Energy Resources, economics and Environment
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Lecture 02 P1
Energy and environment

Welcome to the second lecture in the course on energy resources, economics and environment. In this class we will be focusing on energy and environment and the environmental impacts of energy systems.

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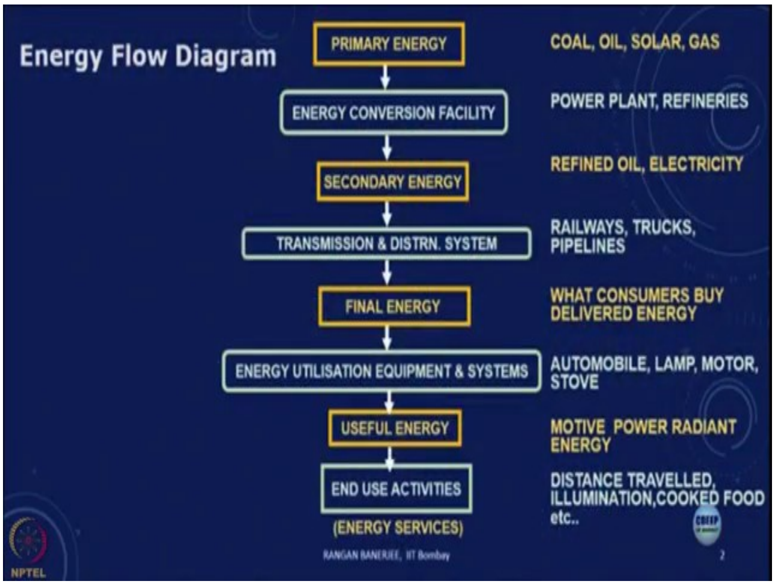

In the last lecture we looked at the energy flow diagram and we saw how, whenever we want to use energy the final energy that we use in terms of the energy service or the end use activity, in order to get that we have the primary energy, the energy that is available in nature which goes through a sequence of conversion steps before we get the final energy service. So at each of these steps, some amount of energy is used and in using that energy there is also some adverse impact and there is an environmental impact.

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So we are going to try and look at this We also saw in the last lecture we looked at the whole phenomena of growth and we looked at the world having a tendency to grow, we have everything in terms of the population grows exponentially and all other parameters follow that exponential pattern. So when we look in terms of the water use or the energy use we said that there would be exponential or unbounded growth.

When we look at unbounded growth, the area under the curve when we take it to infinity is infinite. So when we think in terms of a finite resource situation or the finite ability of the world to maintain and to look at the ways that becomes a problem. So the whole issue is when we design energy systems and these energy systems grow, what are the kind of impacts that happen to the environment and are these impact going to be sustainable into the future.

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So the issues that we are going to discuss in section related to the environment, the first one is why is the environment important? How do the energy systems impact the environment? Is there a trade-off between environment and economic development? What are the major impacts and causes? How do we quantify these impacts and how do we ensure a sustainable future? So, we will take a quick snapshot of why the environment is important to us? What is the impact of the energy systems on the environment? And how do we do this quantification?

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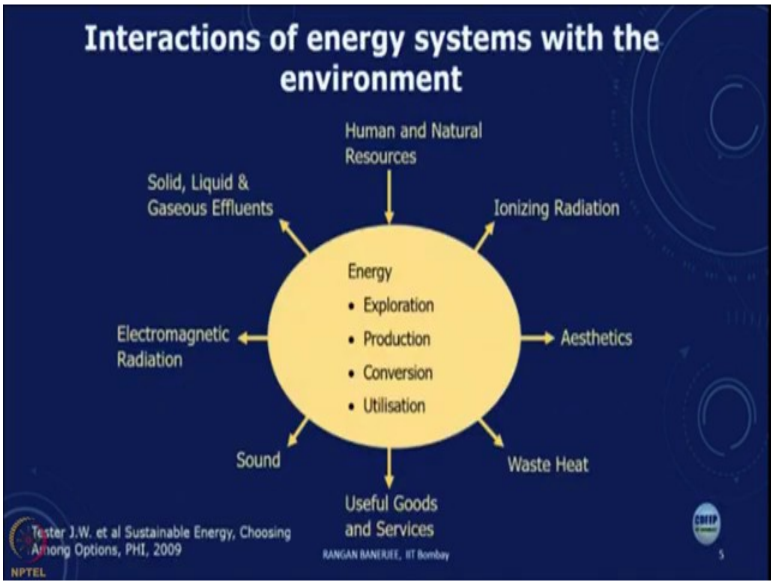

So if you look at this figure, is from the book by Tester on sustainable energy. When we look at an energy system, we are talking of either exploration or production or conversion or utilization and in doing that we are using some natural resources, we are using some human resources and in the process we are then generating, we have the useful effect that we want which is for instance cooling or heating or the transport.

So, there are useful goods and services, but in producing that there are unintended impacts that we cannot avoid and these impacts, some of these are listed here, so you have solids, liquid and gases, effluents or pollutants which go out into the atmosphere into the air, into the land, into the water and each of these depending on the concentration, depending on how you treat it, how you send it out will have different kinds of impacts either on humans or on the ecosystem.

Then there is ionizing radiation, the electromagnetic radiation, aesthetics in manty cases for instances when you have large wind turbines and you look at these wind turbines in the landscape it affects the patterns of birds and its effects the aesthetics some several local communities are not necessarily in favour of this and so this also can create problems.

Many of this situation when we use a certain amount of energy we also reject some heat which is a waste heat and this causes for instance when you have cities and you have a concentration, you have an urban heat island effect where some portions of the cities would have a much hotter temperatures and then there are ways in which we try to mitigate this.

Sound for instance if you look at a large compressor or you look at a power plant these would be a sound and that also has an impact on humans staying in the vicinity, electromagnetic radiations. So these are all these unintended impact and these are the impacts that we need to quantify.

Typically, the way this happens is that we start with using the energy system and we start using more and more energy to make our life’s more comfortable. Many of these problems then get into a, they accelerate and it gets to a level where the problem is seen as a problem that needs solution and then we try to modify the energy system, so this is the way in which it happens.

