Solar Energy Engineering and Technology
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Lecture – 1
Energy Scenarios

Dear students, welcome to the first lecture of the course Solar Energy Engineering and Technology. So, today we will be discussing about energy scenario. So, before we start the exact energy scenario, let us discuss some of the important terminologies associated with this course. So, what is energy?

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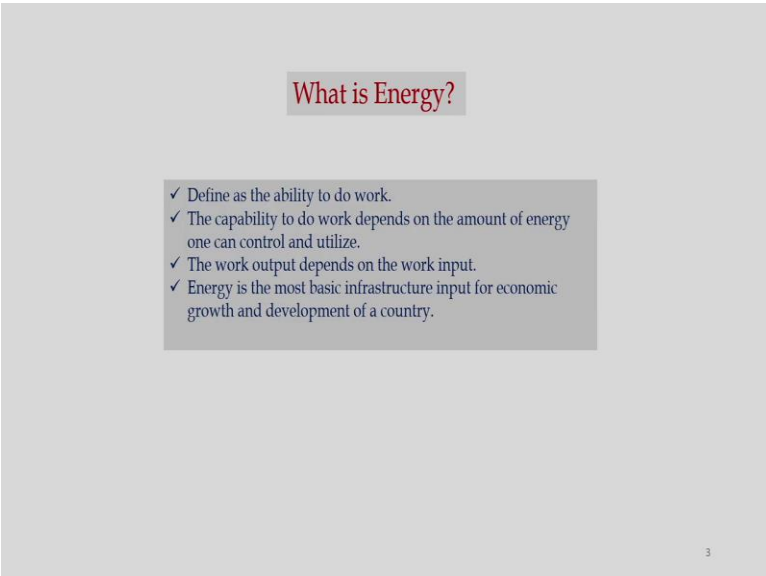

This energy defines as the ability to do work. The capability to do work depends on the amount of energy one can control and utilize. The work output depends on the work input. The energy is the most basic infrastructure input for economic growth and development of a country.

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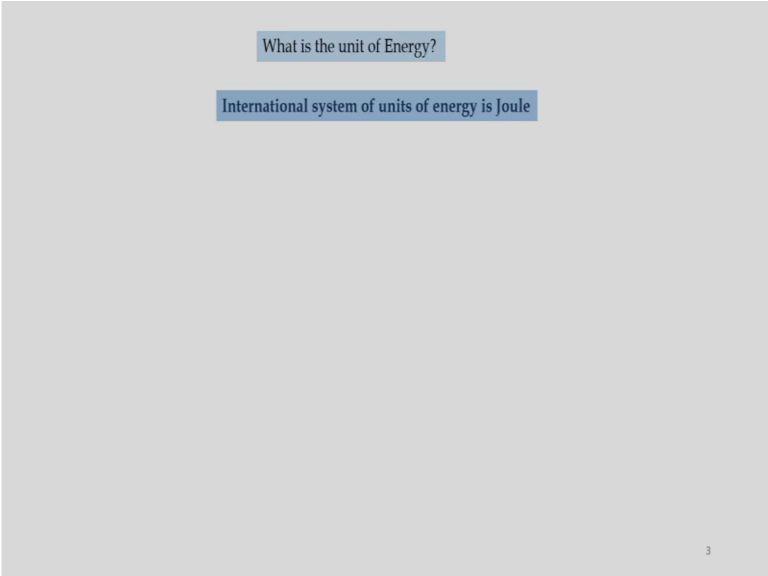

Now, what is the unit of energy? The International system of units of energy is Joule.

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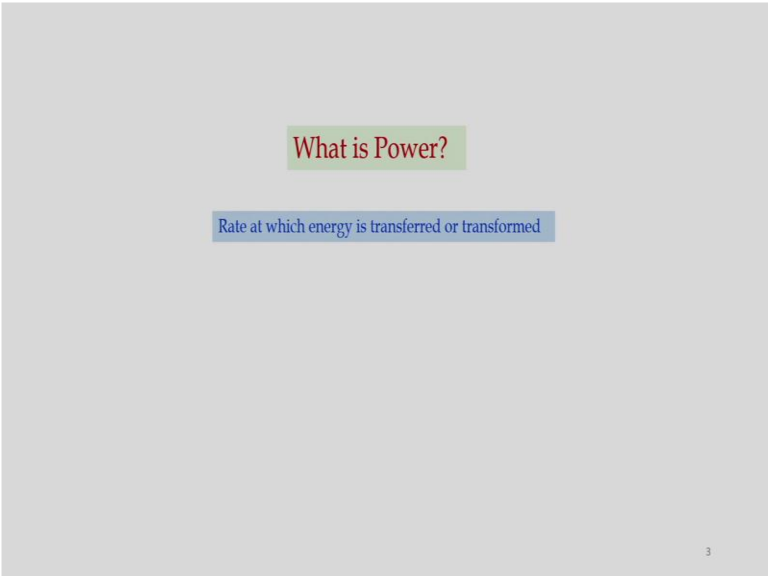

Then what is power? Power is nothing but the rate at which energy is transferred or transformed.

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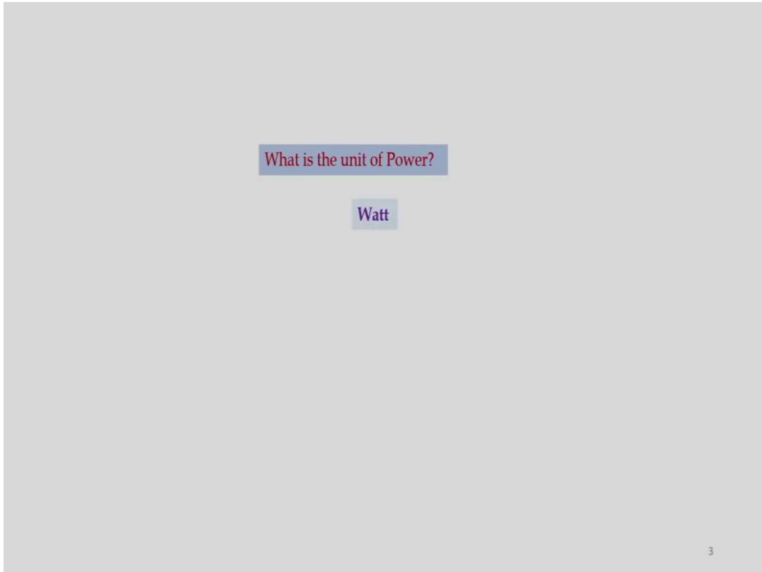

Now, what is the unit of power? It is watt.

