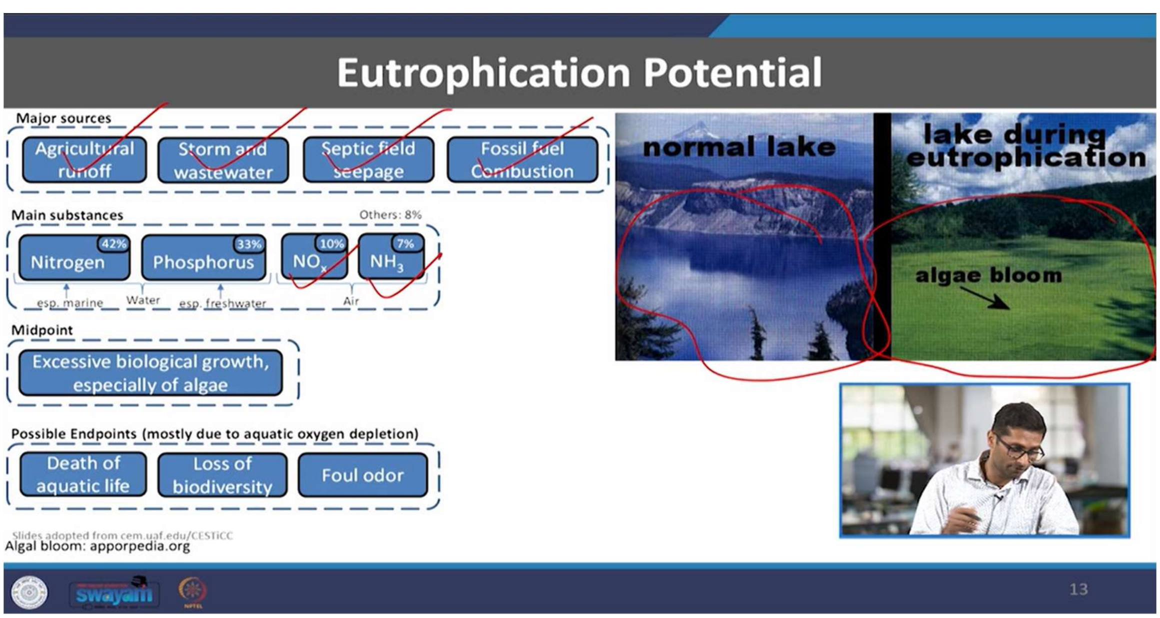
Another impact of ozone which is found at the ground level would be the smog creation potential. This is basically the ozone that is created because the different emissions of NOx volatile organic compounds or other pollutants and the reaction that happens in the presence of sunlight. This impact category is also found with the name of photo oxidation of potential or ozone creation potential nonetheless it all means the same thing. So what is expected that the different NOx and volatile organic compounds would react in the presence of sunlight and create smog which could lead to different health effects. So primarily it's a secondary pollutant smog is or ozone is not directly emitted but it's a result of a reaction of the different chemicals that are emitted and further this reaction would be dependent on many features such as what is the air composition whether the air would have enough amount of NOx or volatile organic compound. What is the time of the day or the year when the sunlight is available because sunlight is something that catalyzes this particular reaction. Then what is the physical characteristic of the area and the weather pattern again it would also like the impact the final impact would also depend upon the population how like how good the population has been exposed to these kinds of emission in the past. One particular thing we need to understand is the concept of these limiting reactant and the surplus reactant. So in case we have a good amount of surplus NOx available in the environment an addition of NOx would not make much of a difference but a small increase in VOC which might be the limiting reagent could have a huge impact and that this is something that is not accounted for in LCA because of the computational structure but it is important and that is where the impact is considered much of a local in nature. The global models for that might not give you very realistic results. Further if you talk about like how would you express the emissions so normally this is expressed in either kgs of ozone equivalent kgs of ethane equivalent or maybe kgs of NOx equivalent.