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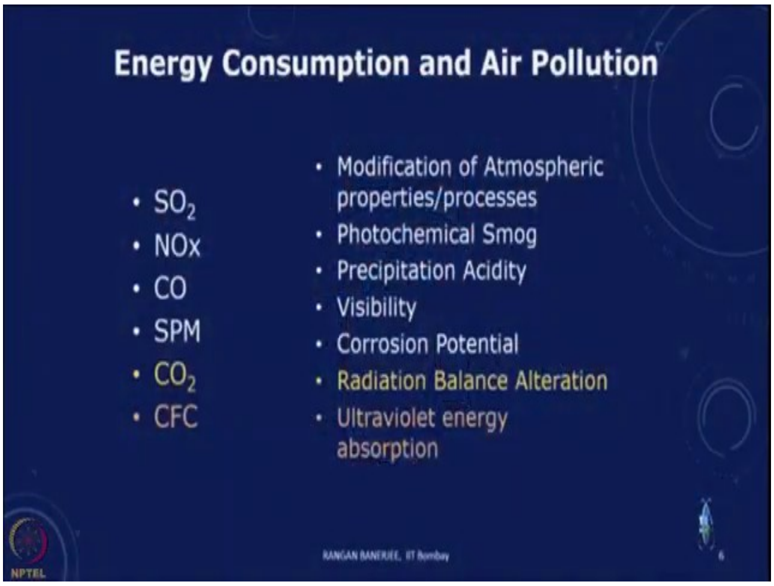

So for instance if we look at typically when we look at all the energy that is being consumed, if you are looking at fossil fuels which is today the present mode of energy consumption, whether it is coal, oil, natural gas the bulk of our energy use today is still from fossil fuels and if you look at the use of these fossil fuels, we have the pollutants or the we let out these gases into the atmosphere and for instance there are sulphur dioxide this happens through industrial processes.

This sulphur dioxide also comes in the power plants, nitric oxide again from power plants in industry, carbon monoxide from vehicles as well as from industrial processes, solid particulate matter and in this particulate matter it is also important to see what is the size range, so we talk of PM 2.5, PM 5 the smaller the particle size the larger the impact in terms of health and so we monitor some of these and this is one of the things which is contributing to air pollution and urban air quality and respiratory health impacts.

Carbon dioxide in chlorofluorocarbons and we will talk about these, these are global pollutants. So all of these have different kinds of impact, so one is its modifying the atmospheric properties or processes in the case of sulphur dioxide and SOx, it combines and then it can cause precipitation, acidity which is called acid rain and that can corrode variety of equipment, there can be smog photochemical smog, it can affect visibilities.

So for instance on days when you have a navy day and you are trying to see out into the ocean often there are restrictions in terms of vehicle movements so that the visibility can get improved and corrosion potential, radiation balance alteration, this is will talk about this little more in detail in CO_2 and ultraviolet energy absorption. So the impacts can be at the local regional or the global scale and these are just some examples of air pollutants which have an impact on the environment.

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So the adverse health impacts can be going from mainly based on local and we can go from local perturbations to global disruptions as the human energy use increase. In the early 80's Professor John Holdren of Harvard University proposed an index called "The human disruption index" and this was to look at what is the disruption at a global scale of a particular pollutant. This is defined very simply as the ratio of the human generated flow of a given pollutant to the natural or the baseline flow.

So the idea is that, in case the human generated flow of a pollutant is orders of magnitude less than the natural of baseline flow then nature has the ability to manage it and nature will have the system it will not show up as a problem, but the moment it becomes of the same order of magnitude as natural or baseline flow, then there are problems because in the human impact is something which nature is not able to regenerate or absorb.

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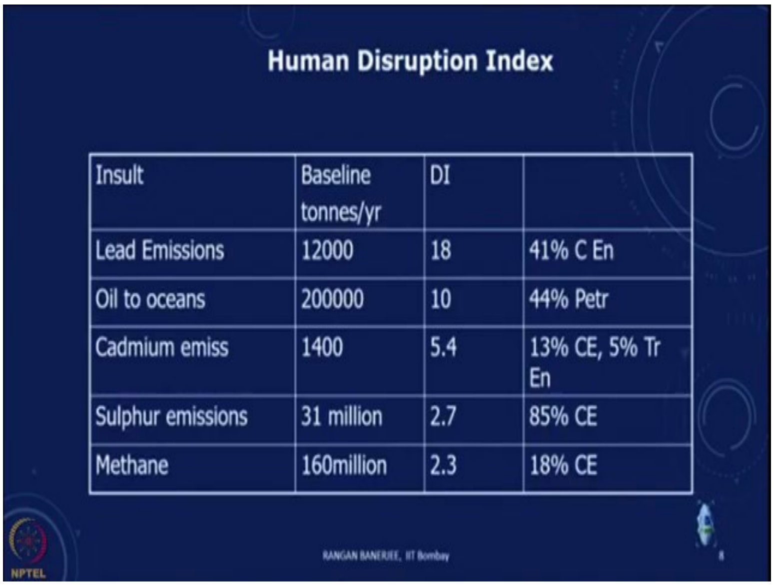

Human Disruption Index

Insult	Baseline tonnes/yr	DI	
Lead Emissions	12000	18	41% C En
Oil to oceans	200000	10	44% Petr
Cadmium emiss	1400	5.4	13% CE, 5% Tr En
Sulphur emissions	31 million	2.7	85% CE
Methane	160million	2.3	18% CE

And so if you look at these ratios, these were the human disruption index which were tabulated by John Holdren and you will see the disruption index lead emission, oil to oceans, cadmium emission, sulphur emissions all are greater than 1 and you will also see on this side that a large percentage of this is because of the energy sector and energy use.

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Human Disruption Index

Insult	Baseline tonnes/yr	DI	
Nitrogen fixation	140million	1.5	30% C En
Mercury emission	2500	1.4	20% C En
NOx	33 million	0.5	12% CE, 8% Tr En
Particulate emiss	3100 million	2.7	35% CE 10% Tr En
Carbon Dioxide	150million	2.3	75% CE

So energy and its impact the current way in which we are using energy has an adverse impact on the environment and this is why we need to change the way look at efficiency, look at ways to mitigate, nitrogen fixation again if you see Di mercury emissions, nitric oxides, particulate emission, carbon dioxide and you can see all of these are showing up as problems because the human disruption index is greater than 1.

