Engineering Thermodynamics
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Lecture - 01
Thermodynamic Concepts: Applications of thermodynamics

Good morning, I am giving 4 modules on Thermodynamics and the way I have organized is as follows here.

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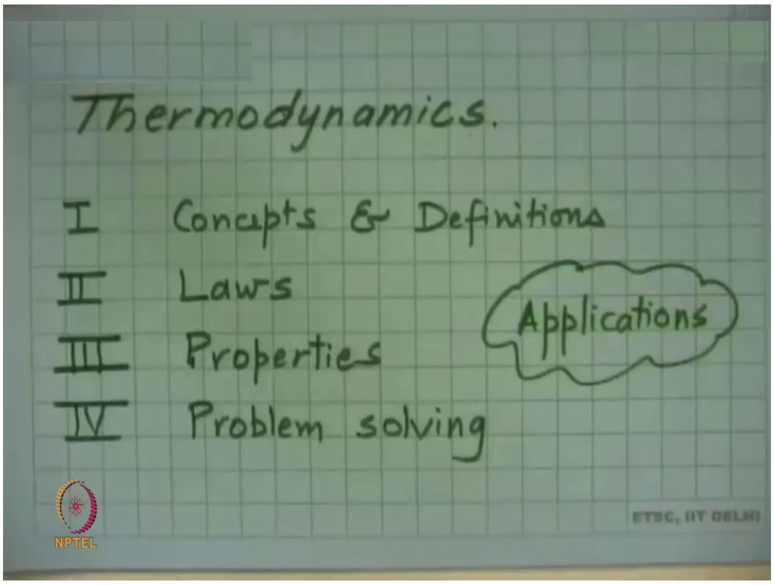

Module 1, which is today, tomorrow, and day after; we will look at some application and start looking at concepts and definitions. So, it is today and day after tomorrow day after tomorrow we will complete this. After that, we will come back after few days and have a second set of 6 hours, there we will look at the laws of thermodynamics and various forms and various appliance.

The third module, we will look at properties of a pure substance and, how we can get data from the laws and the concepts that we got. And, the final session the 6 hours will be on systematic problem solving ok. So, we will start today with concepts and definitions, that the first thing we will do is try to figure out, and look at some applications as to why we should be studying subject like this, or for that matter why is thermo dynamics important?

So, we will look at one of the biggest problem that we society faces today, and that is climate change.

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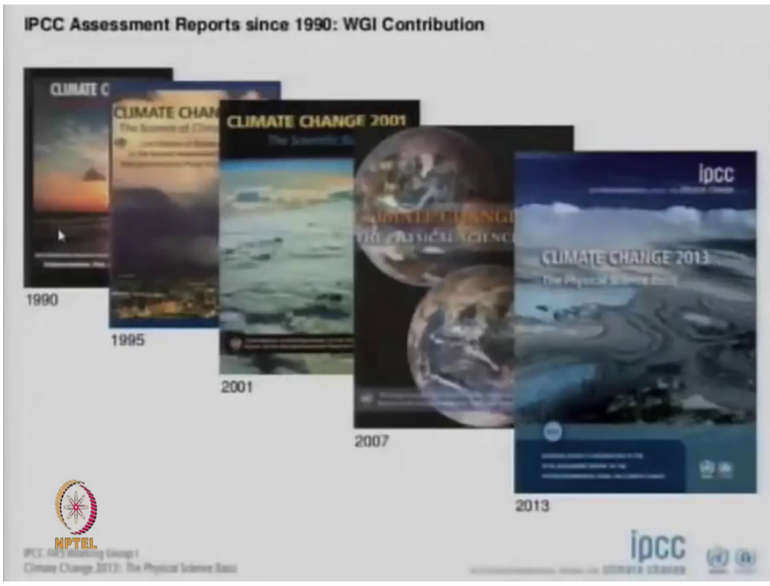

There are few days back all the heads of states of all the countries met in Paris, to discuss and come up with the plan of what we need to do to combat climate change. And, the organisation that has been spearheading this activity is the IPCC; Internet Intergovernmental Panel on Climate Change. And, these are series of reports that they have produced starting from 1990. And, coming now and saying that in the 5th report, what are the issues and what is the importance of climate change.

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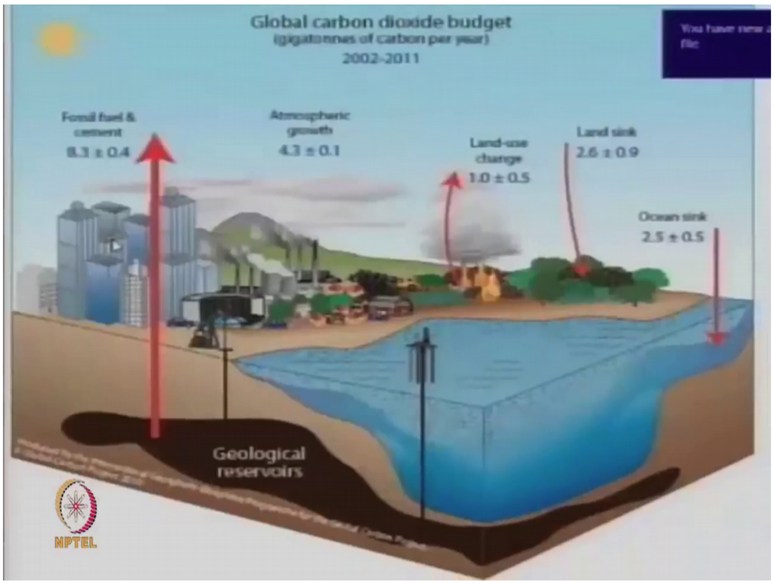

So, what is climate? This is basically accumulation of carbon dioxide in the atmosphere, which traps heat from the radiated that out, and so, the average temperature of the atmosphere keeps increasing. Nature itself does lot of things with both carbon dioxide carbon dioxide methane and CFCS. And, this picture shows in a very crisp way, what are the big items in the carbons there is atmospheric growth, land use change; that means, forests become get converted into agricultural land by burning, land sinks, lands absorb, carbon dioxide, and oceans sinks ocean absorbs carbon dioxide.

But, you see this first column on the left most item on the left side, which is fossil fuel and cement and this is the biggest item that results in carbonate carbon dioxide addition to the atmosphere. And, when we say permanent it means that we are excluding natural phenomena, like say volcano going up. So, how did this thing become so, important whose effects we are now actually seeing all around us.