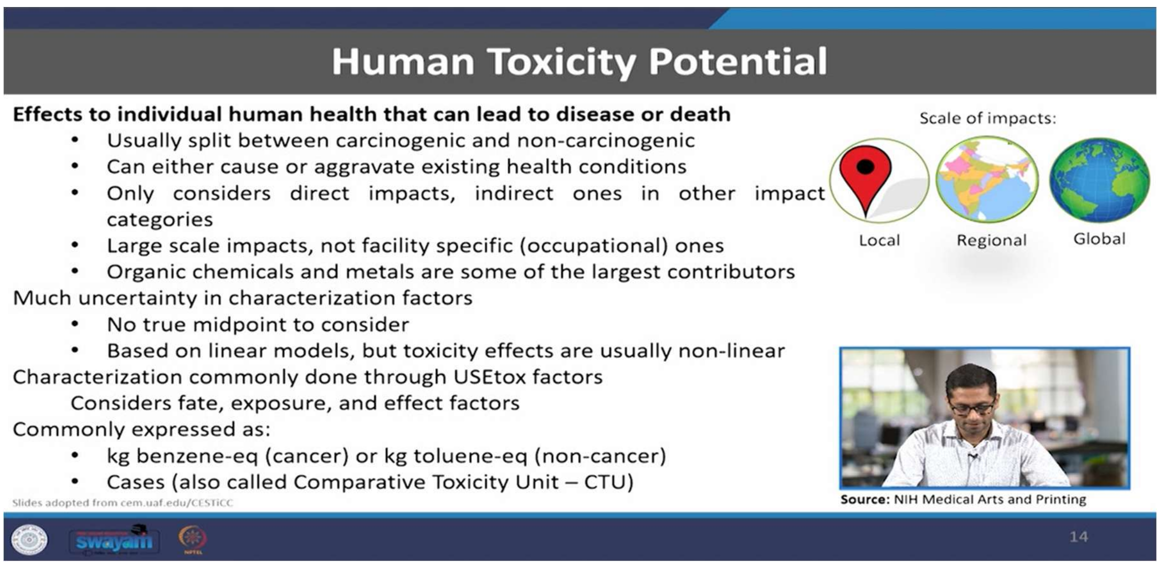
If we talk about again the major sources of this would be the different kinds of road transportation which would be the cars and other vehicles that would be travelling. Then energy production and industrial processes which again lead to production of NOx and other volatile organic compounds are major sources. Particularly it is the NOx which is important which is maybe responsible for more than 80% of the smog related problems. If I talk about the midpoint it would be increase in the ground level ozone concentration. Towards the end point it would lead to diseases such as asthma, lung functioning and aggravation reduction, damage to the crops, eye irritation and particularly this impact is felt in regions which have a huge population density. So what you see in the figure here is like the smog production in the US which is related to the places where you have the higher population density. The smog is found maybe a higher concentration in places which have a higher population density.



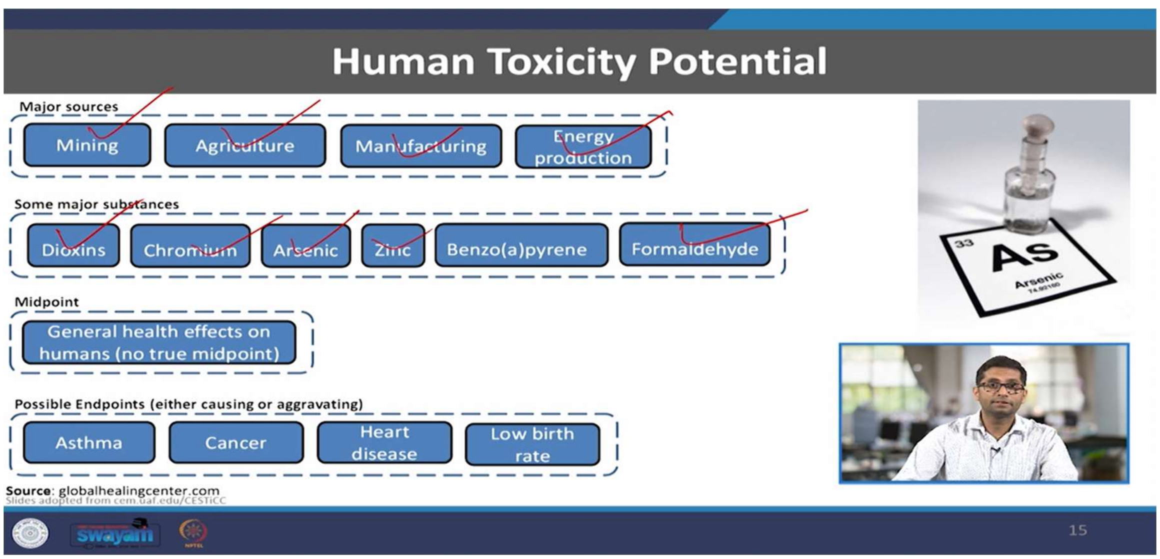
Then if we talk about to move to other kinds of emission categories which affect the soil and the water bodies. One major impact category is that you are likely to come across is the eutrophication potential. So when I say eutrophication I am basically referring to over-eutrophication and this is why this kind of impact is sometimes also called as eutrophication potential. So it is basically providing an excess of nitrogen and phosphorus based compounds to the water body which could lead to production of certain flora in the terms of algal blooms and what happens when this algal blooms flourish and they would destroy the biodiversity and the habitat that is in place. So ultimately leading to a degradation of the local biodiversity and so we all understand that all plants would need certain minimum nutrients for their growth and this kind of impact is something that we see when we are providing these nutrients in a huge amount of quantity. And why is there an increase in nutrients? One of the major reasons is over fertilization or pesticides or use of excess nutrients in the fields which basically run off to these water bodies and cause an increase in the nutrient profile leading to phenomena