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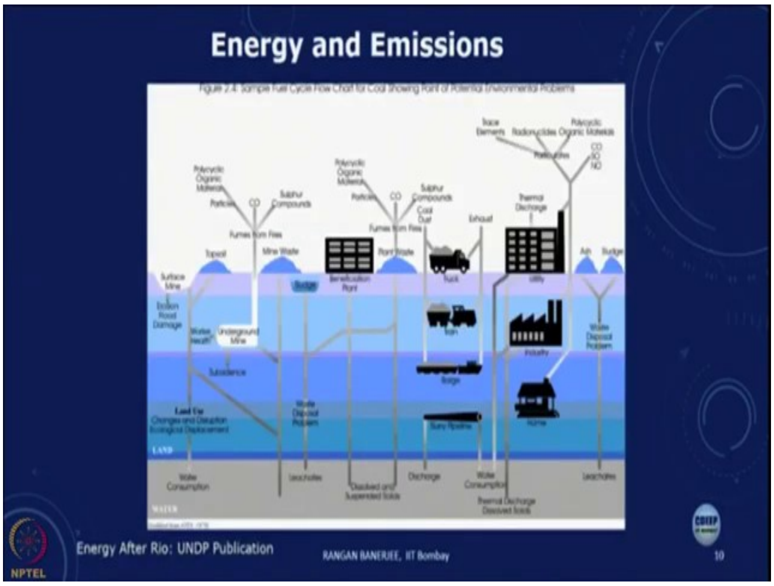

So we go forward in this in that if you look at the energy flow diagram that we discussed, at each element of that energy flow wherever there is a conversion they will be associated with it some emissions. So if you look at some electricity which is being used in the household, in order to get that electricity we start with the mind, if it is coming from coal, it is the coal that we are mining.

So at the mine itself there are some emissions which are going into the land and the water there are emissions which are there in the air pollution, then that mine goes to a cold bay there is a transport and that has some emissions, then it goes to a facility where you are beneficiating the coal again at that point there are some emissions, the transportation has associated with some emissions, then you have the power plant which has the bulk of the major emissions and then we take it to the transmission to the household.

So you can see that we have to calculate the emissions over the entire cycle of use, entire fuel cycle. So just like we looked at the total energy used, we can look at the total emission.

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So now the question which arises is – what is safe for humanity? What kind of regime is safe for humanity? And a group of researchers lead by Professor Rockstrom worked on this and there is a paper in nature which I would urge you to read which is published in 2009 it is called the safe operating space for humanity.

So what the researchers did is they looked at a large number of different parameters and they looked at what were the natural equilibrium for these parameters before we started industrial activity and then based on that they also identified through some models that how much, what is the limit for that criteria. So with that they identified a set of 9 different criteria which were critical for humanity to operate within a certain safe regime and in those 9 criteria they identified 3 where we had already exceeded the limits.

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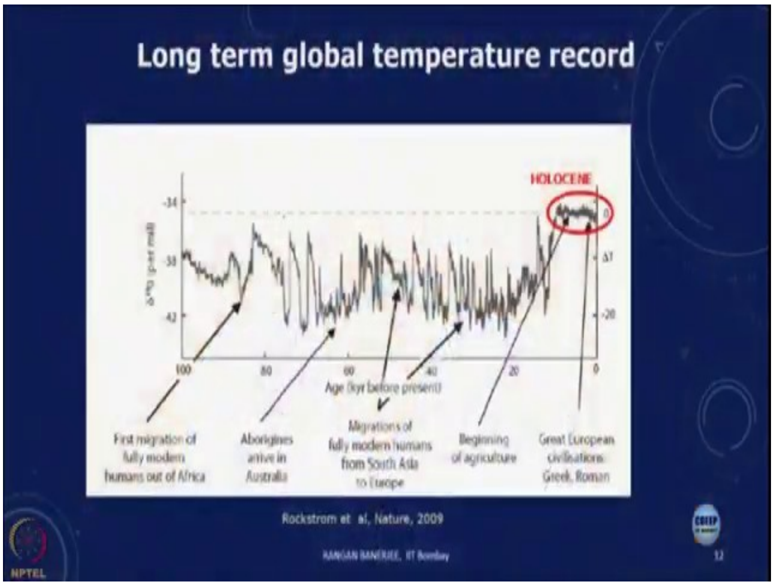

So, I will suggest that you look at this the papers starts off by saying that the history of human development has had a number of different eras and if you look at the history of the world on large time, large time scale means we are looking at thousand, hundred thousand years so that axis which is there on this graph is starting from here 0 to 20,000 40,000, 60,000, 80,000, 100,000 years before and in this year trying to see what is stable environment for the earth as far as we know the earth is the only planet where there is life and this is because we have the atmosphere which maintains the temperature constant at a particular value.

Seen here is an isotope of oxygen which is a proxy for the average temperature and if you look at this you will see that in nature we have had different kinds of eras and in all of these eras there has been a significant fluctuation in the temperature and the climate. It is only in the last 3, 4 thousand years where we had we have enjoyed the relatively stable environment and this is the period where actually life evolves and the civilizations evolve. This is called the Holocene and this is the period where we had significant growth and we have had significant development and improvement in human kind.

This is now threatened by human activity and the geologist have coined a term where this is called now we are now going into the Anthropocene. Anthropocene mean this is an era where it is human activity that is dictating the changes which are happening on the earth and on the earth's climate and this Anthropocene it has been shown that is not something that it is going to be sustainable into the future unless we make some changes in the way we develop and operate our energy systems.

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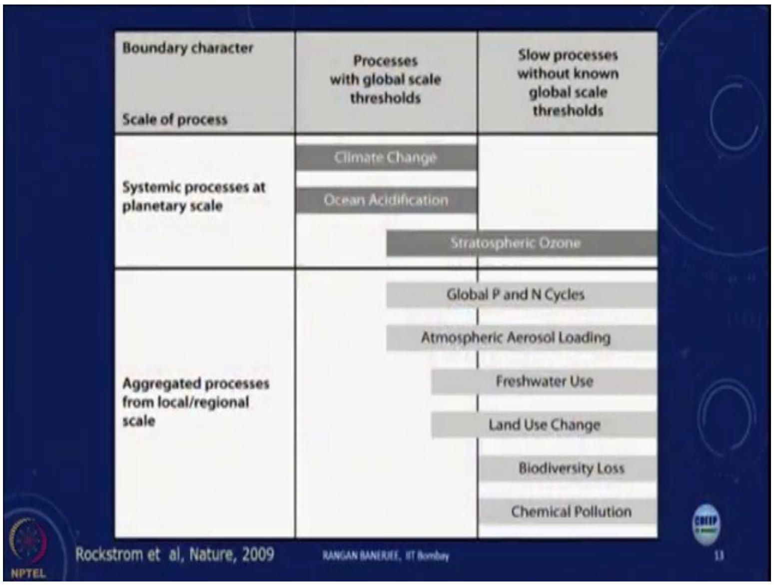

So in this paper they looked at a number of processes at a planetary scale and three of these processes are climate change, ocean acidification, the stratospheric ozone and there are also aggregated processes from the local and regional scale that means chemical pollution, biodiversity loss, land use change, freshwater use, atmospheric aerosol loading, global phosphorus and nitrogen cycles.