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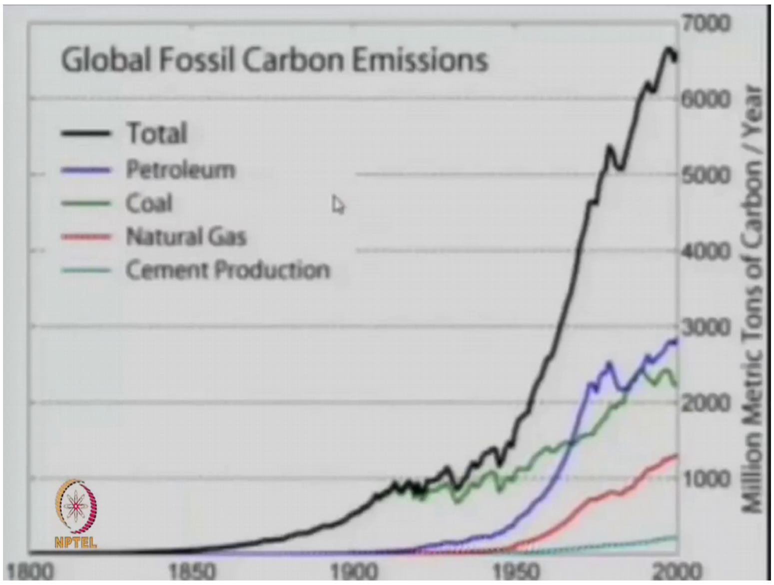

This graphs shows us a historical trending from 1800 near down to 2000, this graphs can now be calculated another 15 years. And, it tells you: what is the total amount of global fossil carbon emissions in million metric tons of carbon per year. And, you can see the graph for until 1850 and there is historical data that you will before this you have to was not going up at any rate like that. Then, it slowly started going up and something around 1950 onwards there has been a spike and it is going up quite rapidly. So and where did this permanent addition of carbon comes from, you can see here this line there is coal until 1900 predominantly coal, that was responsible for permanent carbon addition to the atmosphere.

So, early 1900s on wards petroleum started coming in and now petroleum and coal are a about of comparable magnitude. And, then must later 19 above 50 years back Natural Gas started coming in and cement is still a very small amount. So, it is not a really big issue for us, but here is consumption of natural gas consumption of petroleum which is oils and consumption of coal. The question is who and why and how do we consume these things?

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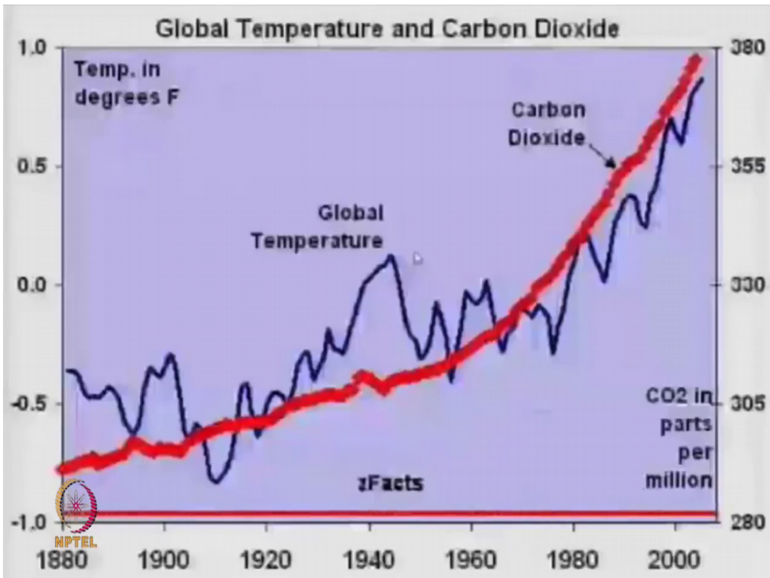

And are we also in this before you get to that, here is some evidence from how carbon dioxide concentration in the atmosphere has changed and this is this line here 1880 onwards, it was about 200 and 90 parts per million; in 2000 it had reached close to 300 and 75 parts per million. And, we know now that at last year fuel to concentration in the atmosphere heat 400 parts per million.

This looks like a very very small number. So, why should be worry about such a small number, but it is impact on climate change is substantial and that is what is the whole worry of all about. And there is now increasingly agreement in the scientific community that climate change is for real. Even around us that are happening every day can in some way be attributed or a aggravated by climate change.

And, this is the reason behind this is the increase in the average atmospheric temperature and, this is what this graph shows here. It goes up and down and this is the average temperature of the atmosphere, and it is the change in average temperature of the atmosphere in degrees Fahrenheit.

So, to get degree Celsius T to them just approximately half these, precise the it shows that it graph is very zig zag type of a thing. And, one has to go into lot of statistical and computational techniques to be say, how do I calculate the average temperature of the atmosphere, when at any given time somewhere in the atmosphere here it is minus 60 degree Celsius and somewhere else it could be plus 50 degree Celsius it is changing all the time.

There have been methods lot of research has been done on this and now people agree that ok. This is a way we should calculate the average temperature of the earth and yes it does go up and down, but then what one does is you get something called trending. And, that tells you that pre 1940 or may be even 1950 temperatures were little bit less than the average there. And, in the last 50 years there has been a substantial increase. Increase means it is a just about one degree Fahrenheit that a half an degree Celsius in rise in the average temperature of the atmosphere.

This may again look like very very small number and one can always argue that when there are such wide variations in the temperature across the planet, how can even talk about an average temperature like that? But, all those discussions and debates happened about 25 years back and scientific community is now pretty much convinced that, this is for real and the ifs and buds are approximately simple.

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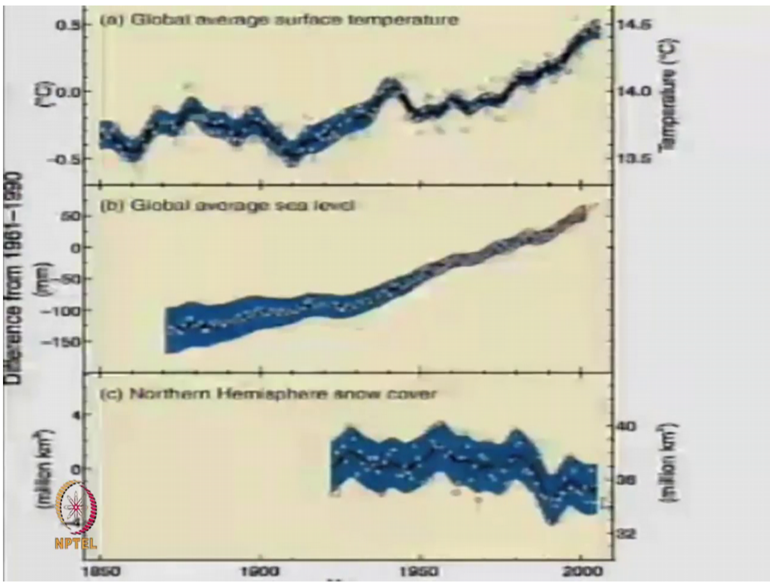

So, we have been adding carbon dioxide to the atmosphere and what are the impacts of that? Here, we have 3 graphs; the first one shows the global average surface temperature and this comes about little more than 2000. And, it shows that with base as 1960 the temperatures have which were half a degree Celsius below that prior to that are now about half degree Celsius more than that. And, implications of that global average mean sea level one of the first things that people are worried about is that because of heating, it is like a mercury thermo meter, the water will get heated up, it will expand and the mean sea level will rise and that will what this graph shows.

It shows that between about 1870 and now mean sea levels have increased by about 300 millimetres, 400 millimetres, somewhere in that range. That may be a small number, but this trend is what is really worrying, you can see that this is very clear trend that the mean sea level is going up and in the last 15 years again this has gone up further.