of algal bloom and then destruction of the local flora. If I talk about the unit in which they would be reported it would normally be like phosphorus based unit for fresh water so kgs of phosphate equivalent or and then if I talk about the marine environment this would be kgs of nitrous ion equivalent. The reason why we would have the different kinds of units for different kinds of water bodies is because normally the fresh water bodies are like have quite excess of nitrogen ions but are limited in terms of phosphorus. So any impact of phosphorus is expected to make a greater contribution as compared to the nitrous compound introduction and the opposite is true for the marine water bodies which are found to be rich in phosphorus but not very rich in nitrous. But of course these statistics might not apply equally everywhere so and this is why a degree of caution has to be there when you are using or applying these kinds of characterization factors on a regional or a global scale.



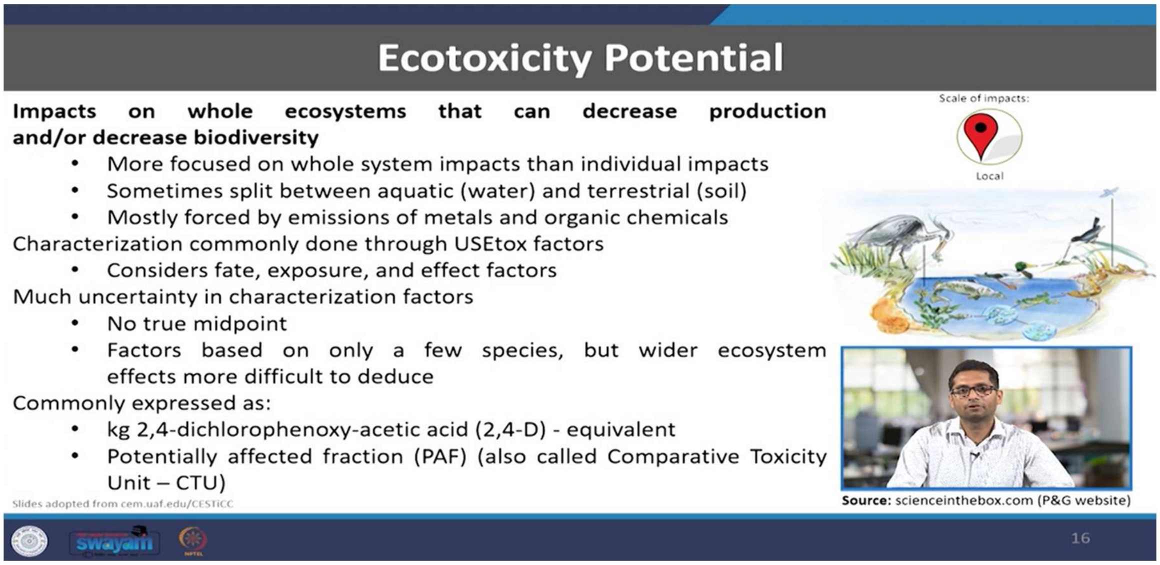
If I talk about the major causes again we have the agricultural runoff that is coming from the fields, the runoff of storm and the wastewater, the septic field seepages and as well as the fossil fuel combustion. Most of these emissions for nitrogen and phosphorus are coming in the form of the runoff that is coming from the fields. Further we also see that the emissions of NOx and ammonia that can come from the different kinds of combustion also can have an impact on eutrophication such that these chemicals are absorbed by water and then enter the water bodies through some means. So we also have minor contribution being caused by the air emissions as well. And if I talk about the midpoint it would be the increased biological growth and what I say that like it's specially to deal with the algae and as you can see on the figure on the right so we have a photo of a normal lake and this is what would happen to the lake if there's an excessive nutrient provided to that lake we can see a lot of algae growing and this would lead to destruction of the local habitat. If I talk about the end points this basically has to deal with the death of the aquatic life which might not get enough oxygen for the survival, loss of biodiversity, the foul odor.