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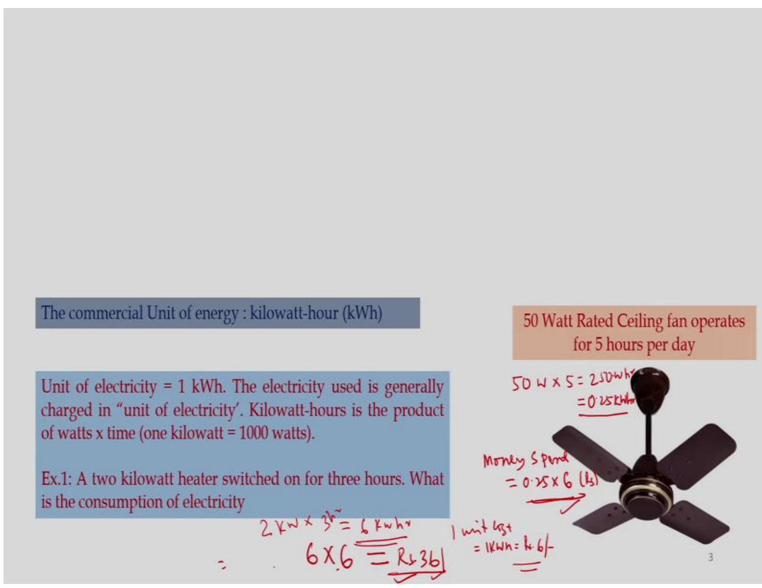

Now, what is the commercial unit of energy? It is kilowatt-hour. Let us learn in deeper sense what is kilowatt-hour? So, normally we know unit; what does it mean? So, 1 unit is 1 kilowatt-hour. The electricity used is generally charged in unit of electricity; the kilowatt-hour is the product of watt and time. That means one kilowatt is equal to 1000 watt, and if we multiply with time, it becomes watt into time; that maybe in hour, minute or second.

Normally, if we have to define unit generation, then we need to multiply watt with hour. For example, 2 kilowatt capacity or rated heater, switched on for 3 hours. What is the consumption of electricity? So, straightway you can calculate it. So, 2 kilowatt is the rated power multiplied by 3 hours. It will be 6 kilowatt-hour; so this will be in hour.

So, if we know 1 unit cost, 1 unit cost means 1 kilowatt-hour is equal to say rupees 6. Then amount of money required will be how much? So, it will be 6 multiplied by 6, which will be equal to rupees 36. So, these rupees 36 we have to spend if we have to run the heater for 3 hours in a day. So, this will be 36 rupees per day. If we take one more example, say 50 watt rated ceiling fan operates for 5 hours per day, then what will be the electricity consumption?

So, straightway you can calculate 50 watt multiplied by 5 hours; it will be 250 watt-hour. So, if we have to convert to kilowatt, then it will be 0.25 kilowatt-hour. And then if we multiply it with 6 then what will happen? So money spend will be 0.25 multiplied by 6, which will be in rupees. So, that will be in per day, so that much of money will be spent if we operate the ceiling fan for 5 hours.

So, that way you can calculate the amount of energy requirement to run a particular electrical utility. Now, why this energy is required? Of course to meet energy demand in different sectors. It maybe domestic, it maybe transportation, may be agricultural or maybe industry. So, if we talk about domestic.

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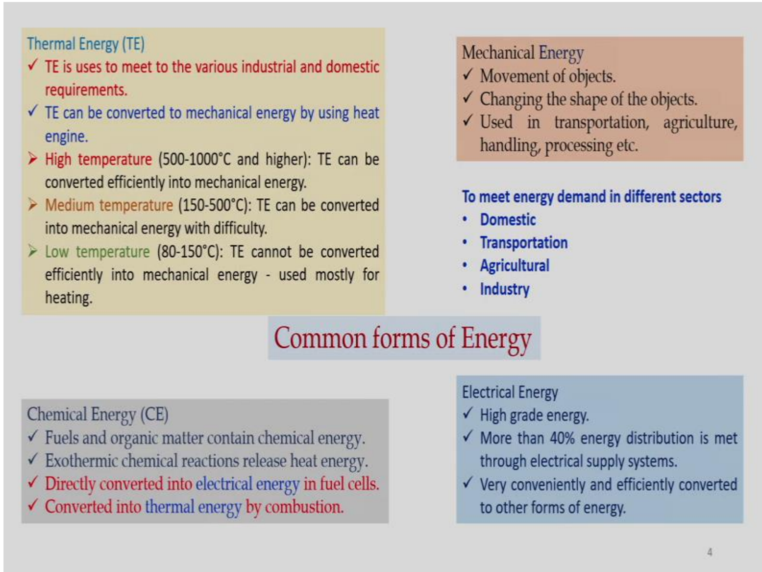

It may be for offices, maybe individual households and other commercial buildings. So, this sector requires different energy at different forms so let us learn different forms of energy, which is commonly used. So, what are the common forms of energy? Let us first consider thermal energy.

This thermal energy is used to meet to various industrial and domestic requirements. Thermal energy can convert to mechanical energy by using heat engine, and this thermal energy can be categorized into 3 primary groups based on the temperature ranges. So, first category is high temperature if the operating temperature varies from 500 to 1000^0 C or above. And second category is medium temperature operation if the temperature varies from 150 to 500^0 Celsius and third category is for low temperature.

So, if the temperature varies from 80 to about 150^0 Celsius. For high temperature applications, this thermal energy can be converted efficiently into mechanical energy. For medium temperature applications, thermal energy can be converted to mechanical energy with certain difficulty. But, in the last case for low temperature applications, this thermal energy cannot be converted efficiently into mechanical energy. So, it is mostly used for heating applications.

Now, let us discuss the second category of energy which is commonly used is chemical energy. So, fuels and organic matter contains chemical energy and exothermic chemical reactions release heat energy. And sometimes we can convert directly electricity from chemical energy, by using fuel cells. There are different kinds of fuel cells which can convert chemical energy to electrical energy directly; may be PEM fuel cell, proton exchange membrane fuel cell, maybe solid oxide fuel cell.

There are many kinds of fuel cells which operate at different temperatures. Also we can convert chemical energy to thermal energy by using combustion route. And about mechanical energy, this mechanical energy is required for movement of objects, changing the shape of the objects, and used in transportation, agriculture, handling, processing and different other activities. Now, let us discuss about the electrical energy, which is the high grade energy and more than 40 percent energy distribution in the world is met through electrical supply systems.

And this electrical energy is very conveniently and efficiently converted to other forms of energy.

