Physics of Renewable Energy Systems
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Lecture 18
Introduction to Tidal Power

Welcome, till now we have been talking to you about the energy generation using renewable based sources such as solar, wind, and water. Let us now try to move to the remaining two topics which we plan to cover in this course, that is use of tidal power and geothermal power, which are two of the emerging technologies that I hope will be exploited in future and they will become quite prevalent all around. So, in today's lecture, let me give you a brief introduction towards the tidal power.

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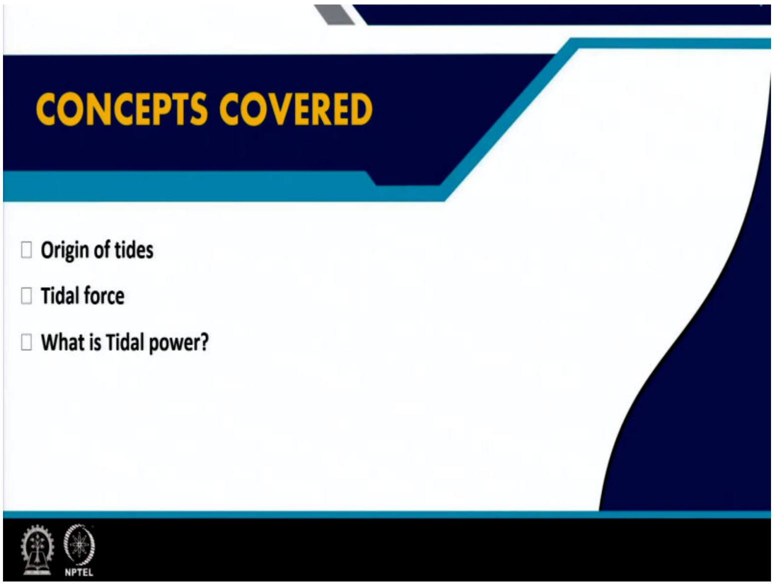

And we will try to cover the following topics over the next half an hour or so, we will revise the origin of tides, most of us have been reading and understand what is the origin of tides. So, we will quickly revise it. What is the tidal force that can be used to generate tidal power? These are the three main topics which I plan to cover in this lecture.

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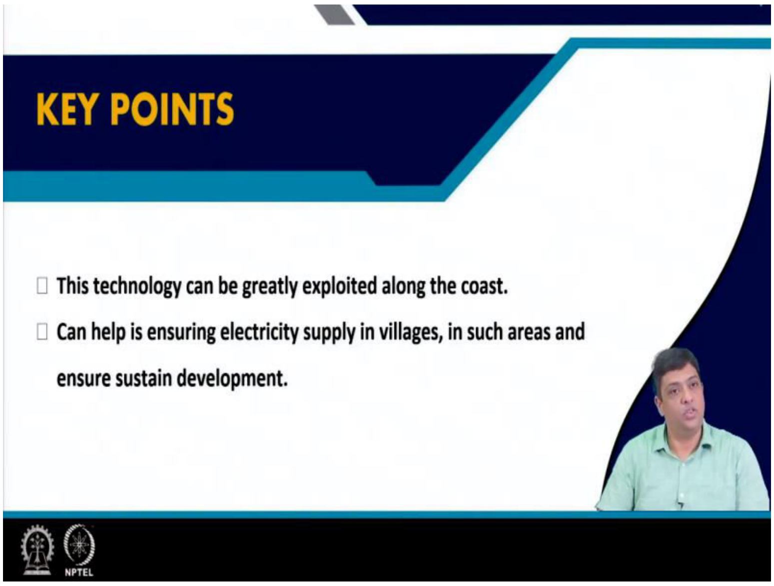

By the time I finish this lecture, I hope I will be able to convince you that this technology can be greatly exploited all along the coastline of our country and if we are able to implement these technologies, then we can ensure availability and security of electricity supply in villages, which are still not connected to the national grid and are lying near to the coastal belts of our country.