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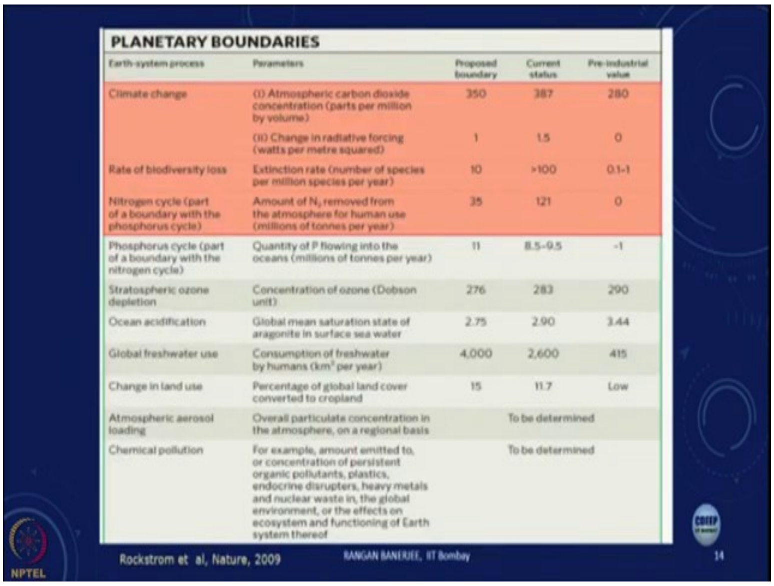

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1-1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5-9.5	-1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

And in all the cycles, you can look at the paper for details there is a proposed boundary, there is a current status and then there is a pre-industrial value. So for instance for climate change the pre-industrial value is 280 parts per million by volume of CO2 and the proposed 350 parts per million by volume and current status has gone up.

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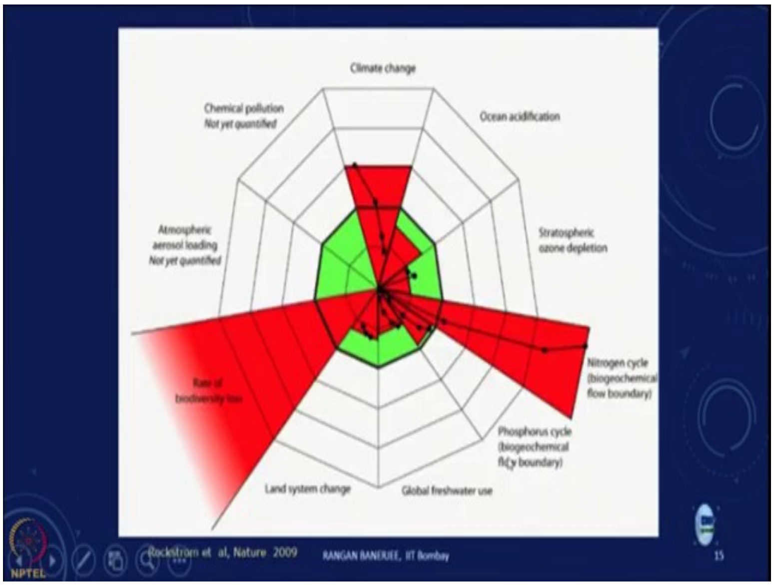

And in this if we look at it this shows you where we are exceeding the limits and you can see that we have exceeded the limit on the rate of biodiversity loss, the nitrogen cycle and the climate change cycle and we will discuss the climate change cycle in a little more detail.

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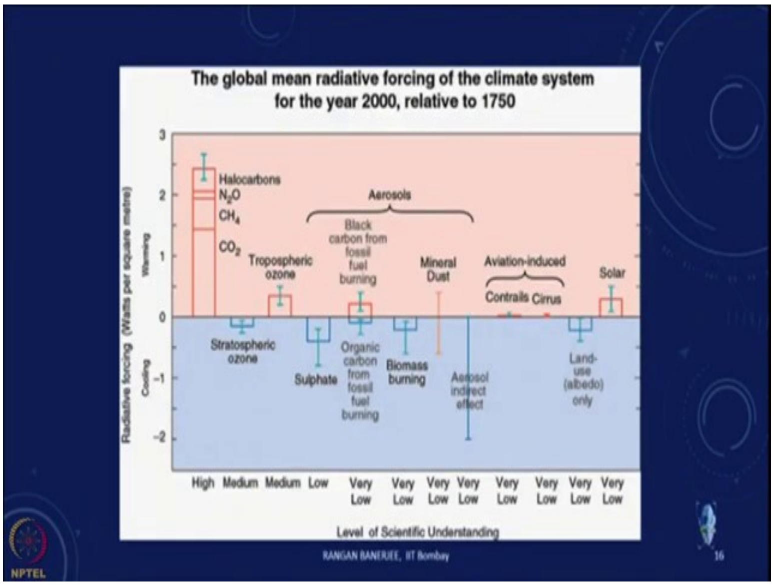

So in the case of CO_2 as I mentioned to you earlier as we know the only planet where there is life is the earth and the reason for that is a thin layer which is the atmosphere and in the atmosphere we have the main constituents are nitrogen and oxygen, carbon dioxide is actually at a relatively lower concentration but carbon dioxide has an important parameter which is radiative forcing.

So carbon dioxide actually permits the incoming radiation to come in but traps the outgoing with the result that it increases the overall temperature and the radiative balance created by this CO_2 concentration results in an average temperature of land and water of 15.5 degrees. If you look at a greenhouse, you will find that in a greenhouse the, because the greenhouse traps the outgoing radiation and does not permit it to go out, the temperatures are higher and this improves the growth of the plants.

So in a similar fashion if this CO_2 concentration is increased, we will have a temperature rise on the surface of the earth and this will affect the climate patterns. You can look the evidence, of course there is a natural variability as we saw when we looked at the thousands of year time horizon, you can look at the evidence that this there on the IPCC.

There is a inter government panel on climate change, www.ipcc.ch, you can look at that site there are reports on the science and technology option and on climate change and that will give you all the evidence. Now, if you look at this graph, you can see that CO_2 is a critical gas in terms of radiative forcing the others are CH_4, nitric oxide and then there are other effects of aerosol in moisture.