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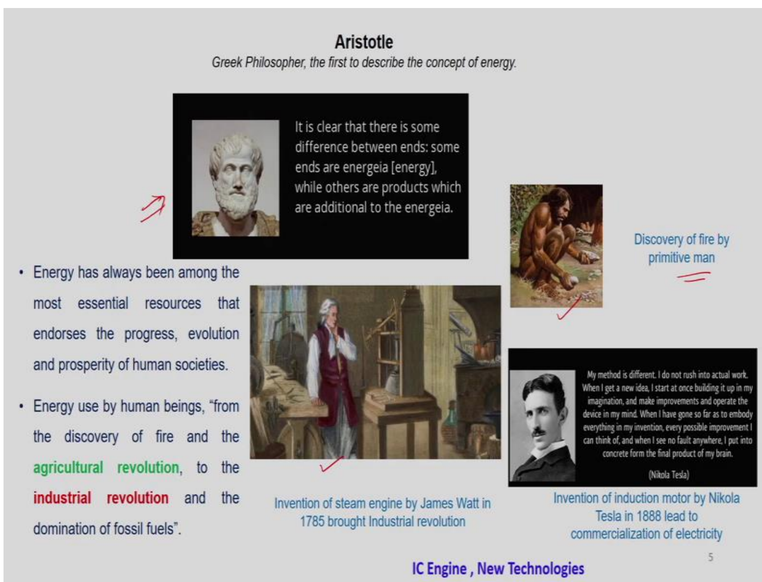

So, this slide shows the development, how industrial development takes place, and how and when electricity was developed and after that what happens. So, as you are familiar with this famous philosopher, so he is Aristotle. He is the first man to describe the concept of energy. So, he has given one statement. So, statement goes something like, "It is clear that there is some difference between ends". Some ends are energeia means energy; while others are products which are additional to the energeia.

The energy has always been among the most essential resources that endorses the progress, evolution and prosperity of human societies. Energy use by human beings, from the discovery of fire and the agricultural revolution to the industrial revolution, and the domination of fossil fuels. So, this man busy with generating fire, so that indicates discovery of fire by primitive man. So, this picture is very famous picture, so he is James Watt, he invented the steam engine in the year 1785.

The invention of steam engine brought the industrial revolution. After that many more mechanical devices were developed including internal combustion engines. So, this era from 1785 to 1888, the time when Tesla discovered induction motor. So, this era is known as mechanical era. Lot of mechanical machines or which develops or which generates mechanical energy was developed. In the year 1888, Nikola Tesla developed the induction motor.

The invention of induction motor leads to commercialization of electricity. So, from 1888 that electrical era was evolved. So, many more technologies were developed so, without electricity now we cannot think of our life. So, Tesla changed the entire scenario of the world. So, now this increases the energy requirement by leaps and bounds. After that many more technologies were developed.

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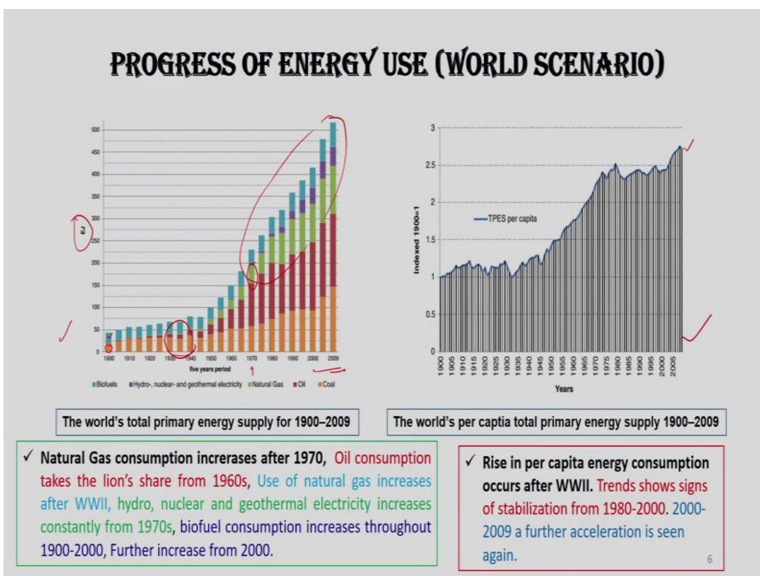

Now, let us pay attention about the progress of energy used that is, world scenario. So, this figure shows the energy used versus years. So, it was started in the year 1900 to 2009. So, this combination has been reported in this figure. As you can see energy requirement was very very low, when you compare 1900 and if we see in 2009 you can see the rise in requirement of energy. It is about 10 times more. So, this unit is Exa-joule. So, 1 Exa-joule is equal to 10^{18} joules.

So, now see here the share of energy comes from different sources. So, this colour indicates biofuel and then it is it is a coal. Coal and biofuel starting from 1980 all were present but the share increases with time. But, this year is also very very important. These years after World War II, many more things happened and people were given lot of attention to harvest energy from other sources.

Again if we see 1970s, this natural gas uses increases after 1970s. So, this is natural gas and oil consumption takes the lion's shares from 1960s because all the machinery developed by that time and that is why it was oil who takes the lion's shares. And use of natural gas increases from World War II and hydro nuclear and geothermal electricity increases constantly from 1970s.

As you can see here these are increases constantly, and biofuel consumption increases throughout 1900 to 2000 and further increase from 2000 to 2009. And this figure shows the world's per capita total primary energy supply from 1900 to 2009. As you can see here this is almost flat curve, and then after World War II there is a rise in total primary energy supply.

And then it is continuously increases till 1980s. Then 1980s to 2000 again it is almost constant, some fluctuations were there and then after 2000 there is rise in total primary energy supply. That means what, once primary energy supply is increases means quality of life is increases. So, that way you can see if we have to increases the quality of life, then we need to burn more fuels. And if we burn more fuels, then it will emit lot of greenhouse gas emission. So, that we should keep in mind.