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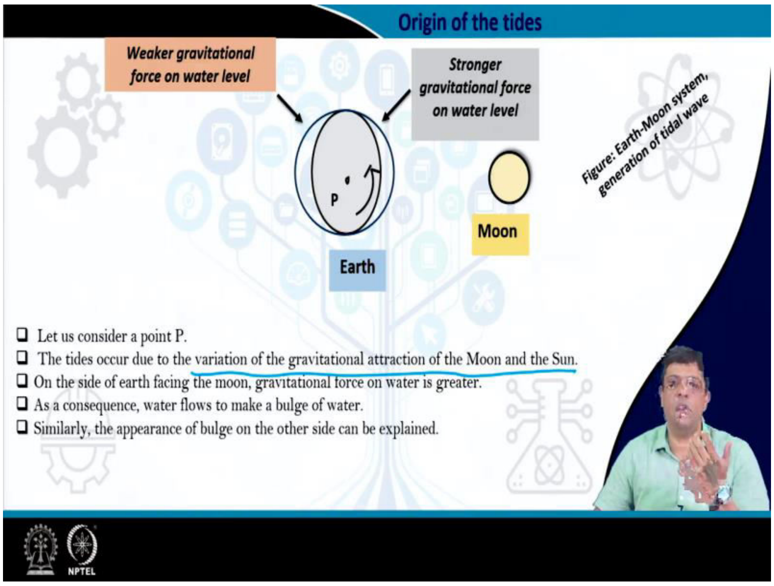

Let us start with a quick revision on the origin of tides. As we know the origin of tides occur due to the variation of gravitational attraction of moon and the sun. For example, let us take Earth and then we have Moon. So, on one side Moon is facing the Earth surface and the other side the moon is away from the surface.

And the side which is facing the Moon, you know that the gravitational force on water is greater because of this enhanced gravitational force what happens, the flowing water makes a bulge, makes a bulge and similarly, you will find that the appearance of bulge on the other side can also be explained.

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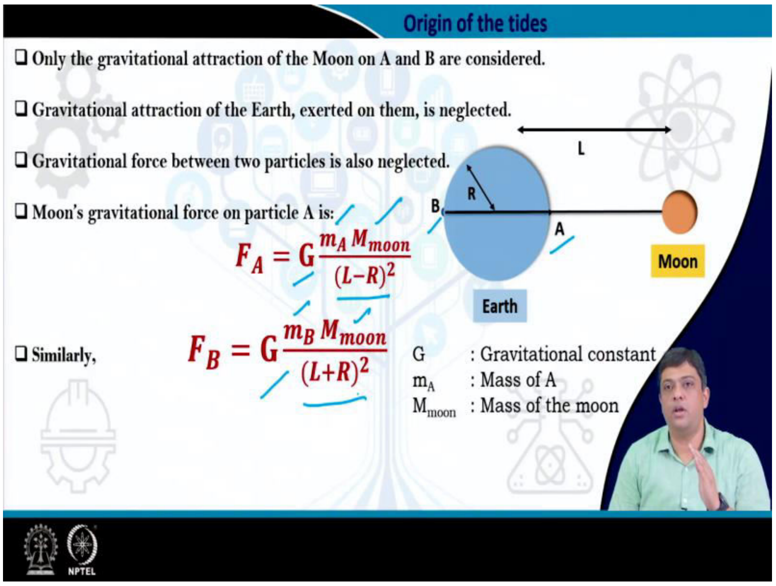

Let us try to give you a mathematical model and you will be able to understand the concept very clearly. Let us take two points A and B, A and B on the Earth's surface and for the discussion which is relevant to us, let us consider only the gravitational attraction by moon at these two points and the gravitational attraction of the earth exerted on them is neglected.

Also, the gravitational force between these two particles is also negated, using the formulations which we have studied in school, what is the moon's gravitational force on a particle A, it will be given as G m_A M_{moon}, divided by L minus R whole square.

Similarly, you will have the gravitational force, which you will observe at point B given as G m_B into M_{moon} divided by L plus R whole square, where R is the radius, L is the distance from the moon to the points which you are considering. G is the gravitational constant, masses of at point A and B can be written as m_A or m_B respectively and capital M subsequent moon is the mass of the moon we are considering.