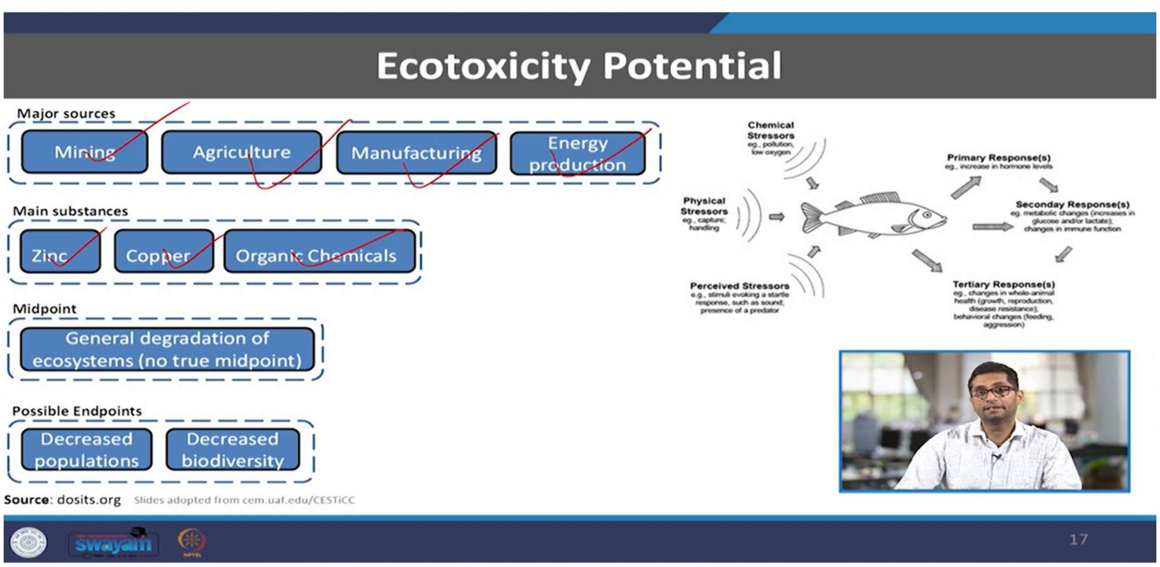
Coming to another impact category is the human toxicity so this is basically affecting the individual human health that can lead to a lot of diseases and ultimately to death. In this impact category we are not dealing about the secondary effect of a few emissions like we have done in the past impact categories like you would have the CO2 emissions leading to certain kind of health effects and that might cause diseases. So here in we are not leading to indirect effect but the direct effect of a certain chemicals which if inhaled or ingested by the human body could lead to different kinds of health effects. So we are just talking about the direct effects and further this impact category could be bifurcated into the carcinogenic and the non-carcinogenic effect. So normally in using the different methodologies you are going to come across like human toxicity carcinogenic and human toxicity non-carcinogenic. Further we are also talking about the large-scale impacts we are not talking about the facility specific ones like the occupational health hazards we're not talking about a particular factory and what could be the results of the chemicals just in that factory but we are looking at this at a bigger scale and specifically we are looking at the ingestion of the different organic chemicals and metals that can come up from the different processes. If I talk about the midpoint so there is no true midpoint indicator for this it's basically an extrapolation of the endpoint which would be the effect on the human health and one thing that we need to understand about this is like the models most of them that are available would be linear in nature which means a certain exposure to a particular emission could cause a particular percentage of a disease whereas in reality the dose exposure and the effect would not be very linear in nature but could have a very different relationships so that is a sort of weakness of the models that are available and a particular characterization model that is normally used depends upon the US ETox factors which have been developed specific to the US and if I talk about what would be the unit for expressing this this would normally be kgs of benzene equivalent for cancer-causing compounds and kgs of toluene equivalents for non-cancer causing compounds and further another commonly used unit is in the form of CTU which stands for comparative toxicity units.