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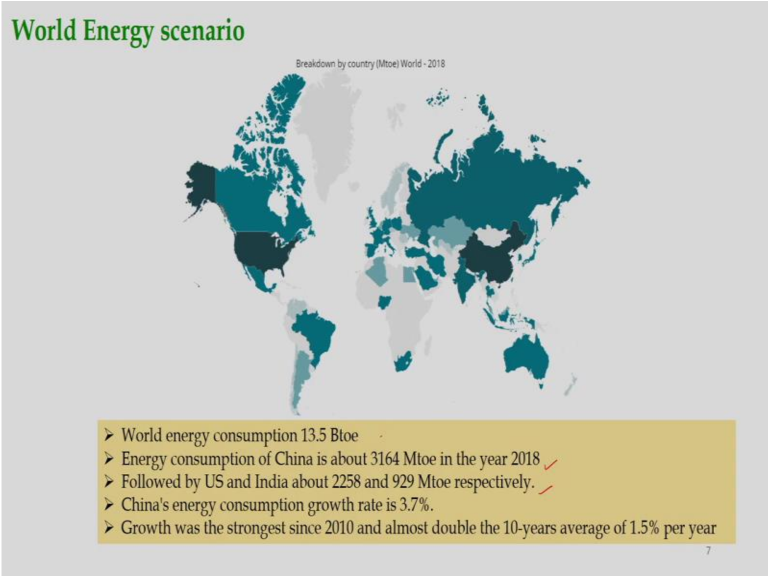

Now, let us pay attention about the world energy scenario. So, this is the world map and this old energy consumption is about 13.5 billion tons of oil equivalent. In the year 2018, the energy consumption of China is about 3164 million ton of oil equivalent in the year 2018. Followed by US and India about 2258 and 929 million ton of oil equivalent respectively. China's energy consumption growth rate is 3.7 percent, and this growth was the strongest since 2010 and almost doubled the 10 year average of 1.5 percent per year.

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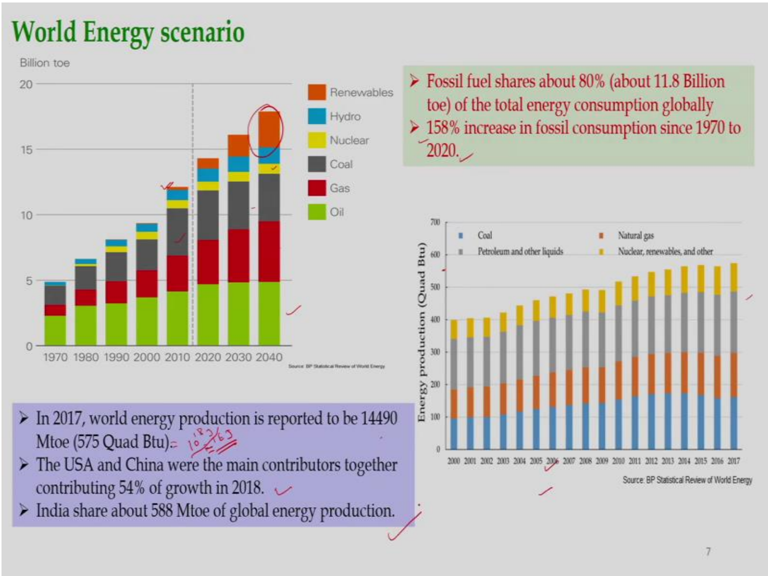

Now, let us see this figure. This figure shows the comparison of energy mix from 1970s to predicted 2040. So, as you can see this share is increasing. So, this green colour is oil. Then this part is red is gas, then this grey is coal, then nuclear is this yellow, then blue part is hydro and renewable. As you can see renewable was nowhere in 70s and 80s very nominal and as you can see in 2010, you can see some kind of visibility. And it is predicted that this renewable energy will take a rider seat in the coming years.

So as you can see here about 80 percent of the share is coming from the fossil fuels, and as you can see about 158 percent increased in fossil consumption since 1970s to 2020. It is huge increase in fossil fuel consumption. So, this slide shows about energy production versus years. So, as you can see over 3 years, energy consumption is increasing. So, what we can conclude from here in 2017, the world energy production is reported to be about 15000 million ton of oil equivalent.

So, it is equal to 575 Quad Btu which is nothing but this is equal to 1 Quad Btu is equal to 10^{18} or 1 Exa-joule; exa-joule or 10^{18} joule. So, this is joule and equal to one exa-joule. The USA and China were the main contributors together contributing 54 percent of growth in 2018. India share about 588 million ton of oil equivalent of global energy production.

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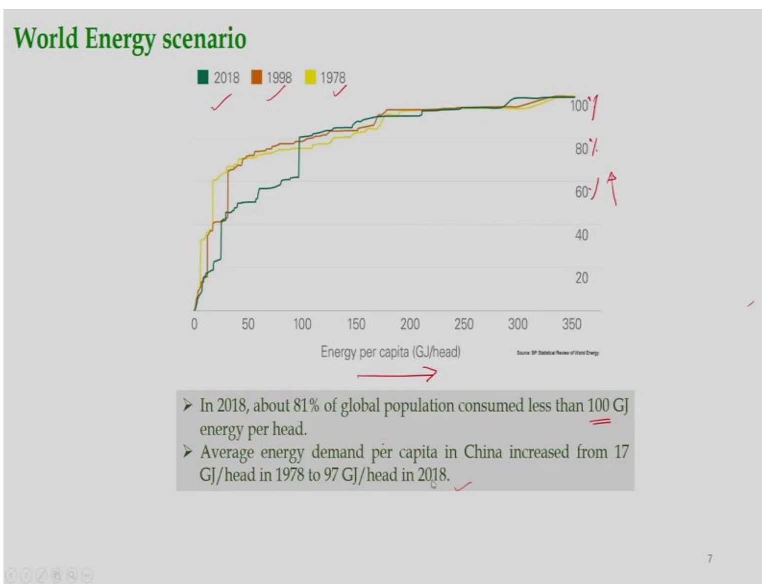

So, this slide shows about the world energy scenario at 3 different years. So, one is at 1978, one is at 1998, and other one is at 2018. So, in a horizontal axis it shows energy per capita in Giga-joule per head, and in the vertical axis it shows the population in percentage, these are percentage.

So in 2018, about 81 percent of global population consumed less than 100 Giga-joule per head and rest 20 percent consumes the from 100 to 350 Giga-joule per head. You can see the non uniformity of utilization of energy. The average energy demand per capita in China increased from 17 Giga-joule per head in 1978 to 97 Giga-joule per head in 2018. This is a huge rise in per capita energy consumption.

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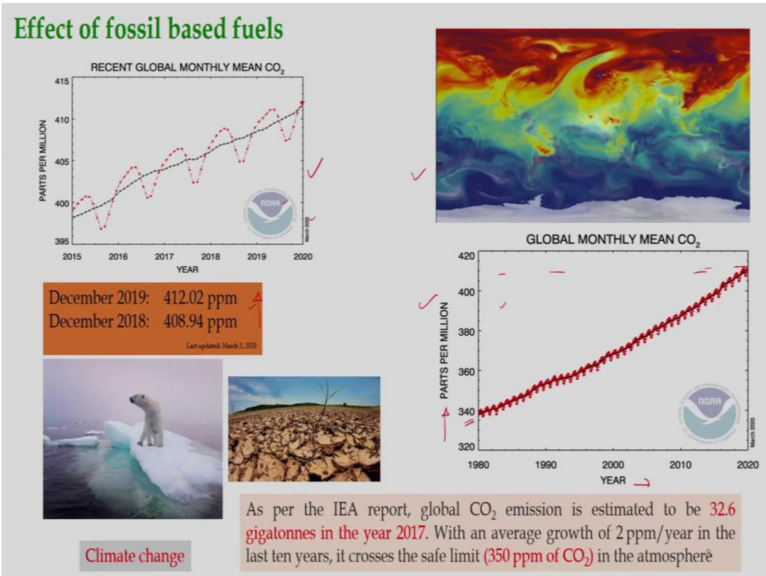

Now, let us learn about effect of fossil based fuels. So, this figure shows the carbon dioxide present in the art atmosphere, you can see the red color. So, as per IEA report, the global carbon dioxide emission is estimated to be 32.6 gigatonnes in the year 2017. And if you see this figure and this figure, this figure is enlarged view of this figure which shows global monthly mean carbon dioxide. So, if we see very precisely this figure, this vertical axis shows parts per million of carbon dioxide and here is the year from 1980s to 2020.