This has got tremendous implications for people all across the world, because 70 percent of the world's population lives along coast lines. And, they depend on the sea for their survival and many low lying areas are already facing the prospects of submergence. Maldives in the first nation which may actually go under water or neighbouring country Bangladesh, very large section of the land is already gone under water. And, if sea level continues to rise this way I will increase an about a metre in see mean sea level, about third of Bangladesh will go under water.

This will be a huge human tragedy. The other thing that people are worried about is the snow cover. This is the region which is most sensitive to change in the temperature of the atmosphere. So, the arctic pole the Antarctic pole and there is lot of data on that, but what I have presented in here is not the hemisphere snow cover, which is the large chunk of it beyond the poles is the Himalayas.

The Himalayan glaciers are probably the biggest chunk of ice, inventory of ice beyond the north and the arctic and the Antarctic. And, there is enough evidence to show that the area of snow cover has been decreasing. One only has to travel to Himachal or Uttarakhand or Kashmir or anywhere else in the Himalayas to recognize that, what was snow covered until about say 20 years ago the snow has disappeared now. The glaciers have stunt by several kilometres. And, this is very alarming because all the Himalayan Rivers on which we depend on so heavily.

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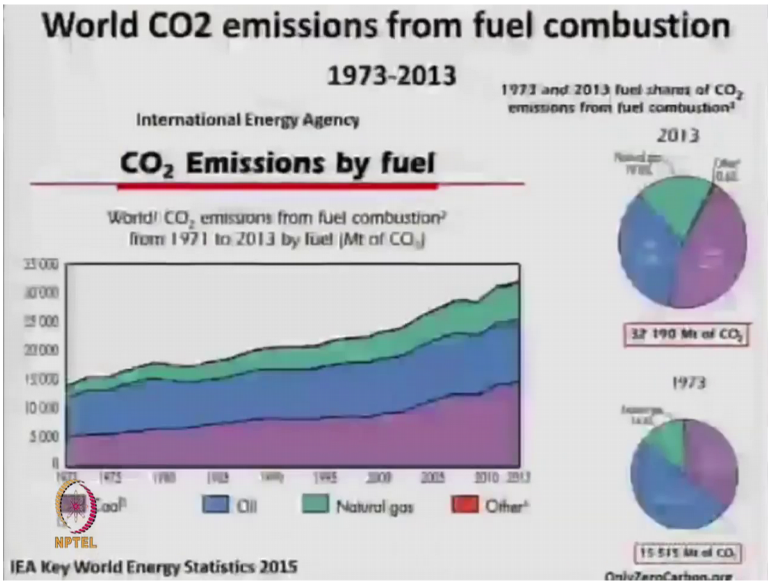

So, let us see where this the permanent C O 2 to the atmosphere come from. So, you have see here with a graph from 1971 to 2013 world C O 2 emissions from fuel combustion. This is coal, this is oil, and natural gas. Coal is clearly the biggest chunk of there then comes oil and then there is gas. And, so, we ask now the question; who is burning this coal, why, how and how do we benefit from it?

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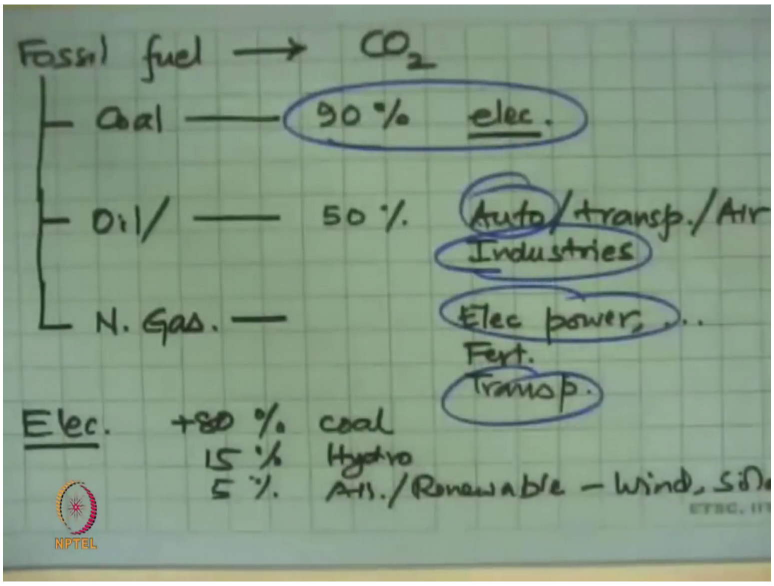

So, there is burning of a fossil fuel, this has resulted in CO 2 in to the atmosphere. And, now you see what is it that this comes from coal, then there is oil, or petroleum, and gas natural gas. Coal when over 90 percent of this is used for generating electricity. And, that is why even in our country about 80 percent of our electricity comes over burning coal; similarly, the story in China same with Russia and the US. So, these are that is the extent to which very large number of people actually depend on coal the burning of coal to get electricity.

And, this is very important because we think that electricity is very basic necessity of life and it in many ways defines how will we live? Oil for large fraction of that oil about 50 percent plus and that very strong country to country is used in transport car, good transport, somewhat less on rail transport, and increasingly air transport.

Natural gas similarly, it used for power generation, but some other direct heating purposes also. Oils are also used in very large quantities in industries the any industry, that needs steel or needs to heat want to use oil. So, they have a 4G manufacturer, they need to heat bullet us of steel. So, you have a furnace in which you have (Refer Time: 13:05) oil put the steel in it becomes hot take it out fold it and make the component.

Natural gas also goes for fertilizers, but that was one of the big thing and in our country still a much smaller amount for transport. So, this is the overall picture that we get almost 80 percent of our electricity 90 percent of our electricity from coal. We will look at the reverse metrics, where does the electricity come from where 81 plus percentage it will by burning coal, and then the rest comes about 15 percent from hydro hydroelectric power plants, and then 5 percent and increasing slightly from all other sources like wind, solar and so on.

So, what we are seeing is that C O 2 what generated because we wanted electricity and transport and many other good things of life. And, in the process we are all adding a small amount of carbon dioxide to the atmosphere ok.

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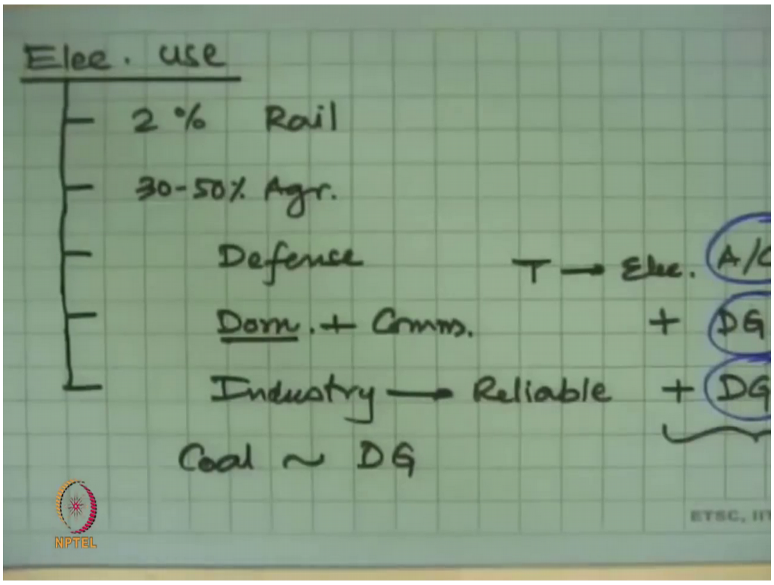

So, now we look at the second part where do we were we use electricity. It varies again from country to country we take numbers for our country get approximate in for what it like. A couple of percent of this is used for rail transport, you have seen electric locomotives remember that loco looks quite nice it is not throwing out any smoke, but it got it is electricity and that came most of it from coal burning. Then, then agriculture depending on the season anything like from 30 to 50 percent of the electricity depending on which state and which region they are looking at could be going well, because agriculture in all season it could be less the monsoon will go this number comes down.