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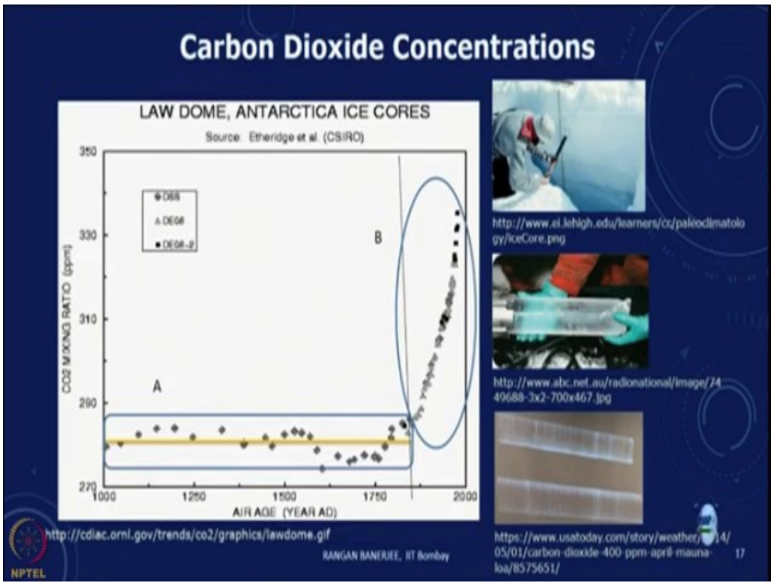

So we are basically going to focus on CO2 this graph shows you the time series evolution of carbon dioxide in the atmosphere. Now this is for a thousand year time horizon, the first question that should may come to your mind is that was this a problem over the last thousand years and how we have been tracking it. So the earliest initial mention of this problem of carbon dioxide and climate change problem happened in 1950's and only since the 70's there has been serious efforts in the IPCC.

So when we look at a thousand year time horizon, this record is something that is actually available to us in nature. So, if you see on this graphs on this side you have this image we have these expeditions to the arctic and the Antarctic where scientist actually go to the ice cores so typically when you look at in the ice which has been formed at depth that ice has been formed at a different periods of time and based on the isotope of carbon one can actually identify what is the age of the ice based on the depth.

Once you look at the age of the ice and you have the ice core, the air which is trap at a particular is the air which was there when that ice was formed, so we have the year and we have the air, we can look at the composition of the air and that will give us a frozen record of what was the CO2 at the time when that ice was formed. So you will find if you just Google you will find many different expeditions and all of them have a similar kind of plot.

So if you look at this plot on the X-axis it is the age of the air, so we start from, let us say 2000 and going back a thousand when thousand AD when the ice was formed. So, at different depth this will be at a higher depth and on the Y-axis is the carbon dioxide mixing ratio what is the percentage of carbon parts per million by volume of CO_2, so that gives you the CO_2 concentration in the air.

And if you look at the first from 1000 to about 1800, around 800 years you will see if we get, got this kind of data in a laboratory experiment you would say that this is more or less constant it is process under control, there is some variation but it is within plus minus 5 ppm. So you see this level the straight line that we draw here is at 280 parts per million by volume and this is the pre-industrial equilibrium of CO_2 and this is what the earth can take.

Then what happens? You will see that it is almost like the second curve which I have shown here, this curve is has a different trend completely, this curve represents the trend that we had seen in all these other cases where we have population growing exponentially anything that humans are consuming growing exponentially.

So this has an exponential growth rate, so clearly there is a diversion from the equilibrium and what happens here, so this is the point where we had the industrial revolution we had James Watt in the steam engine and we had the use of coal to use to develop industry, to create mines, to have power and this is where we started using more and more coal and more and more oil and natural gas.

And so we have two things we have the fact that CO_2 has a radiative forcing component and that all life on the earth depends on the equilibrium temperature, radiative component with an increase in the CO_2 concentration would imply and increases in the global temperature and this is what is called global warming and this is would result in climate change.

There are large scale models operating where you can try and figure out what will be the impact there are uncertainty of course in the model but what is reasonably certain is that in any case this is a disruptive effect which we need to mitigate, which we need to we cannot continue with this kind of exponential growth of the CO_2.

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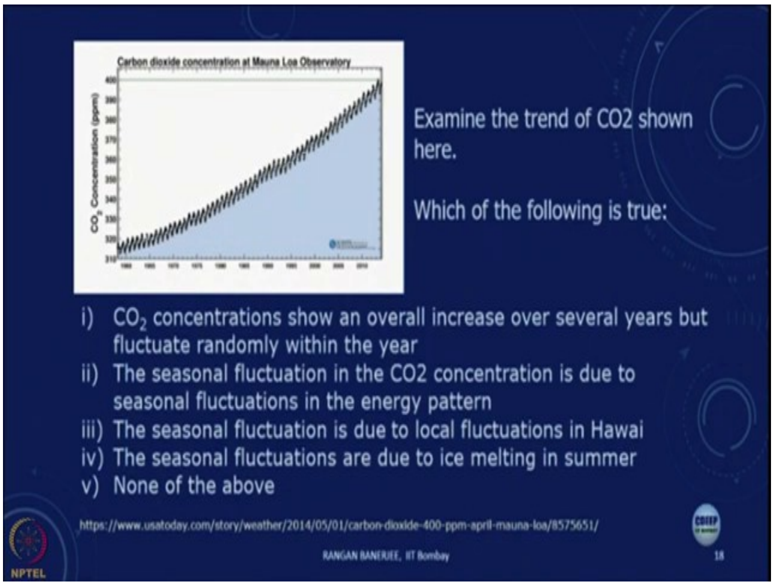

Now, to look at this in more detail there is been, from the 70's there has been a trend of actual measurements an observatory Mauna Loa in Hawaii in the U.S and you can see this on this graph and you can see and you will see when you look at this graph you can see very clearly that it goes to ups and downs. Now when you observe this carefully, you will see that one crest that is the peak and one turf happens every year and this is how but overall there is a sort of exponential growth but it goes through a turf and then a crest and so this is this peak.

Now the question is why do we have this seasonal kind of variation we have a number of reason which you can think about is it because the CO2 concentrations show an increase over several years but fluctuate randomly within the year or the seasonal fluctuation in the CO2 constructions is due to seasonal fluctuation in the energy pattern. Seasonal fluctuation is due to local fluctuations in Hawaii, seasonal fluctuations are due to ice melting in summer or none of the above.

So if you think about it you will find that well this fluctuation is not random, there is clearly an increase in trend and clearly there is an annual pattern, so it is not the first one which is true. The second one which you think of seasonal fluctuation in the CO2 concentration is due to seasonal fluctuations in the energy pattern.

If you want to check whether this is true look at annual energy used over the globe and see whether that changes over the seasons and you will see that there is a trend of increase of the years but there is no clear cut seasonal pattern, so this also is not true, this is a CO2 is a global pollutant this is not due to local fluctuations in Hawaii, if you did this in some other place also you would get the same effect.

And ice melting is summer does not create enough of an impact to be able to show this, so the answer actually is none of the above. The reason for this is because of the trend in the growth of vegetation and there are deciduous trees which will grow and grow in a particular season so that the CO2 sync increases in a particular season and decreases when there is a fall and because of that growth and CO2 absorption capacity vary we see this kind of trend.