So, you can see the variation of carbon dioxide in earth atmosphere. It was 340 in the year 1980s and it is keep on increasing and now it is about 410 close to 410. So, as you understand the permissible limit of carbon dioxide in the earth atmosphere is 350. So, you can imagine we are in the very dangerous situation now. So, we are really in a very dangerous situation because this earth atmosphere contains more than 410 ppm carbon dioxide. So, this can be magnified view of this, it will be starting from to 2015 and 2020. You can see how it varies and now we are here.

So, for comparison, so in December 2019, it was 412.0 ppm and in December 2018 it was 408.94 ppm, you can see the rise in single year. So, what are the adverse effects of this? There is a climate change. So, you can see the melting glaciers and then drought in many part of the globe. So, we need some kind of alternative solution to mitigate those environmental problems.

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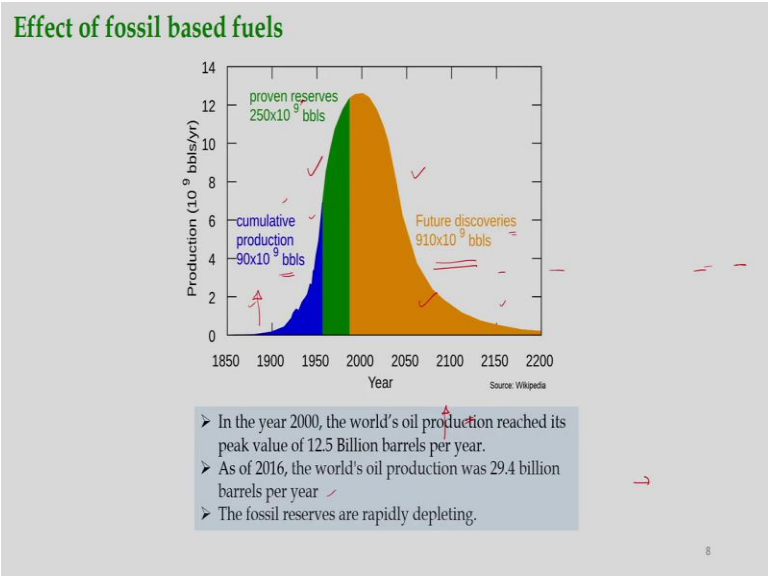

So, let us see the production of fossil fuel with years. So, this cumulative production this bbls is something called billions barrels per year. So, cumulative production till 1950s was 19 into 10 to the power 9 bbls and proven reserve is about 250 into 10 to the power 9 bbls. So, with the existing technological intervention, we can predict the kind of reserve we have. But, this part we do not have that kind of technological solution to estimate the amount of reserve we have.

So, that is why these future discoveries are required which estimated to be about 910 x 10^9 bbls. So, in the 2000 the world's oil production reaches its peak value of 12.5 billion barrels per year. As of 2016, the world's oil production was 29.4 billion barrels per year. So, this fossil fuel reserves are rapidly depleting that we really need to understand.

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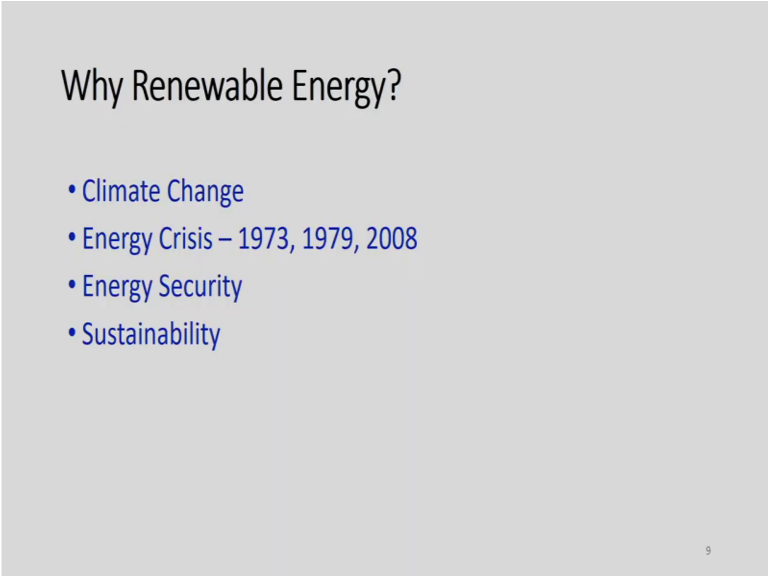

So, why do you need renewable energy? Because of this climate change, we need to do something about this climate change issues, and we know very clearly about the energy crisis. In 1973, these OPEC countries, they stopped providing oil to the other countries. They increased the oil price to a very high value so it was very difficult to afford the countries not producing the oil.

Then people thought about some kind of alternative solution. What to do? From where we can generate energy? So, this year is very very important for development of renewable energy technologies. Again in 1973, there was a crisis and people were really forced to think abut new development and generation of energy from alternative resources. And again 2018, there was a financial crisis.

So, this all together crisis actually forced researchers to think about some kind of alternative solutions and of course you need energy security and sustainability. So, what are the alternative sources we have?