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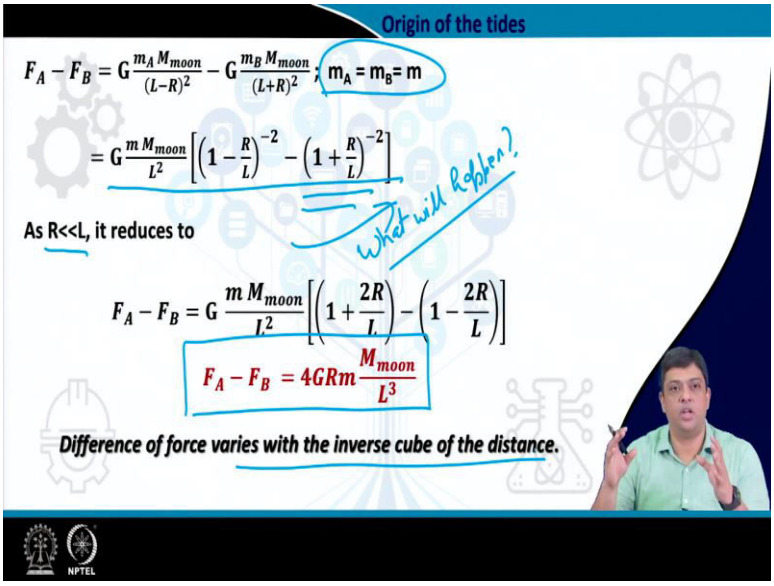

Take the difference F_A minus F_B, you will obtain can be written as G into m into M moon by L square into 1 minus R by L raised to the power of minus 2 minus 1 plus R by L raised to the power of minus 2 and you have considered the condition that m_A is equal to m_B is equal to m. If R is much much smaller than L, what will happen to this equation, what will happen to this equation, you will find that this equation reduces to F_A minus F_B is equal to 4 into G into R into m into a factor M moon by L cube.

So, you see what happens, the difference of the force which is observed or encountered at point A and B varies with the inverse cube of the distance. So, now we have found two points on this earth surface and now, we have also estimated the difference of the force which is encountered at the two points, if considering the gravitational force of the moon.

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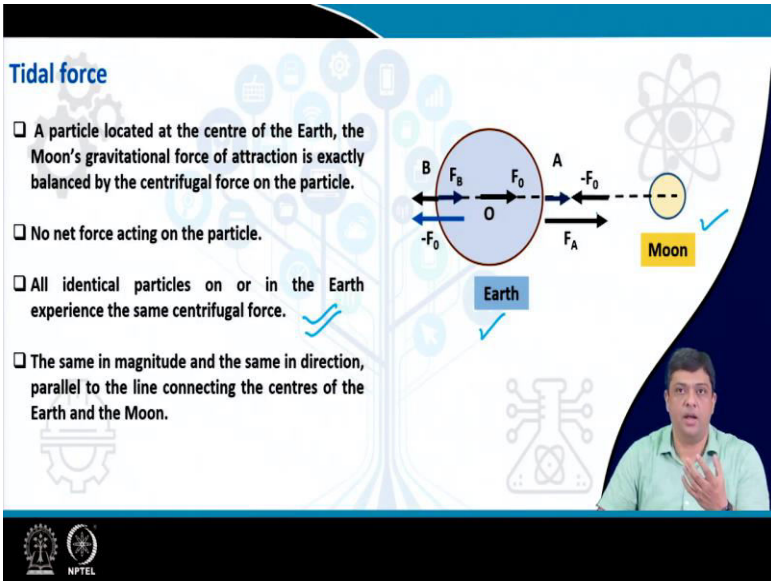

Let us continue. Now, what happens, the moon's gravitational force of attraction is exactly balanced by the centrifugal force of the particle. So, the result is no net force is acting on the particle and if you are considering all identical particles on or in the earth, then they will experience the same centrifugal force.

As a result, they are same in magnitude and same in direction, parallel to the line connecting the centres of the, parallel to the line connecting the center of the moon and the center of the earth. So, you have a line which is connecting the center of the Moon and the Earth and the force which you are going to experience would be same in magnitude and same direction.