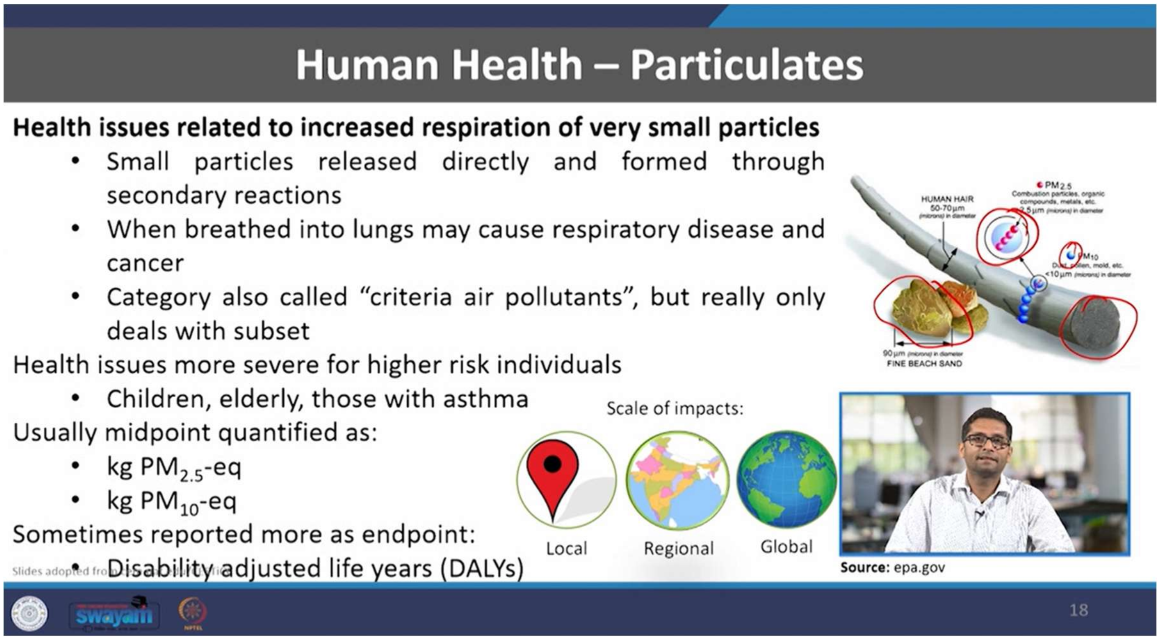
If I talk about like what are the major places from which the emissions for human toxicity takes place it again has to do with mining, agricultural, manufacturing and the energy production. Energy production is something that we would find is related to like a majority of the emission categories or the impact categories that we have been discussing. If I talk about the different kinds of substances this would be the dioxins, chromin, different formaldehyde, zinc, arsenic metals and as we have discussed there is no true midpoint for this it is most probably an extrapolation of the endpoint and what is the endpoint? Endpoint would be the causing of this is like asthma, cancer, heart diseases, low birth rate are some of the particular endpoints which are in the form of diseases.



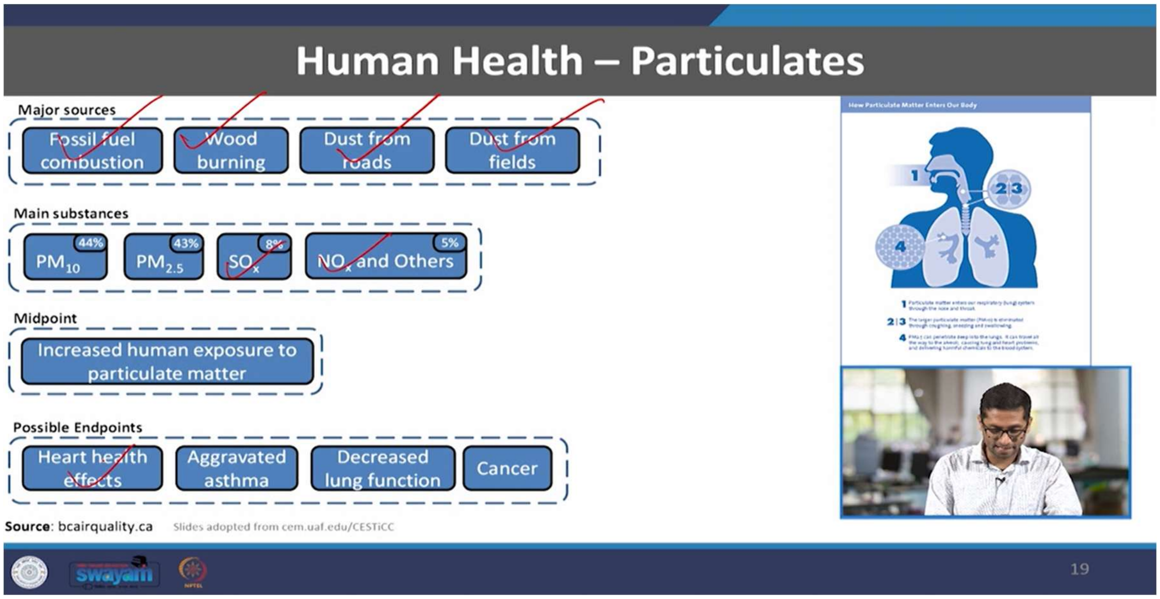
Now similar to human toxicity we also do have ecotoxicity which is the effect on the ecosystems which again would come from the direct emissions that are happening in the terms of the different metals or different compounds and it is more focused on the complete system. Sometime you can see it split between the aquatic ecotoxicity as well as the terrestrial ecotoxicity which deals mainly with soil and again we would be using the US ETOx factors is one of the