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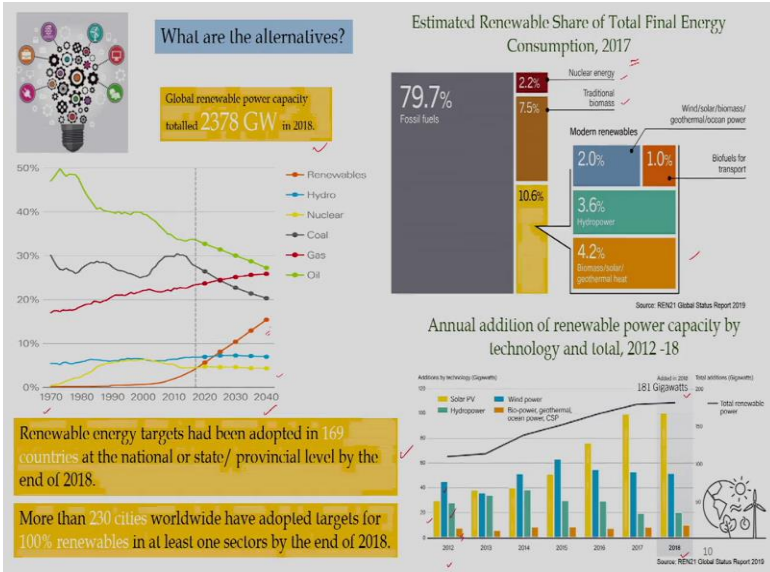

We have many like solar energy, wind energy, geothermal energy, hydro energy, bio energy and tidal energy. Now, let us see this figure how the share of all the energy sources varying with time. So, from 1970s to 2040, from 2020 to 2040, there is a prediction and these are the actual values. So, as you can see this oil production is decreasing with years and if we see coal, coal is sometimes decreasing increasing, decreasing increasing, and then recent trend is to decrease. And it is predicted that coal utilization will decrease with coming years.

And gas of course, it will increase and hydroelectric it is almost constant and it is predicted that this will slowly grow. And nuclear is almost constant now and it will remain as per the predicted models. But, as you can see this renewable energy, it will grow and it will it will be in the driver seats looking into the environmental problems and sustainability. So, share of renewable energy is growing at a rate of 7.1 percent per annum.

The predicted to increase up to 15 percent by 2040 from 4 percent today. So, here what is shown here? Like estimated renewable share of total final energy consumption in the year 2017. So, as you understand about 80 percent of energy is coming from the fossil fuels and rest is from other sources. Maybe nuclear, maybe traditional biomass, maybe other sources like hydropower biomass, solar, wind etc.

This figure shows the annual addition of renewable energy capacity by technology from 2012 to 2018. So, as you can see this yellow colour is for PV, then this blue colour is for wind and this green colour is for hydropower, and this orange colour is for bio-power and CSP. So, with year you can see the contribution of all the different sources of renewable energy. And as you can see here in 2018, this contribution of solar is extremely higher compared to other sources.

And this axis is secondary axis shows the cumulative of all. So, it is found that it is about 181 Gigawatts in 2018. That much of energy is produced from renewable sources. So, what we can see here, this global energy power capacity total is about 2378 Gigawatt in 2018. This renewable energy targets had been adopted in 169 countries at the national and state provincial level by the end of 2018. More than 230 cities worldwide have adopted targets for 100 percent renewable energy in at least one sectors by end of 2018. So, this kind of agreement has already been done globally.

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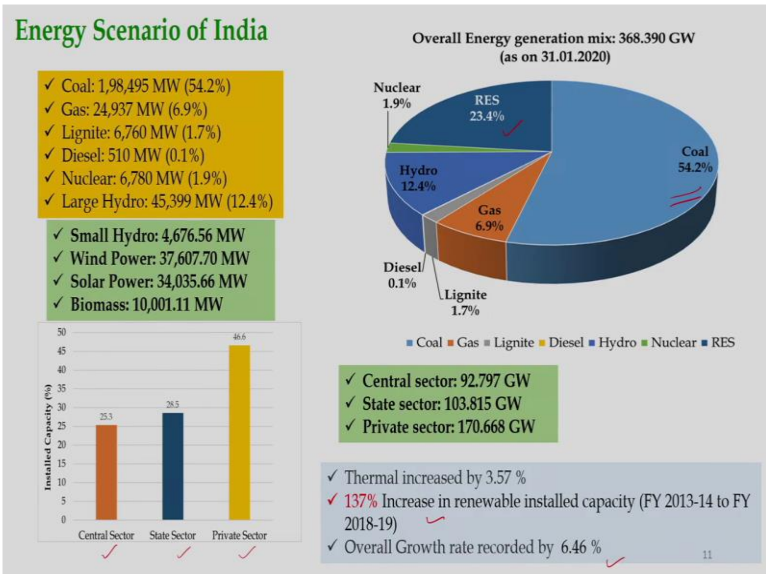

Now, let us pay attention about energy scenario in India. So, as you can see share of renewable energy and other sources in this pie diagram. So, share of renewable energy is about 23.4 percent, nuclear is 1.9, hydro is 12.4 percent. Diesel is about point one percent. Lignite coal contribution is about 1.7, gas is 6.9 and major contribution is coal which is about 54.2 percent.

So, this 54.2 percent is equivalent to about 200 Gigawatt of energy, and gas contribution is about 25 Gigawatt. Then lignite coal is about 6 Gigawatt, then diesel is about 0.5 Gigawatt, nuclear is almost 6.7 Gigawatt; then large hydro which is not renewable. Its contribution is about 12.4 and it is equivalent to about 45.3 Gigawatt of energy received from this large hydro-power plant.

And as far as renewable energy is concerned, so we get energy from small hydro, wind power, solar power and biomass power. So, from small hydro, it is about 4.6 Gigawatt, from wind about 37 Gigawatt, solar about (4) 34 Gigawatt and biomass is about 10 Gigawatt. Now, let us analyze sector wise. So, we have 3 sectors: Central sector, State sector and Private sector.

So, you can see the installation capacity. So, Central sector installed about 25.3 percent and State sector installed about 28.5 percent and Private sector is about 46.6. So, if we equalize in terms of Gigawatt; so Central sector contribution is about 93 Gigawatt, State sector is about 104 Gigawatt, and Private sector is about 171 Gigawatt.

And this thermal contribution increased by about 3.57 in this year and about 137 percent increased in renewable installation capacity from 2013-14 to 2018-19. It is a huge increase in installation of renewable energy. An overall growth rate recorded by 6.46 percent, that means people are using more energy. That way also you can think about now quality of people in a particular country.