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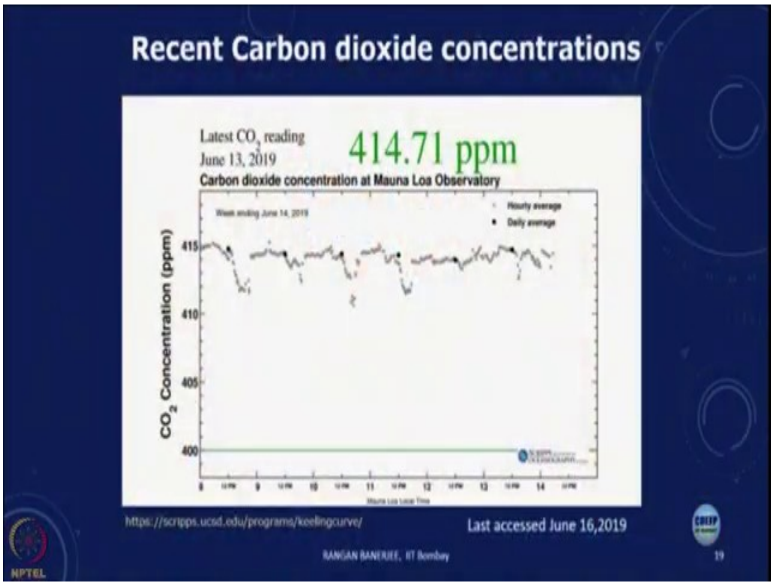

So, let us move on, there is a website you can look at that and I looked at this number in recently in the month of June 2019, but you go to CO2 now and you can see the CO2 concentration, so we said to 280 parts per million by volume was the pre-industrial we are already on this particular day the average is about 415 parts per million much above the norm that we have set in terms of 350 parts per million. And so this is the problem that we need to mitigate. We have a situation where we have an energy system which is having these kind of CO2 emissions.

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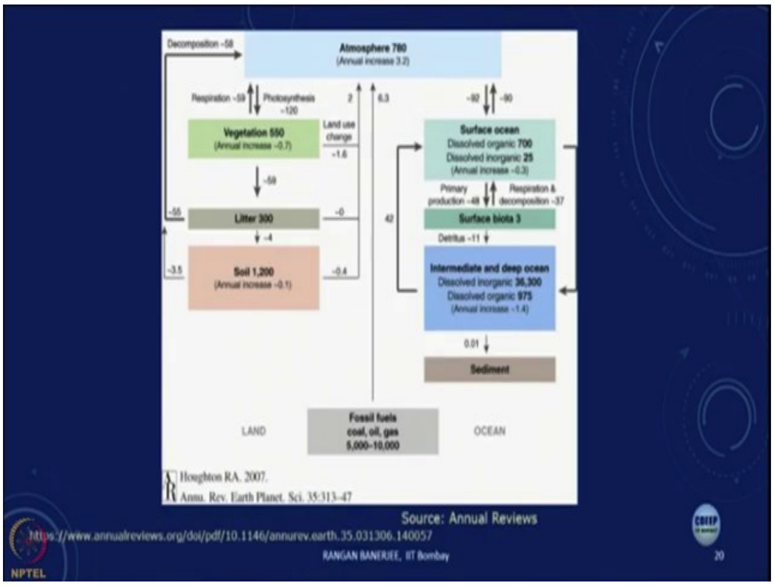

Now, when we look at we talked about the 280 parts per million by volume as a natural process and something which is coming through an equilibrium. So we can look at the carbon balance. There is this paper in the annual review of annual research of earth planetary earth and in these annual reviews can see that there is the carbon balance, there is already carbon in the fossil fuels, there is carbon in the ocean and there are flows.

And in the flows that we are talking of there is an equilibrium in the atmosphere and then there is a flow which is coming in true, because of decomposition there is respiration and then there is human generated activity. So, in this carbon dioxide can carbon balance, it is the human activity which is causing the imbalance which is then related to the change in the concentration and this is something that we need to try to mitigate.

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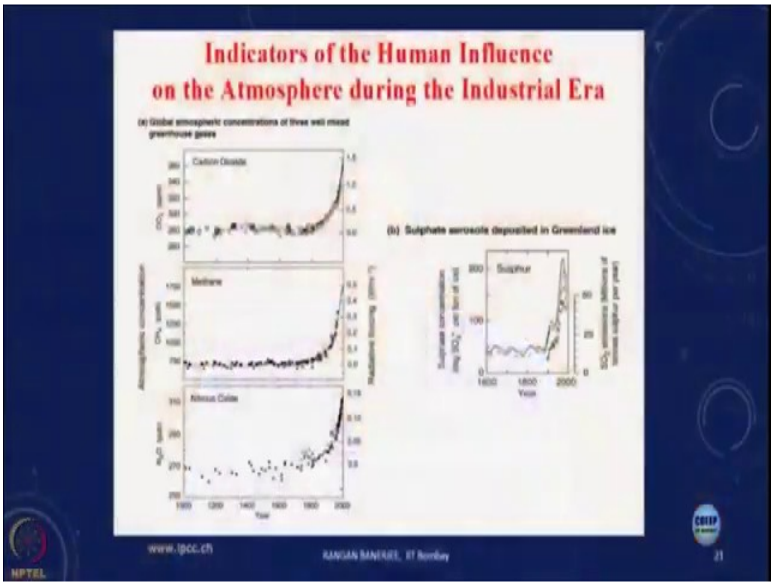

So the indicators of the human influence of the atmosphere again this is from the IPCC report you can see we talked about CO2 but we can see that similar kinds of things are visible when you look at methane, nitrous oxides, look at sulphate aerosols, so these are all human generated impacts and these are things where as we design energy systems we have the option of redesigning the energy system or we have the option of mitigating, trapping it, capturing it. So these are some of the things that we.