Then, there is defence we do not have exact numbers, but very many things are that are there especially in the storage of emanation, it critically depends on the availability of electricity. Then, we have domestic consumption and last is industry. Industry critically depends on reliable electricity supply and to remain in business, if the power supply keeps going off and on it is quite disaster in the soil industry. And, quite often they and many others start installing or in sometimes completely unique the diesel generator set.

It is a diesel engine coupled to generator and you buy diesel oil burn it and use it. If, you have seen at homes or even in your institutions if the electricity goes off, you have back up diesel generator on the campus and (Refer Time: 16:35). So, what has happened is because our electricity system was not very reliable many people started putting a diesel sets, and both these are small in size they are very large in number. And, today the total capacity also generating electricity from diesel sets is comparable to that that we have from burning coal burning thermal prostrations.

So, that is a huge amount of investment and also continuing diesel consumption that happens just to keep things going. Within say domestic and say even you can put here commercial sector the situation varies from place to place, but you can take an urban area say like Delhi, then the ambient temperature drives the electric power consumption. If, there is a shower index goes down, the power consumption goes down, it becomes hot in unit or the consumption goes up, and the reason this happens is air condition. And, this is the single biggest reason for increase in the shear or domestic electric power consumption in the local sector.

So, this a quick scenario of what we have around us? And, that is let us see where the thermo dynamics coming. First, let us look from assume side the analysis of diesel generator sets, we un understand from this course, air conditioners, refrigerators, this is the application that we were look at in this course. And, then comes to generation this is entirely the domain of thermo dynamics, automatic transport sector also in directly industry is also natural gas electric power and transportation which is also consumption.

So, you see the thermo dynamics is in some way connected in a very big way to with consumption of fossil fuels and in the end consumption of electricity. So, now, let us see the real world and do we see something on that.

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So, this is we are in Google maps and this is our campus here, I am this is our main building and it is ending somewhere in this. And, let us see what is around us here? Great this is the Yamuna River and we see this patch here, black star, let us see what this is? So, what is coming in to view is this big thing which is a black thing which is a storage of coal, and this is the Badrapur thermal power station of NTPC ok. So, here we see one chimney there and this whole thing you see here is a smoke coming out of this thermal power plant.

And this of course, includes carbon dioxide, but then there are some ash particles in it and some amounts of nitrous oxide, sulphur oxides, and other that. And, what you see here this rectangular thing here is a boiler, into which we continuously feed coal burn it. We also shunt the thing pump oil through tubes, which get heated by this fire generated by the coal and we produce high pressure, high temperature steam, which is then let through pipes into this building inside which there is a steam turbine coupled to an electric generator. And in that is how we get electricity in further out here into the switch yard and then in to the transmission system and all the way to be users.

So, what you see here is one boiler, we do not see the turbine here we will in a minutes see some pictures on that. These things that you see are the exhaust gases coming up from the boiler, it goes into these 2 things and then also in to these. So, this is a cleaning system called electrostatic precipitator, which removes a lot of the ash from this gas. And then finally, it is led in to the bottom of to the chimney and it goes off.

So, this is one power station and that gives electricity to Delhi, it is a felly old one about 40 years old and, in the process of being shifted out now. And, this is being replaced by new power stations and one of the relatively new power stations is at Dadri, it is about eighty kilometres from Delhi. And, this is this is the entire area only the power station is placed. And, so let us see what are what do we see here?

So, we look understand what this whole thing is all about bottom line is that, it is supplying electricity or to the northern grid about 3000 megawatts. And, like other power station we saw few minutes back, here we have these square things of them these are 4 independent boilers, these are the electric electro static precipitators, and the gas from all of them is let into this big thing of which you see 4 openings, there are 4 chimneys rope the boilers out here very likes smoke you can see coming out from this.

So, some of these are operating, it is in this building that the generators and the turbines are flip kept from there is electricity comes out. So, these are 4 units each generating 200 and 10 megawatts not generating, but capable of generating 200 and 10,000 kilowatts. Next to that, again 2 structures here with one chimney you can see 2 opening at the top. These are relatively new boilers that is about 4-5 years back each one capable of generating almost 500 megawatts they burn coal and. So, that is one old power plant this is the new one and again it have got it is own substation and something else.

On the same space we see here something else and this is a combined cycle power plant. This burns this can burn gas or nuptial and what you have here is inside this building over here is the decant turbine, where you will burn gas and generate electricity, and then the hot gases come into this device here, where this energy is given to water which produces steam, and that is again let back into this building, and there is a steam turbine which generates electricity and then the gas is thrown out.

So, a little more complicated system, but environmentally more friendly you are not burning coal. And, also it is efficiency the thermo dynamic efficiency is greater than that of a coal burning power plant. So, that is a say that there are you can see there are 2 things there. So, there are 2 gas turbines and in between there in one steam turbine and the same arrangement is repeated in this part of the power station.

A little further down is this facility here. These 2 are very tall buildings and what they do is through this transmission system they receive electricity generated about 800 kilometres away 300 super thermal power station. It is converted in to DC power and straight away from there it comes here. And, through solid state systems this 1500 megawatts of electricity this converted back into AC power into this switch yard again added to the northern gate.

So, now we have such systems where if you want to the transmit electricity over long distances, we use this technique called HVDC transmission, high voltage D C transmission, and one of the biggest planks recent now that is operating is from culture in Orissa the electricity is send directly to Bangalore. So, these are some this tells us what the actual machine, what will I see?

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First, we look at the picture of a coal burning power plant. So, these all things are the boilers and this is NTPC coal bar and you can see how many chimneys and how many generators are there? In this whole area there are many more generating stations and this is the power so, called the power capital of India. Because, there is a huge amount of coal mining taking place and all that coal is also be burnt smoke and carbon dioxide.