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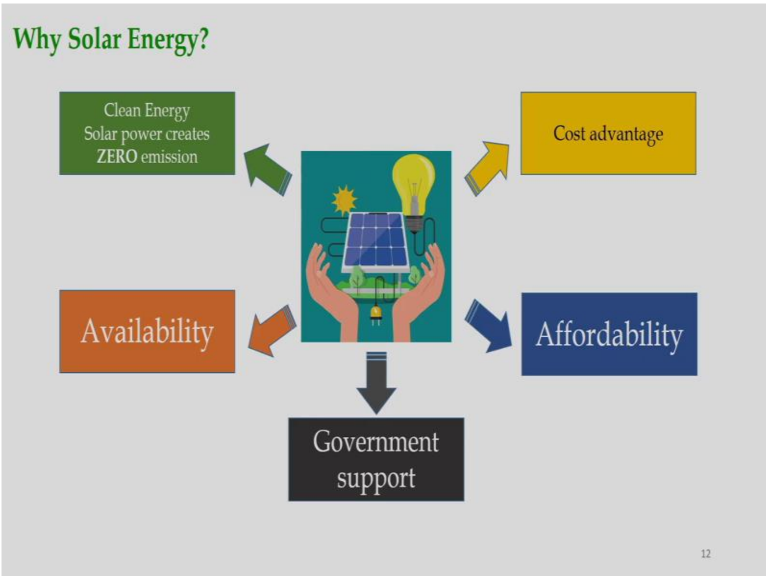

So, why then solar energy we have learned different alternative, then why so special about solar energy? So, we must know about that first thing it is a clean energy, and see solar power creates 0 emission during each operation and its availability. So, solar energy is available throughout the globe and it is affordable now, and cost advantage. Since, it is affordable then people can take solar plant in their home to generate energy for their utility as well as to sell the electricity, what they have generated in their household. And of course, government support is required for installation of plants and get subsidies.

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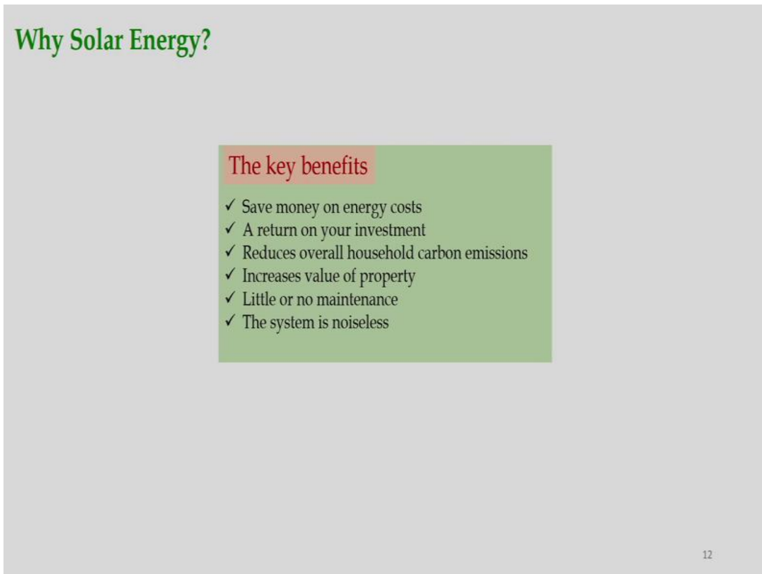

So, what are the key benefits of utilizing the solar energy? Save money on energy costs, a return on investment, reduces overall household carbon emission, increase value of property. So, it increases the value of property. Little or no maintenance is required for this kind of installation, the system is noiseless. These are the key benefits of utilizing solar energy.

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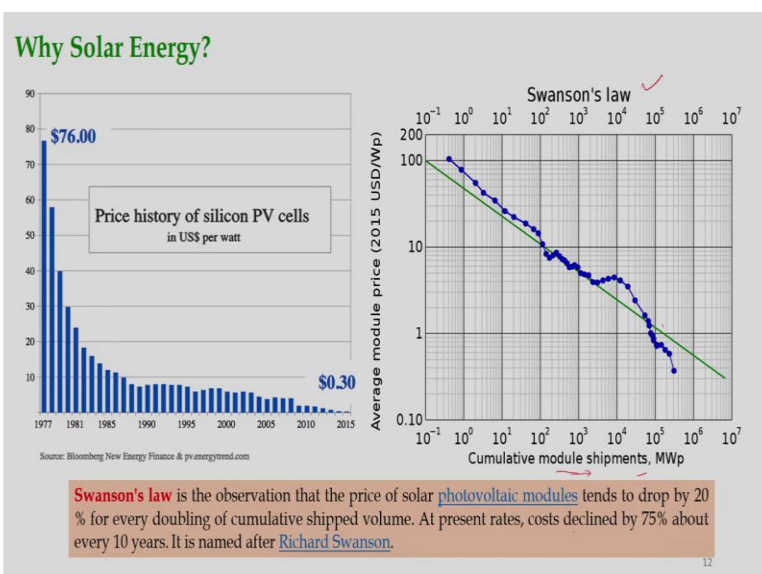

And other advantages are as you can see this cost. So, if you compare in the year 1977, cost was about 76 dollar per watt. Now, you see it is about 0.3 dollar per watt that means, in recent times in India if government supports, we get a value about 2.5 rupees per unit cost. Or if subsidies are not there, then maybe it will go up to 6.5 rupees per unit cost. Also we need to understand this Swanson’s law. So, this was developed by Richard Swanson, one of the owner of the solar company. So, that is how it is known as Swanson's law.

What it tells, is the observation that the price of solar photovoltaic modules tends to drop by 20 percent for every doubling of cumulative shipped volume. At present rate, cost declined by 75 percent about every 10 years. So, this horizontal axis tells about the cumulative module shipments, which will be in megawatt peak. And in vertical axis shows average module price. You can see how it is decreasing with cumulative module shipment. This law can also be applied to understand the futuristic reduction of cost.

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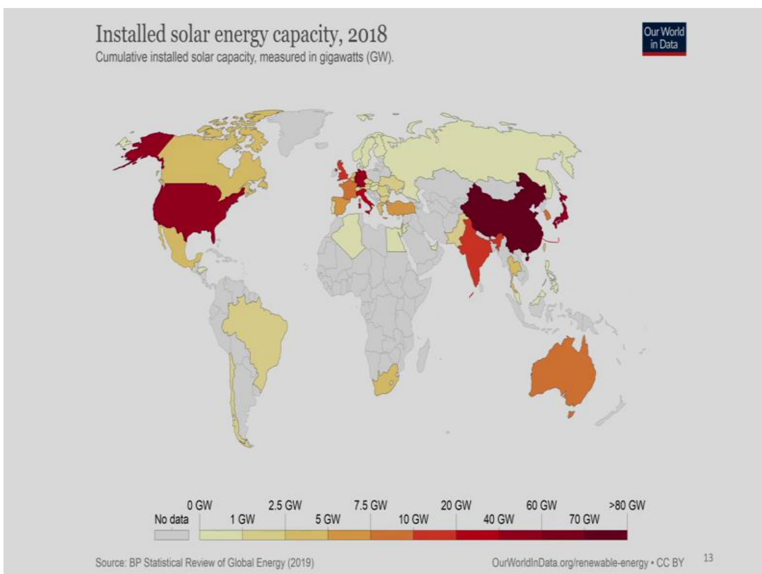

Now, let us pay attention about installed solar energy capacity in 2018. So, as you can see these dark colours are for China, it is China. So, they have installed huge amount of solar gadgets. So, they can generate more than 80 Gigawatt of energy followed by US and some of the European countries. And if we talk about India, it is more than 40 Gigawatt in this range; and you can say, you can use this scale and we can understand the installations of solar energy across the globe.