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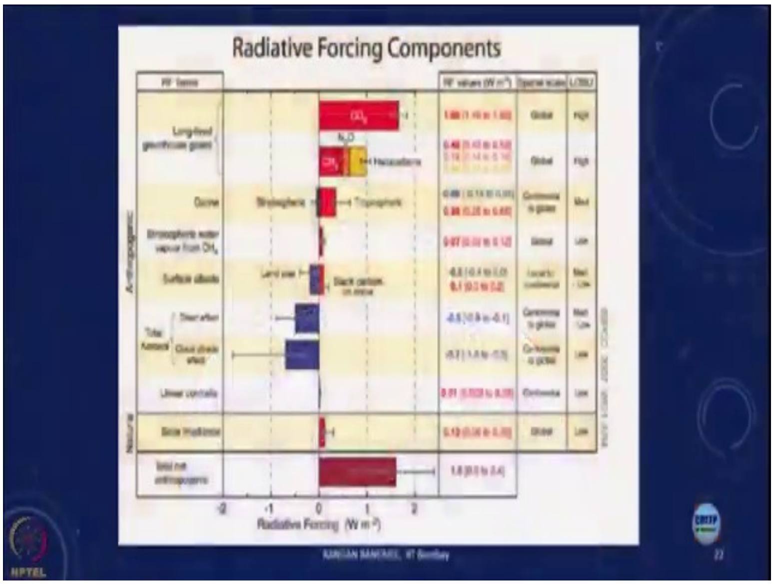

And we talked about the radiative this is another from the IPCC another figure which shows you the kind of radiative forcing components.

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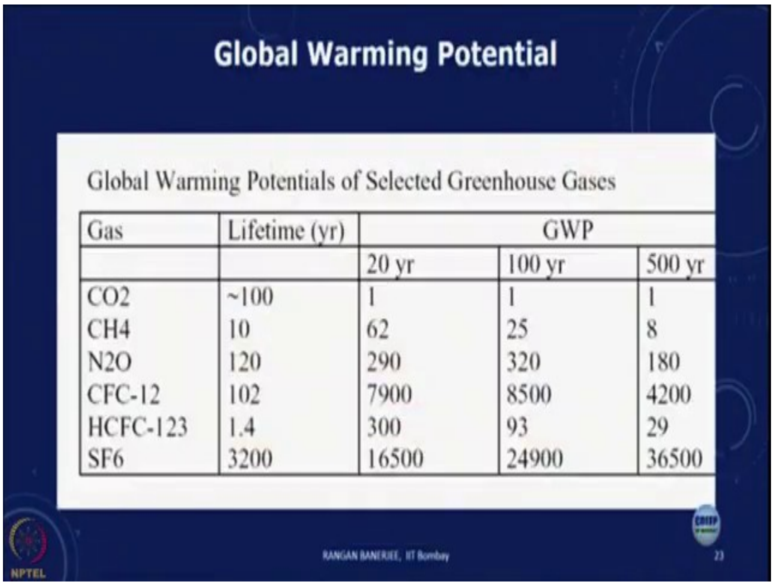

Global Warming Potentials of Selected Greenhouse Gases

Gas	Lifetime (yr)	GWP		
		20 yr	100 yr	500 yr
CO2	~100	1	1	1
CH4	10	62	25	8
N2O	120	290	320	180
CFC-12	102	7900	8500	4200
HCFC-123	1.4	300	93	29
SF6	3200	16500	24900	36500

Different pollutants that we talked of have different lifetime in the atmosphere, so it is not just about today's pollution if you are looking at CO2, it lasts in the atmosphere for about a 100 years, so it is a cumulative effect that we need to calculate and that is this is captured in the form of a global warming potential. CO2 is considered to be one and the equivalent value for all the other gases is converted and these are the numbers.

So what happens is that some of these like SF6 and the chlorofluorocarbons have significant global warming potential, so even though they may be at much smaller or trace levels they may have a greater impact. So everything which is calculated in the case of global warming is usually done with the CO2 as a baseline. So when we talk about CO2 we also talk about CO2 equivalent and we take all the other gases and convert them into CO2 equivalent.

So whenever we talk in the course, we will be mainly talking about CO2 but please remember this means CO2 plus the equivalent of CO2 from other gases which are also creating global warming.

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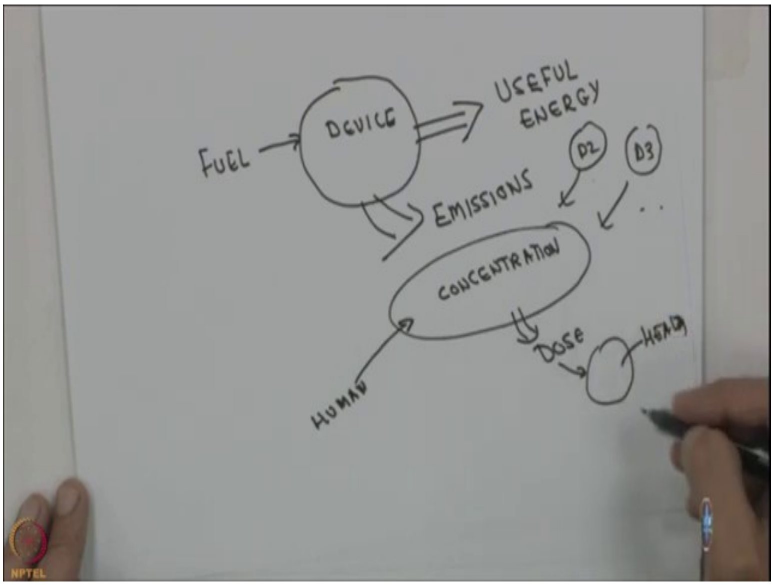

So now let us look at any pollutant we would like to see what happens when you we have a fuel and that fuel is being used in a device, that device gives your useful energy and then we have some emissions. So if we look at a vehicle, these emissions will go in the place where the vehicle is moving. If we look at a power plant these emissions will be, there in the location of that power plant. These emission now this is one device in that area there will be other devices, D2, D3, Dn, there are different things.

So, all of these emissions will come together and then you would basically get a concentration. So, if you look at for instance in the city of Delhi, you look at a number of vehicles at a traffic signal, each one is emitting some particulate matter. We will take all particulate matter which is there. Now depending on the air velocity some of it will defuse and move out, some of it will remain there and you will have a concentration.

Now in that place, if there is a human and that human is you are in that place for a certain amount of time then you will get a dose of how much of that gets absorbed that will go to your lungs and then that will have a health impact. So you see the change, it is about what kind of fuel we are using, what is the composition? As we use it for useful energy there are some adverse impact that emissions of course if it is in an area where it gets diffused out then it will not result in too much of a concentration.

We can have a norm in terms of emissions cannot be more than this, we can also have a norm in terms of trying to see what is the concentration for instance in the case of Agra because of the Taj Mahal and the kind of discoloration which was happening to the Taj Mahal, several industries were asked to close down and not use fossil fuels in the location, so that you could reduce the emissions and do that.

So we can look at concentration and concentration norms and if you see you will find that these norms are monitored by environmental stations at different locations, so that will be a function of location. Then if you have people who are there depending on the amount of time you will have an intake and based on that intake then you can look at the impact which is there on respiration, it will have a health impact.