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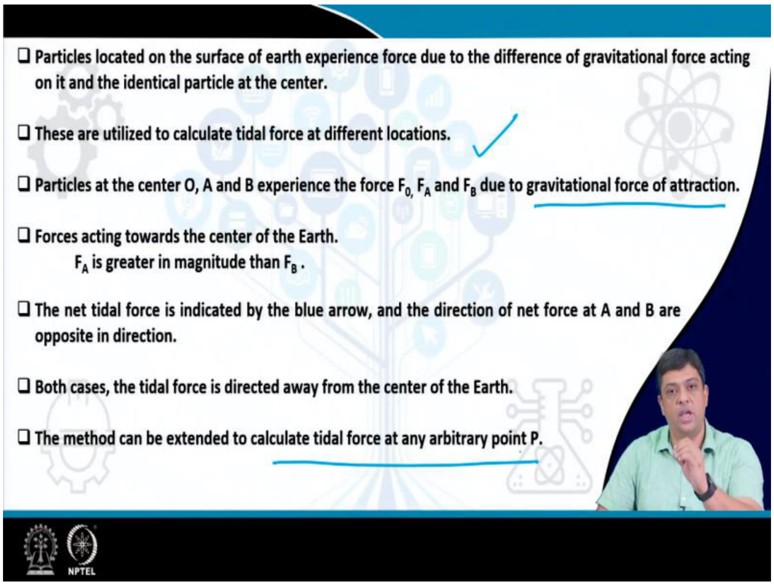

But you have chosen two points A and B which are separated from each other. So, what happens, these two points can be utilized to calculate the tidal force at different locations. Let us say we consider particles at the center O, A, and B. What will be the corresponding force they will be encountering?

They will be encountering the force F_0, F_A, and F_B respectively and this force will be due to what, this force will be due to the gravitational force of attraction. The force acting towards the center of the earth is F_0 and what you are also observed is F_A is greater in magnitude than F_B. What is the net tidal force? That is indicated by the arrows in the figure which was shown in the earlier slide.

And the direction of the net force at A and B are opposite in direction. In both the cases the tidal force is directed away from the center of the earth, away from the center of the earth. Now, we have a way to determine the tidal force which is acting on the particle on the Earth surface. This method can be extended to calculate the tidal force at any arbitrary point on the Earth surface and then you can find out what is the magnitude and the direction of the tidal force acting at that point.

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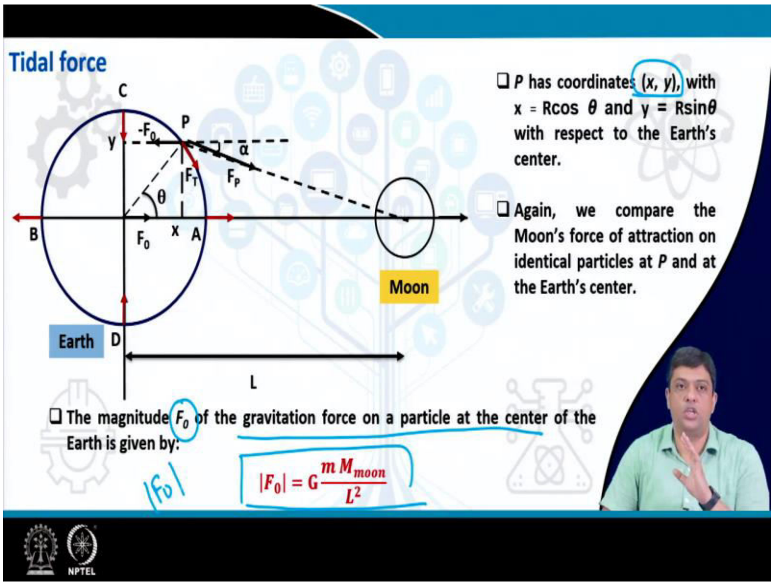

Similar calculations can be obtained if you choose any arbitrary point which can be having a coordinate x and y and, again you can repeat the process and compare the Moon's force of attraction or identical particles at P and at the earth center, you can clearly see using the same formulation which we discussed in the previous two slides, you will find that the magnitude F_0 of the gravitational force on a particle at the center of the earth is given by what, is given again the magnitude and that is why we are writing magnitude is equal to G into m into mass of moon divided by L square.