common way how they are determined. It basically has to do with like what are the emissions and how would they cause an impact on the local ecosystems particularly these kind of impact categories are again local in nature where like you would have and you that would depend upon the conditions. Further note to midpoint exist here as well and it is based on few species and then the system is extrapolated so we have a considerable range of uncertainty in this particular impact category. If we talk about the unit in which it is expressed one of the common unit is 2,4-D which basically stands for dichlorophenoxyacetic acid which is a common herbicide and particularly in the later versions of different methodologies they are also keen on using the CT unit which is the cumulated toxicity unit.



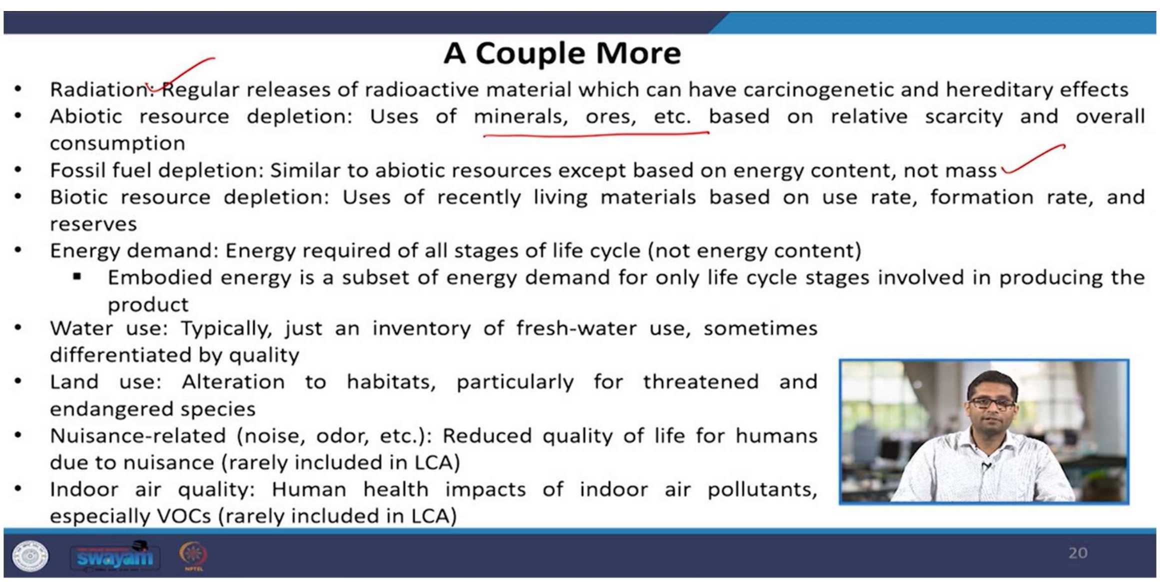
If you talk about how these emissions are taking place again we have the same industries the mining, agricultural, manufacturing and industry production energy production. The major substances that would cause these kinds of emission would be the zinc, copper, organic chemicals. Midpoint would be hard to estimate and what we are more concerned about the decreased population and the decreased biodiversity in the ecosystems and that is the end point that we look for in this kind of impact category.