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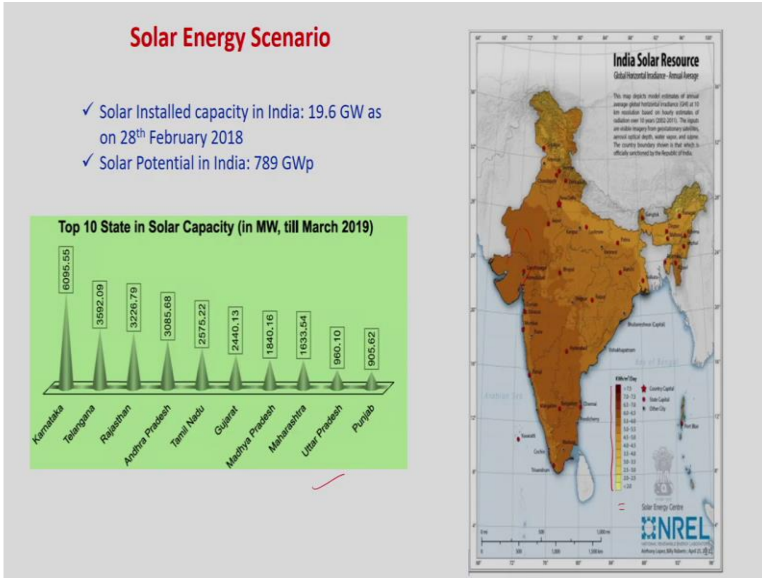

Now, let us concentrate about the solar energy scenario in India. So, this is a India map, and you can see the scale here based on the colour code. So, darker the colour is the higher the solar installation. So, we can understand the kind of energy available here. Maybe the darkest section is 7.5 kilowatt-hour per meter square per day. These regions are known darkest and then we get higher solar concentration here.

The solar installed capacity in India as on 28 February 2018 is about 19.6 Gigawatt and estimated solar potential in India is about 789 Gigawatt peak. So, this chart shows about solar capacity of different states of India. 10 states are shown here. They are the major solar capacities. Karnataka followed by Telangana, then Rajasthan, Andhra Pradesh, Tamil Nadu, Gujarat, Madhya Pradesh then Maharashtra, Uttar Pradesh and Punjab. You can see the kind of solar capacity they have. So, once you know this colour code of a particular region we know the amount of solar radiation falling on that particular region.

So, that way also we can think and also we must know the solar hours. So, that way you can understand, how many hours solar normally present in a particular locations and we can estimate the amount of radiation available for conversion.

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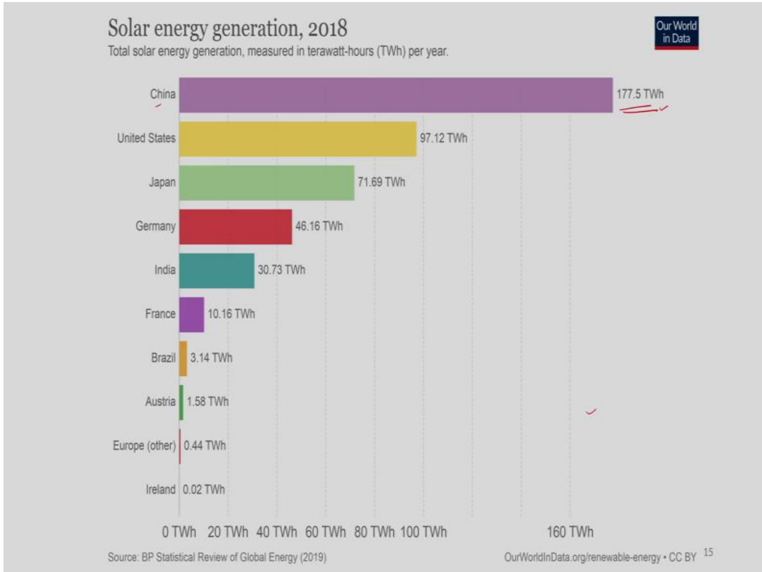

And we can see this solar energy generation in 2018, so here total solar energy generation which is measured in terawatt-hour is shown here. So, China is producing about 177.5 terawatt-hour followed by United States. It is about 100 terawatt-hour followed by Japan. Then 72 terawatt-hour, then Germany, then India is about 31 terawatt-hour. So, this figure shows the total solar energy generation by countries.

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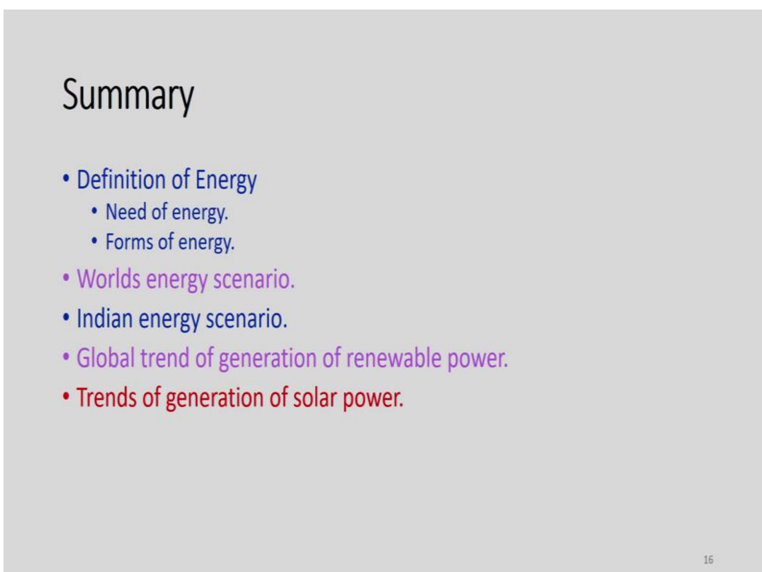

So, we can summarize what we have discussed today. We have primarily discussed about the definition of energy, the need of energy and what are different forms of energy, and where these different forms can be applied. And also we have discussed about worlds energy scenario, then Indian energy scenario. Then global trend of generation of renewable power and finally we have discussed about trends of generation of solar power.

So, I hope you have enjoyed this lecture. Thank you for watching this video.