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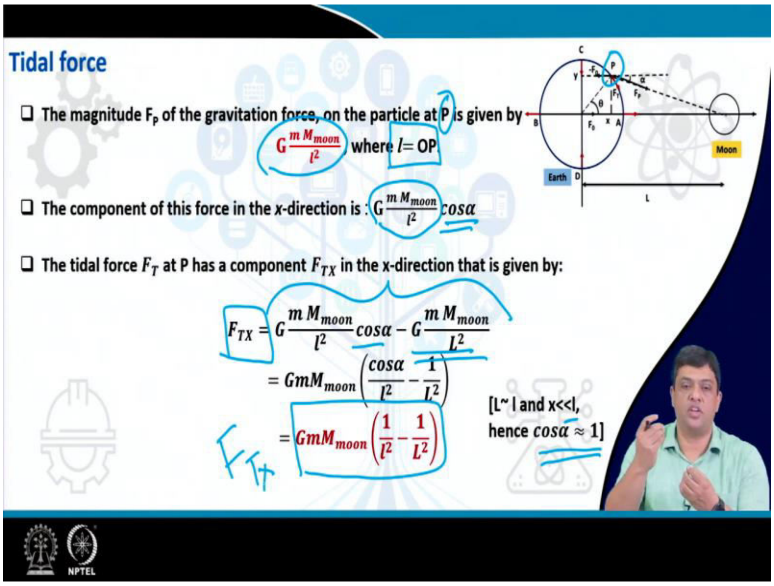

Now, we are determined at the center of the earth and the second point was what, we were planning to find out the magnitude at any other arbitrary point on the surface of the earth. Here, we have chosen the point as P, arbitrary point P on the surface of the earth. You will get the magnitude F_P is given by Gm into M moon divided by l square, where l is equal to that distance OP. Now, let us see what is the component in the x-direction.

The component of this force in the x-direction is given by G into m into M of moon divided by l square into cos alpha. The tidal force F_T at P has a component F_{TX} in the x-direction that is given by the relation F_{TX} is equal to G into m into M moon by l square cos alpha minus the second term that is G m into M moon by L square.

If you consider L is approximately equal to small l and x is much much smaller than l, then cos alpha is approximately equal to 1 and then you will get F_{TX} is equal to G m M moon into 1 by l square minus 1 by capital L square. Now, we have extended the initial calculations to determine the tidal force at any arbitrary point P on the surface of the earth.

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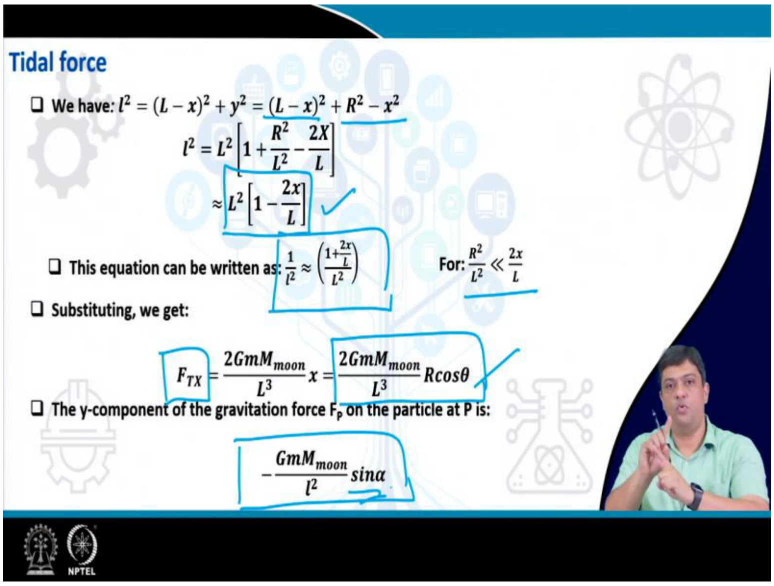

We have what we know that l square is L minus x whole square plus y square, that is equal to what, L minus x whole square plus R square minus x square. This reduces to the term that small l square is equal to capital L square into 1 minus 2 x by L. This equation can be written as 1 by small l square is approximately equal to 1 plus 2x by l divided by L square, for R square by L square is much much smaller than 2 x by capital L.