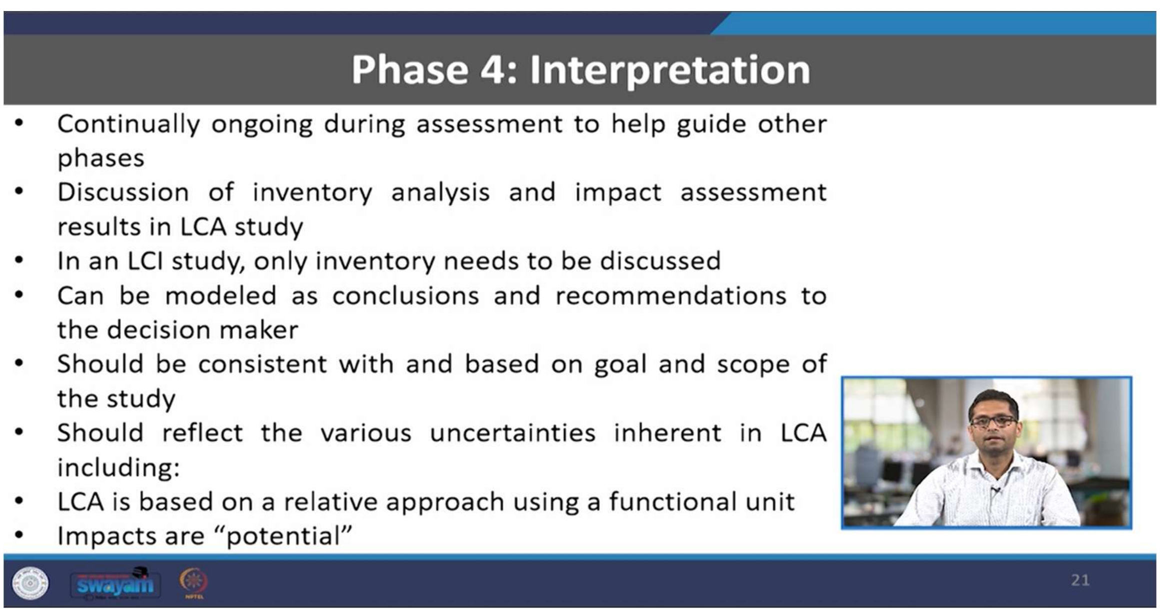
Further there is another impact category that you would come across and that has to do with the release of particulate matter. Now these particulates are agnostic of the substance or the atoms or the compound that they are made of. So it is basically the size of the particles that we are more concerned about rather than their composition. So if I go the definition it is the health issues related to increased aspiration of very small particles. So what we are talking about here is the particles of PM2.5 and PM10. So basically this is PM10 refers to 10 microns and 2.5 microns of particles. So just for a visualization so here you have the size of a normal sand particle that you might come across on a beach and this is how a hair would look like magnifying and if I am talking about PM10 this is how small the PM10 would look like and within that PM10 you can have almost 4 PM2.5 particles. So this is the type of size that we are looking for and when these kinds of particles would be inhaled by the humans it can lead to different kinds of diseases starting with the lung diseases and ultimately into severe diseases such as cancers. So who are more susceptible to these diseases this would basically be children, elderly and those with a disease like asthma. And the normal midpoint indicators that would be used would be kgs of PM2.5 equivalent or kgs of PM10 equivalent and normally again this the endpoint that would be used for these kinds of impact category would be DALYS which basically is disability adjusted life years which takes into account both the mortality and the morbidity that can come as an effect of the inhalation of these particles.