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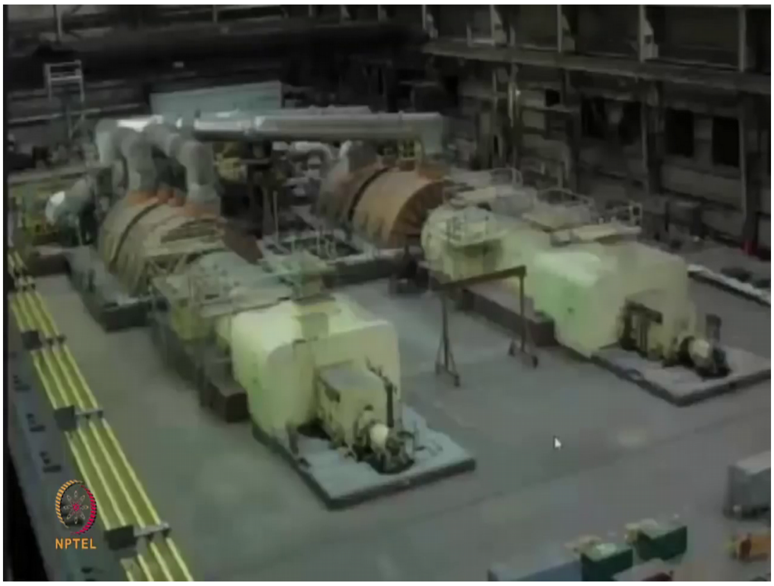

Let us go inside the power station and see what happens. So, this is a picture not from an Indian power plant, but which till date is the largest steam turbine generator in the world.

It will the 2 streams here, what you see on this side from here to that other end, this is the steam turbine this is the generator. And, so like that there is a second arrangement that side and the second generator here each of these producing 600 and 50 megawatts. So, it can total generate 1300 megawatts ok. This is a com coal burning power plant and what you see here I just lots of big structures pipes these are pipes.

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Now, see another picture and looks very clean and you can get an idea how big it is, there is a person walking over there. These are all steam turbines, in which steam is coming from these pipes going in and exhausting some below and condensing it. And, all of these are opening a shaft which is connected to a rotor of this generator and that is producing electricity and sending it out.

This is a nuclear power plant. And so, except for the nuclear reactor where there is a very different phenomena taking place, rest of it the analysis comes from thermo dynamics. Whether, it is a breeder reactor, whether it is a thermal reactor, or whatever type of the powers nuclear power plant.

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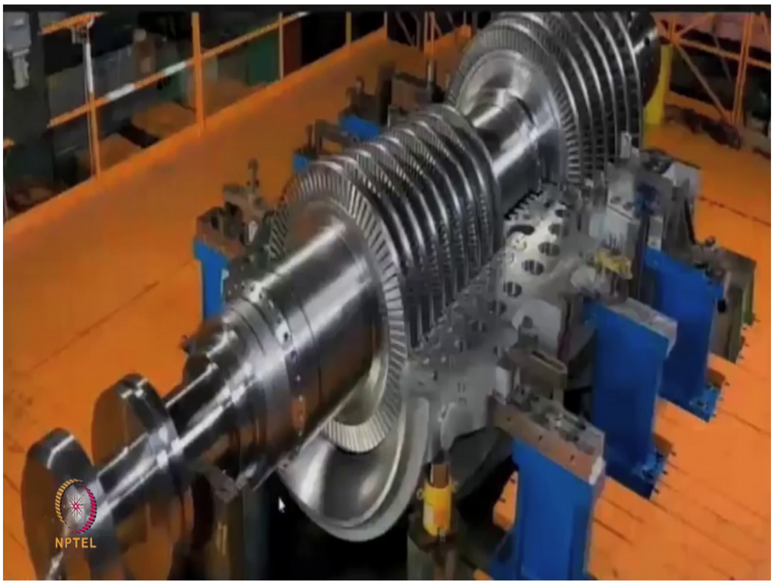

And what you saw on those pictures as big just boxes and you can not see anything in fact, if you stand near it you would not see anything moving probably, you will hear a lot of noise and feel some heat. But, when it is being manufactured in assembled this is what it looks like? These are 4 steel components this is a rotor on which these things are put which is blades and like this each of these thing is called a stage, and like this you got lots of these stages which are fixed on to the rotor. So, the blade is made separately, the rotor is made separately, they are all assembled together in the factory.

And, then it is sent off to be site, where the casing which is you see the housing here, this has been machined in the factory it is installed, and then the rotor is put on it. And finally, the upper cover is put on it and then it is all boated together these are holes or boles and you have steam turbine. It is a very very sophisticated machine, that is one application of thermo dynamics coal or oil burning, combined cycle power plants, and we now look at something else.

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There are lot of talk now about solar energy and there are many places in India we are installing solar photo vortex as for generating electricity. And, that we hope we will reduce our dependence on coal and oil and gas, and that way it will become more echo friendly system. So, this is a risk very recent just in 5 years back, this power plant was completed and this is in Spain. This is the concentrating solar plant and what it does is that there are 2 plants here.

This is one plant and this is another plant; this tower here you see a little bit shiny thing here. Inside this one is pumping water and converting it into steam, and that steam is lead into this system where it drives the turbine like the turbine pictures I showed you just now, it is condensed and put back in here. But, the heating of the water to steam instead of being done by burning coal or oil or by heat from a nuclear reactor is being done by focusing solar energy through all these little mirrors here into this point and generating electricity, the heating of the water.

You can see the huge amount of area that is required each one of these is what is called a Helio stack and all it does is that it reflects the sunlight directly in to this part and that gets heated up. This power plant achieved a unique distinction in that this will work only when the sun is up. And as from morning till evening the sun energy will go up and down, it means that you have to start and shutdown this plant and at night you cannot produce any electricity. Then, what you do where go back to burning coal.

So, can we store this energy. So, this plant use the used a very large storage system. So, during the day it had enough heat that some of heat was used to produce steam and run the turbines. And, some more energy with which a material was heated up. And, then at night or when the sun went down energy was taken from that storage and then electricity was produced from that. So, this is the first solar thermal power plant in the world that produced electricity continuously on a 24 hour basis without resorting to coal or oil or any other back up.

This distance is of the order of a kilometre or 2 kilometres many of these are there and this is one of the designs of a solar thermal power plant. The second type of a thermal power plant is you can see in this picture now.

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This is called a parabolic traps collector. And, what you are seeing here is a 0 parabola and you can see the distance goes several 100 metres. And, their all focusing sun light into this little tube in the centre which is supported above it, through which water or steam is being pumped. And, to get a sizeable amount of steam being produced the length of these are long. So, there is one here one beyond that something more there and then there are many many such rows, and they are all in a straight line, and they you are aligning these with the sun as the sun goes from morning till evening.

The sun light is focused on to this outside of the tube, it is it heats up the water inside it, and that water is then connected through all these you can see these shiny things. These are steam pipes which have been insulated and on top of that there is aluminium cladding. So, these are all the piping that are been done here you can see that here and this steam is then taken to drive steam turbines.

One of them also take this steam to do say process heating like say pasteurization of milk, or using it say in the manufacture of paper, or using it for say in a hotel for cooking, or in a base kitchen for say cooking and washing things. So, that those other options that you have with this and get another option that we have with this steam is to use it in a vapour absorption system to produce a refrigeration defect. So, this is a second type of a solar collector and this is called solar thermal power generation and this is different from solar photo vortex. Because, there we do not produce any steam it is directly converting sun light into electricity.

So, we will leave solar steam generation and look at the another different application, in which thermodynamics can help us see what happens?