Substituting what do we get, we get at F_{TX} is equal to 2 G m into M moon by L cube into R cos theta and similarly, you will find that the y-component of the gravitational force F_P on the particle at P is obtained by minus G m M moon by small l square sine of alpha. So, we have a point and then you have taken the x-component and the y-component.

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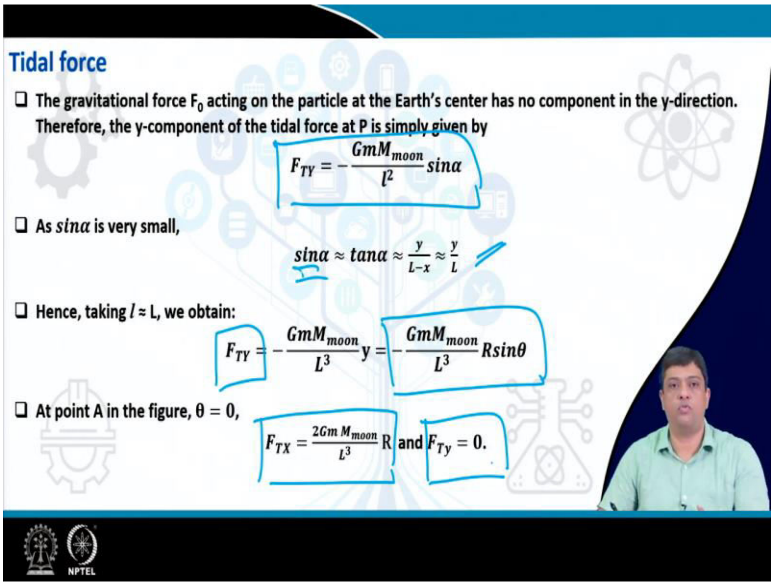

In addition, what have you seen, we have already found out that the gravitational for F_0 acting on a particle at the center of the Earth has no component in the y-direction, you are talking at the center of the earth. Therefore, the y-component of tidal force at P is simply given by F_T is equal to minus G m M moon l square sine alpha. As sine alpha is very small you can write sine alpha is approximately equal to y by L.

Now, approximating the relation that small l is equal to capital L, we get the relation F_{TY} is equal to minus G m M moon by L cube into R sine theta. At a point A in the figure which is used to derive this mathematics, theta is equal to 0. Therefore, what you get F_{TX} is equal to 2 G m M moon divided by L cube into R and F_{TY} is equal to 0. So, now we have also found the components.

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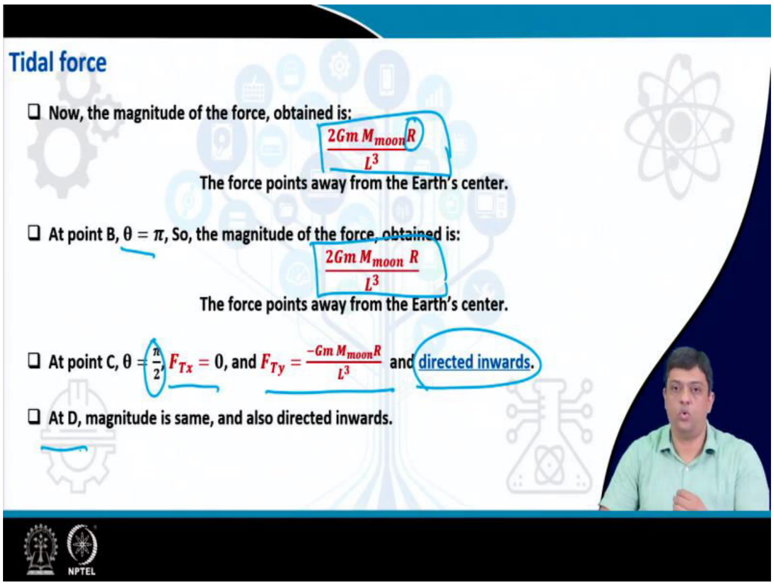

Hence, the magnitude of force is obtained as twice G m M moon divided by L cube into R and the force points away from the center of the Earth. At point B, if you want to see the figure earlier you will point A, B, and P and at the center is O. At point B, theta is equal to pi that is the relation. So, the magnitude of the force will be what, it will be given at 2 G m M moon R by L cube and the force points away from the earth center.