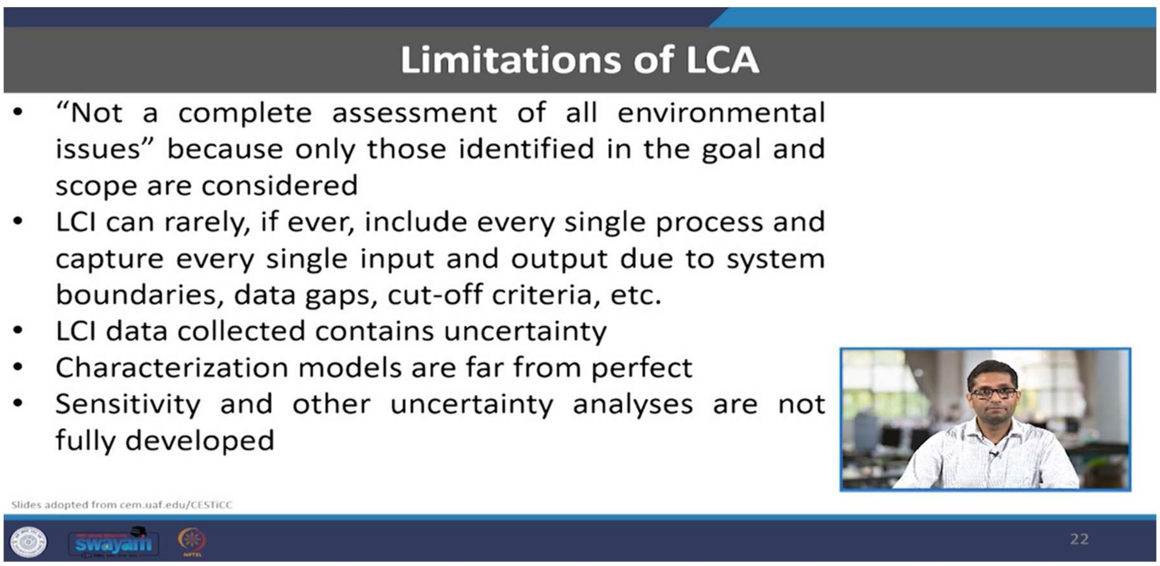
Again if I talk about what are the major sources of this kind of particulate matter emissions this could come from the fossil fuel combustion, burning of open burning of wood and the dust that can come from roads as well as fields. We can have almost similar amount of emissions coming from both PM10 and PM2.5 and again I would like to repeat we are not much concerned about the concentration of these particles we are more concerned about the size and of course we can have significant emissions from SOX and NOX. Midpoints as we have discussed would be the increased exposure to particulate matter finally leading to endpoint effects like human health effects, increase in asthma, lung function problems and extreme diseases such as cancer.



So with this we have tried to discuss few of the major impact categories that you are expected to come across but this is not an exhaustive list there can be a couple more some of them you can find in this slide and of course even this list is not an exhaustive list there might be a couple more beyond that and let me just give you a brief about this. There are some LCA studies that would also focus upon the radiation potential of the different radioactive material that might be used. It becomes more prominent if you would have the electricity production that would be coming from nuclear power plants or something similar. Then there could be abiotic resource depletion basically leading to the use of different minerals, ores etc. which are scarce in nature and could deplete in the near future. Something similar could be for fossil fuel depletion as well as biotic resource depletion which is more to do with depletion of natural resources like wood. Then another major impact category that you can come across is energy demand which is basically the total energy that would be used in the production and use as well as disposal of the particular product. Further this is slightly different from the embodied energy which is another unit that is used. Embodied energy is basically the energy went till the production stage. Then another important impact category with the water use what is the inventory of the fresh water that you would be using. Land use what is the destruction of the land that is particularly marked with a threatened or the endangered species. There could be a few nuisance related impact categories which have to do with noise and odor pollution although they are not used or very rarely used in an LCA. These are some impact categories that you may come across and further there is also an impact category with respect to indoor air quality. Again that is quite rarely used but you might notice it in some of the LCA's. So with this we have discussed some of the major impact categories what are the sources what are the likely impacts in terms of midpoints and endpoints and once you have done this analysis you would go to the interpretation phase.



Of course we have discussed this in the past. So just a brief recapitulation that an LCA is a continuously ongoing process. You don't need to freeze the impact categories from the goal and scope you can always go further and update as in when the data availability is there as your knowledge is increasing your understanding of the process is increasing. Further there are some studies which only discuss till the inventory and that is called an LCA study but that would also entail you interpret the data interpret the different kinds of impacts that might be happening. Further an interpretation phase would entail that you bring up some like concrete conclusions and recommendations for the decision maker so that they can make informed choices about the process or the product that you're handling and of course we should take into care the different uncertainties that are inherent to the LCA as we have discussed in this class that the different impact categories have a lot of weaknesses which needs to be kept in mind and at last we need to understand that all the impacts that we are portraying are potential in nature. There is no 100% guarantee that such and such impact is going to occur.



So what we are talking about here are the potential impacts and finally we would like to end with understanding that it's not a complete assessment of all the environmental issues. We have a great deal of emissions and impact categories that we are trying to quantify but doesn't mean we are covering all the possible emissions. Further the emissions that we are taking in would have the uncertainties involved and they are not perfect the characterization models are still being updated and we need to understand the limitations of the LCA process but again as the popular saying goes that necessarily all models are wrong but some models are useful and we need to quantify the usefulness of this LCA methodology. So with this we end today's class and in the next class we'll try to understand the computational structure of conducted an LCA what are the mathematical framework that we can utilize for if you would want to conduct your own LCA. With that we end today's class. Thank you. .