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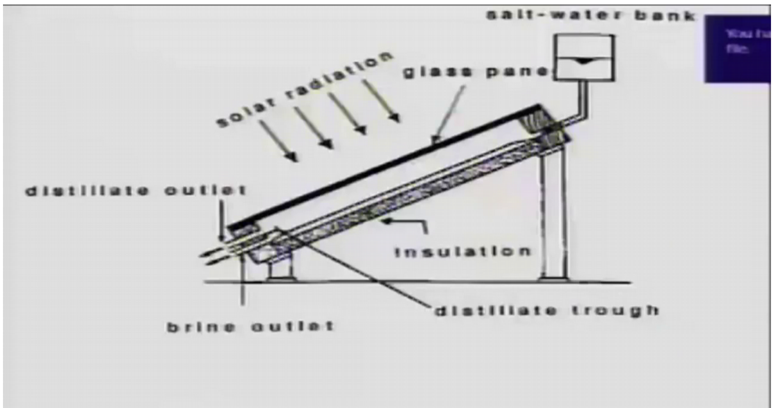

Figure 4. A Tilted Wick Solar Still

Source: Jim Leckie, Gil Masters, Harry Wh and Lily Young, More Other Homes Garbage (San Francisco, Californi Sierra Club Books, 1981), p. 304.

And, that is a fairly old technology very simple thing this is called a solar still. All it does is you made a chamber there the glass screen on the top facing the sunlight, saltwater dirty water it is put here, and it flows down this side. And, because of heat the water vapour the water vapour as liquid vaporizers the glass pane is cooler. So, it condensers on the glass pane, flows along the glass pane gets collected here and move comes out. The result is from dirty water using solar energy we can get clean drinking water.

So, this has been an idea that is been there and it is been developed quite a lot there are some many configurations of this.

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We will now look at another type of a desalination plant, and this photograph is from the Kavarathi Island in the Lakshadweep. These are remote islands where getting anything is very very difficult, it has come it has got to come from the west coast. And, it was a biggest problem facing the people in the island was clean drinking water. They are all surrounded by oceans plus dirty water. And so, this technology was developed at Nayot in Chennai and this is called low temperature thermal desalination. This is the building in which the desalination takes place and you get clean drinking water coming in.

In the last few years such plants have been set up in Minicoy and couple of other islands in the Lakshadweep, and because of that water bond diseases have been largely eliminated from those islands. How do we analyse it? How does it work? That is where thermodynamics can help us see it, basically what we are doing is you take warm water and vaporise it and condensate at a lower temperature. The warm water comes from the upper part of the sea; the cold water comes from 300 and 50 meters below the sea. And, use those 2 sources of heat to produce clean drinking water.

Now, we are look at another application and this is aircraft engines ok. This is a slight I am taken from the web this is not my stuff.

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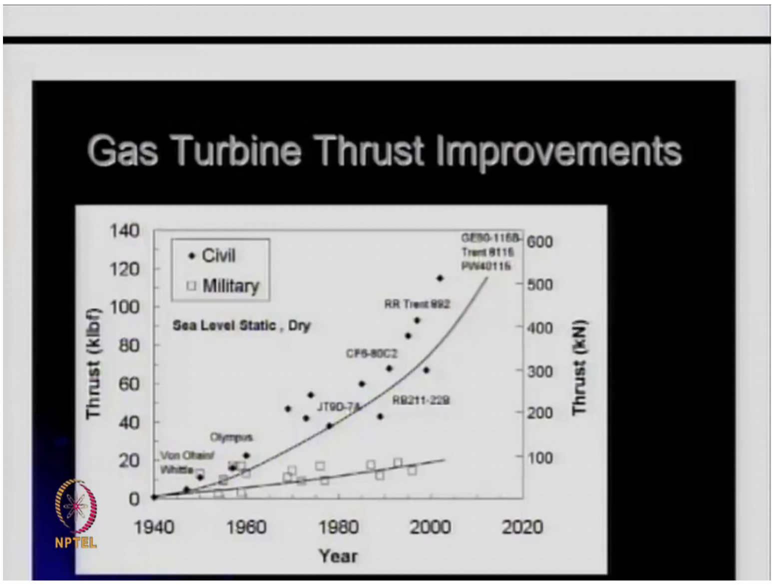

And, it gives a overview of how engine technology has been changing in a minute I will show you some pictures of engines. Year 1940, the first engines were invented there by vital in the UK and then we are now actually here 2015 and these are different model numbers of engines that have been made.

So, what one sees is that engine which were very first few engines were very small, the thrust they produce was not even 10 of the order of 10 kilo pond force. And, these are the squares denote military engines for fighter aircraft. And, these denotes engines for civil in the aircraft. And, you can see these engines getting bigger and bigger and bigger every few years, and now from where it was like 10, we are now looking at engines in this range which are of the order of 100 and 20 kilo ponds per force engines have becomes huge.

They are not just become huge and these are the names of different manufacturers over there RR Trent is Rolls Royce Trent engine, which is used in the airbus 380 and 1787. And, there other competitors are PW Pratt and Whitney and GE general electric. So, these are the 3 companies that make big aircraft engines in the world now.

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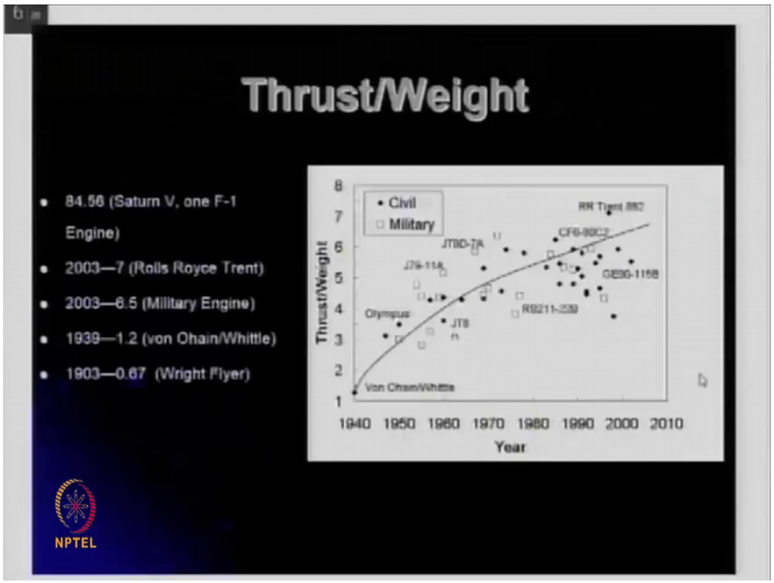

What you see here is a plant which shows year wise, what is the thrust to weight ratio? So, for the same weight of the engine how much thrust do I get? And, you can see that what it was like 1 in whatever units was there this is there. Today today's engines are about 7 times more efficient than what they were when the first engines were made say even in the 50s.