Similarly, at let us say point C, theta is taken as pi by 2, then F_{TX} is 0 and F_{TY} turns out to be minus G m M moon R by L cube, but directed inwards. Similarly, if you take the opposite at point D, the magnitude is same and also directed inwards. So, you can choose the whole idea to explain this exercise is that you can choose any arbitrary point on the Earth's surface and you can find out what is the force which is acting at that point on the Earth's surface, when you consider the gravitational forces of moon acting at those points.

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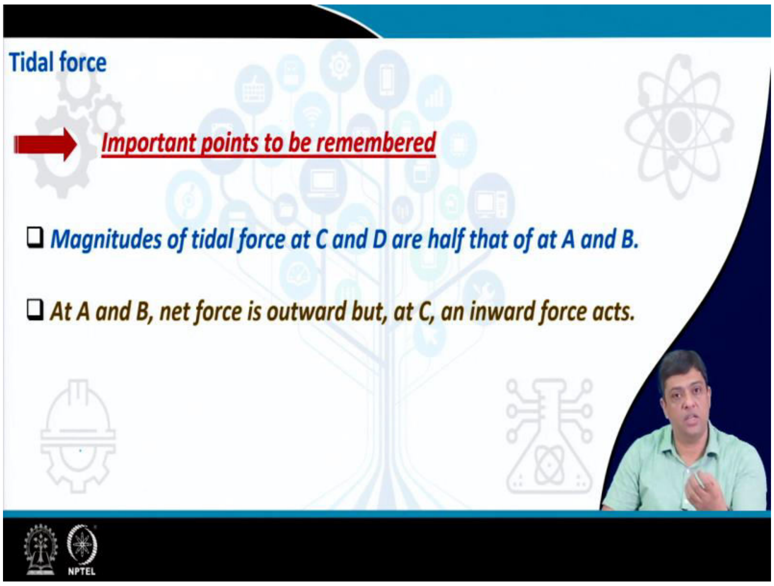

From these two calculations, please immediately realize that the magnitudes of tidal force at C and D are half that of A and B and at A and B the forces are acting outwards whereas, C and D the forces are acting inwards. So, these are the two inferences which you can draw immediately from the calculations we have done till now.

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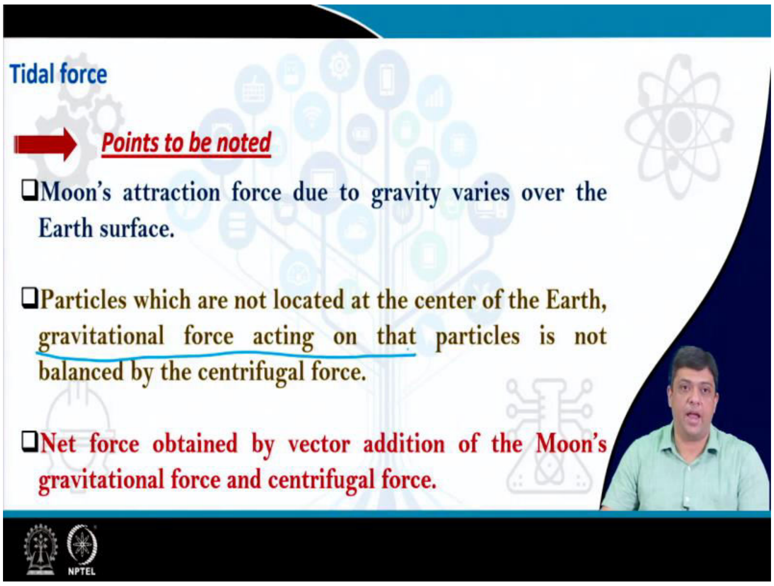

Along with that, what we consider till now, we are considered that moon's attraction force due to the gravity varies over the Earth's surface, why because we are changing the distance L. Particles which are not located at the center of the earth have the condition where the gravitational force acting on them is not balanced by the centrifugal force. Therefore, the net force is obtained by what, by taking the vector addition of the moon's gravitational force and the effect of the centrifugal force which act on them.