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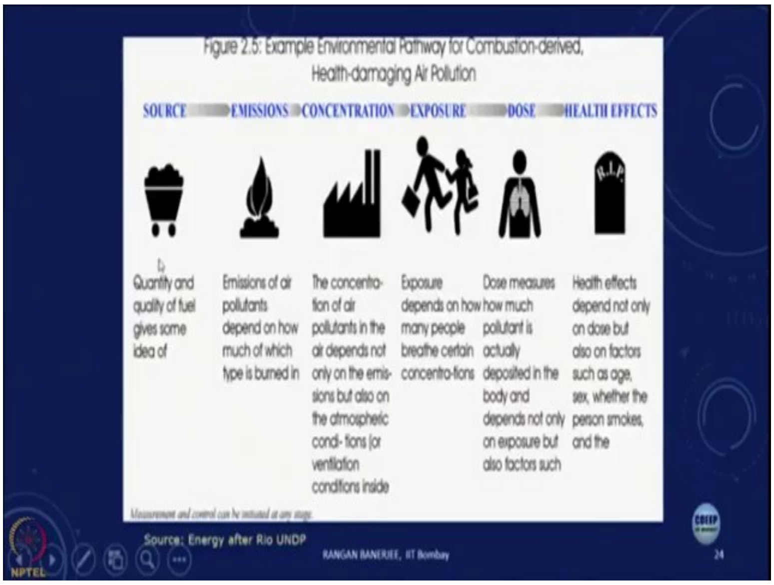

So, if you look at this on this slide you will see that this is illustrated in this his is in from the energy after Rio, so you have the fuel, you have the emission then you have concentration that concentration results in exposure and that exposure is dependent on how many people and how much time that results in a particular dose and then that dose results in an impact and that impact could be as there could be fatal or could be resulting in a other health impact.

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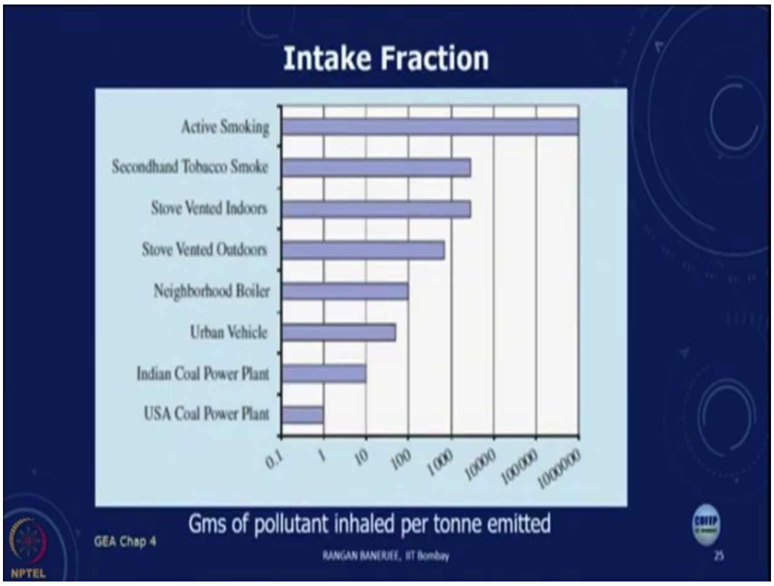

Now depending on the percentage of the emissions which are taken in. So for instance active smoking is something where all the emissions are going in, so it is like one ton, per ton of pollutant almost all 100 percent is going in. If you look at second hand smoke, if you are near a smoker then you will take much less, in stove which is vented indoor you have this is indoor air pollution in a boiler, in a vehicle in a coal based power plant. So we can look at this and then we can see the impact and use it in our models to quantify safe levels, to quantify health impact.

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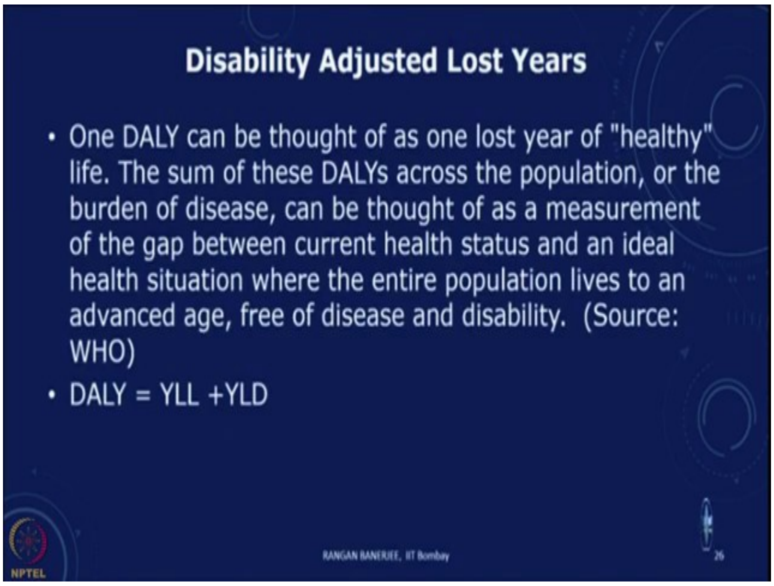

The World Health Organisation has created a parameter called the disability adjusted lost years. So this is in order to, suppose we look at different kinds of impacts of different pollutants and what is the effect and why do we want to do that? Because we want to quantify and see where we would like to put interventions, where we would like to put money, what kind of norms we need to have.

So what is this is defined as disability adjusted lost year is thought of as one lost year of healthy life and then some of these DALYs across the population or the burden of disease is thought of as a measurement of the gap between a current health status and an ideal health situation, ideal health situation where the entire population lives to an advanced stage free of disease and disability.

So when we want to make this calculation, this is calculated as a sum of two factors, the year of lost life. So for instance if due to pollution or if due to let us say tobacco, there is some person dies of cancer at a particular age, we have an expected age which the person would have lived to and the number of years that is lost is then computed into the number of deaths and this is summed up.

And in a case where it is not fatal but because of that people have disability or they are unhealthy and they lose a number of days of healthy life and number of years so this is how it is added. This is then added by different categories and summed up and then this is one way in which you can compare for instance, indoor air pollution from stubs versus vehicle, impact of outdoor air pollution in vehicles versus diseases like tuberculosis or malaria and all of this can be used to see the impact and to then see what kind of norms we should do and then look at it.

So, otherwise in many cases for instance if you look at smoke coming from chulas this the effect is seen over a long period of time, so people may not immediately appreciate the reason or the motivation to go for smokeless chulhas. So, this is a whole impact of energy and health and this is something which one needs to compute when you look at different kinds of policies and different kind of interventions