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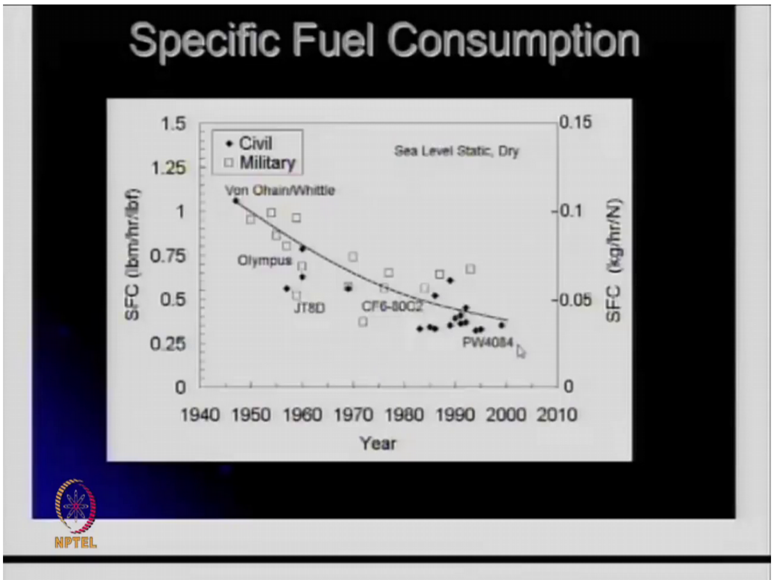

Let us say huge development that has taken place and specific fuel consumption. How much fuel does the engine consume to go to lift a particular weight or a fly a person particular distance? And, here it is that the first engines which were like about 1 or little more than 1 pound per hour per pound force; today we are looking at engines which are of the order of like 0.4. So, in about 40 years the efficiency has increased more than 4 times, that trend as you can see is going on and people predict that this trend will still continue for the next maybe 20 years, you will see more and more efficient engines coming in.

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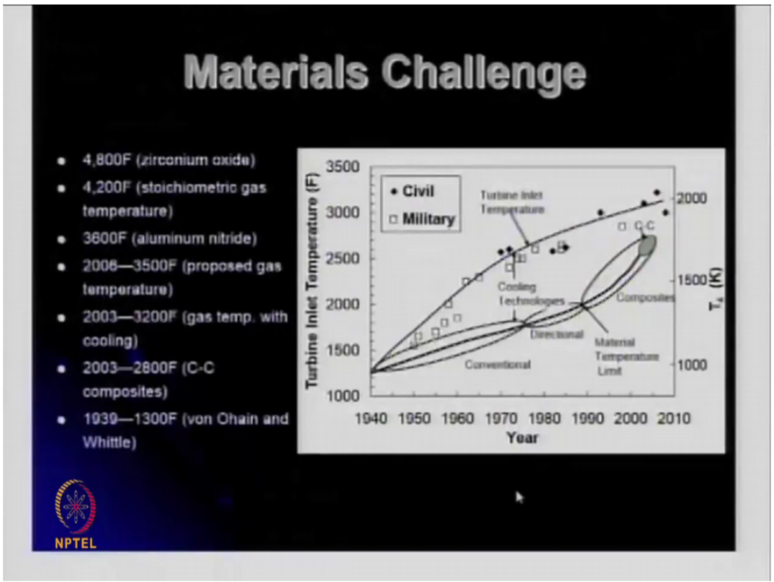

This is where the thermodynamics really gets you to understand why and how things happen? Thermo dynamics board is telling is that year is here and what is the maximum temperature in that turbine? So, in that turbine you have taken air compressed it and then one burns fuel in it typically oil.

So, the maximum temperature of that oil is a direct relation to what is the efficiency of this machine and here is what has happened? If, you look at these are military engines here the square ones their efficiency is their inlet temperature has gone much faster and much higher and civil end engines are over here, you can see all this parts going up.

And, what one sees is that the turbine inlet temperature say which were in 1970s were of the order of about this side is about 1600 Kelvin. So, that is about say 1300 degree Celsius or 1200 degree Celsius. Today engines have of the order of 2000 Kelvin or 92,000 Kelvin, which is about 1700 degree Celsius temperature of the gas. Just compare that with the fact that the melting point of steel is about 1500 degree Celsius.

So, what you are done is enormous amount of research and development, where you are now actually float putting a gas over a material, when the gas temperature is more than the melting point of that material. And, that is why advances are taken place in manufacturing in materials. So, there were you can see these were conventional engines, then various cooling technologies came about in this part. Then directional solidification techniques came in casting, and now you have composite it materials coming in with lot of ceramics in it. So, this is how people are doing research on this, because thermodynamics tells you that higher temperature means higher efficiency.

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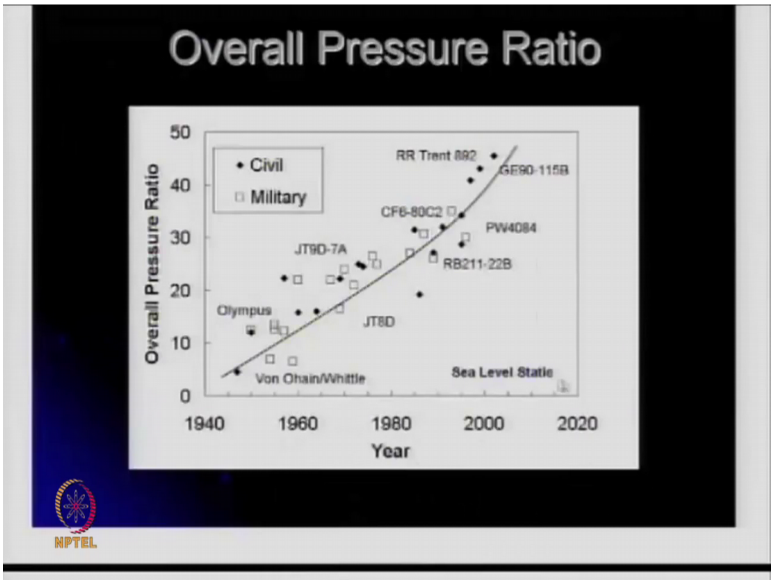

The second parameter that we will come up in thermodynamics is the pressure ratio, what is the maximum pressure we generate? And, here again you can see that over the last 40 years pressures in engines have kept on increasing. So, temperatures have been increased, pressures have increased, aeroplanes are become much more efficient than what they were earlier. What does it mean for an airline?

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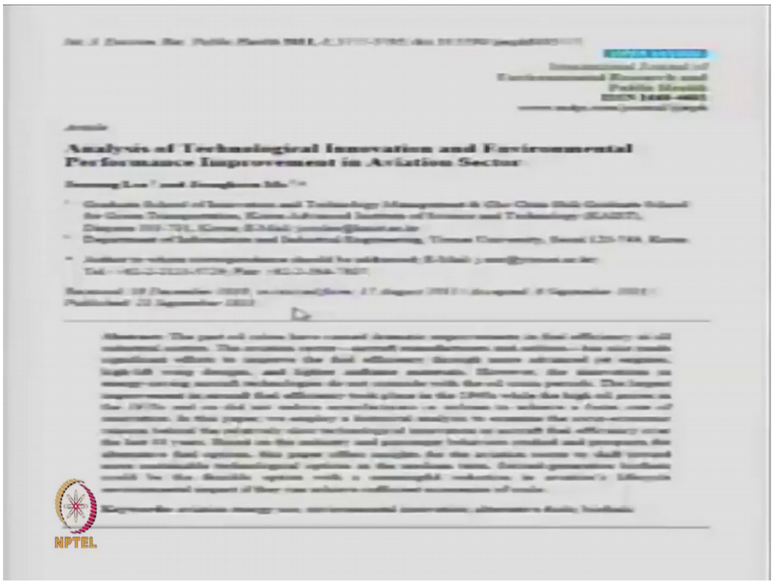

So, this is a paper and I am just going to show you one picture from this.

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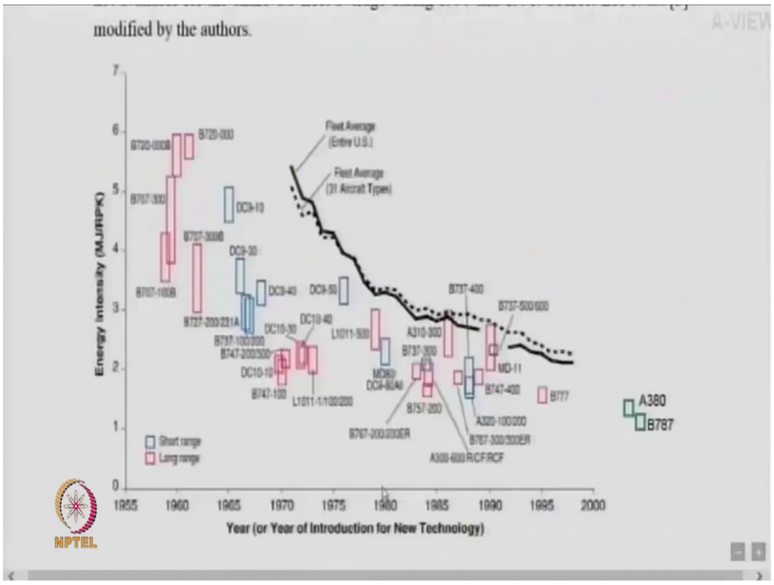

So, here is a picture which tells you on the x axis is the year on which that particular engine was introduced. So, the aeroplane was used. So, aeroplane mean aeroplane plus the engine and on this side energy intensity, it is how many mega joules did one consume for every revenue passenger kilometre.

So, every ticket paying passenger, it was flown one kilometre that is one revenue passenger kilometre. And, here is what you see the older engines which were like Boeing 707 there was something like in this range 4 to 6 on this scale.

And, we keep on seeing as we go along in time DC 9 a 10 11 air bus 310, you still see that in India many places, then you have air bus T 20 most airlines in India are playing on this or the Boeing 737, it will be somewhere on this picture here, it is Boeing 737. And, then there is Boeing 7 7 7 and then here air bus 380 and Boeing 7 8 7. What you are seeing is that these 2 aircraft? Are only order of 1.5, which means they are about 3 times more energy efficient than a Boeing 707 or even if you take an aeroplane from the 1980s say air bus 310 or a Boeing 747 from that time, it is still at least 3 times more efficient or 2 times more efficient than a 20 year old aeroplane.

And, this is a graph that shown what is the fleet average of the entire US. So, airlines have consistently selling of older aeroplanes and buying newer aeroplanes, and that way they are reducing their fuel bill which is the single biggest item in the cost of our airline ticket. And, so, an airline which continuously gets new aeroplanes and uses them for 3 years and then sells them of versus the airline which keeps on aeroplane flying for 15 years, that 15 year old aeroplane and that airline will never be able to make a profit in today's world and that what you see happening with air India.

So, average fleet air is very high and your airlines the average fleets they are still maintaining very very low. So, fuel bill is less and that is how airline tickets still have come down and down to a point where as sometimes they can even start matching railway tickets. All of this has to do with thermodynamics and that we will see this course. So, as I show a picture of an aircraft engine and then we will move on I have already pasted it on the hand out that I given out ok.

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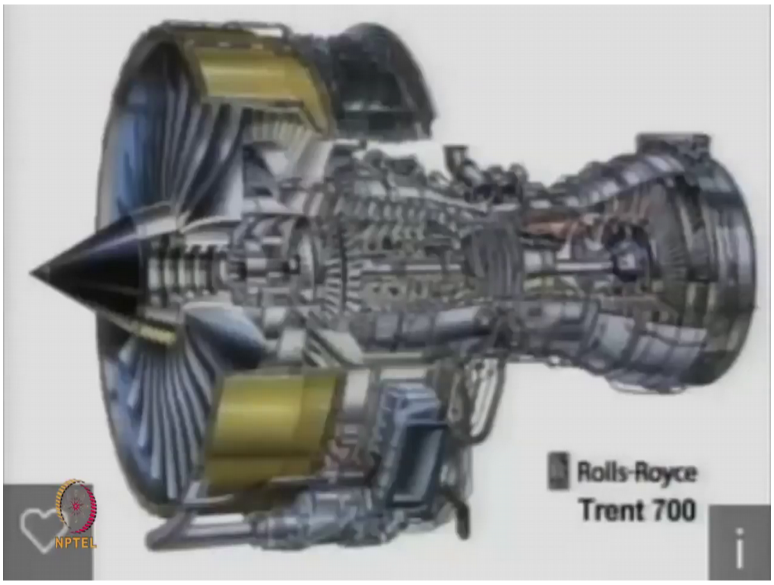

So, here there is a aircraft engine, this is from Rolls Royce Trent 700. It looks very very complicated. And, it is a very very high tech machine extremely reliable and there are lots of moving parts in it, but the instance is that there is a fan here, which blows air and that generates the thrust.

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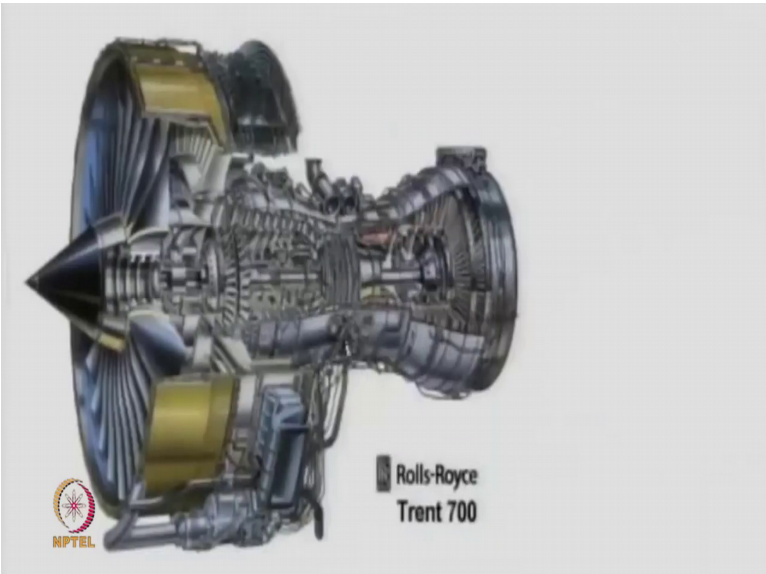

Some of the air else goes in through this and it gets compressed. And, then there is fuel being burnt in this, it goes over these wheels and these to produce these are the turbines and the hot gases exhaust from there.

So, that is a typical construction of an aircraft engine and you can see here there are pipes, there are tubes, there are sensors, and a lot of things that make this aircraft this has machine reliable, but at the heart of this lies in the fact that is something happening in this which has it is basis in thermodynamics. So, with that let us say how do we begin to understand these types of systems.