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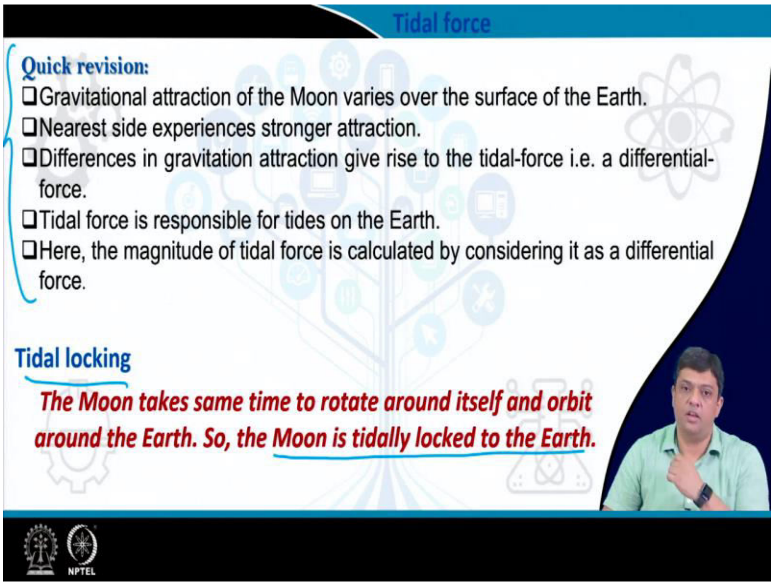

And the same thing has been again explained here in this slide. But please note that there is an additional concept which we will be talking many times that is tidal locking and this means, that the moon takes same time to rotate around itself an orbit around the Earth. So, this is some time said as if the moon is tidally locked to the earth. So, this is the additional term or concept we will be mentioning at few places.

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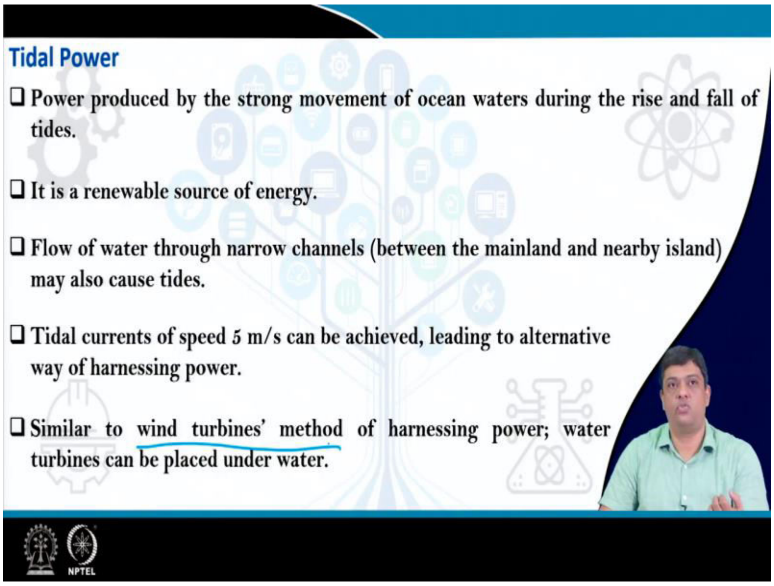

Now, we have seen that because of the gravitational forces acting on the particles at different points on the Earth's surface, the force experienced by a particle is different. Now, if you consider the Earth's surface you find at most of the places you have water. Now, if you consider water and as you consider different points on the Earth's surface, now you calculate the gravitational forces of moon acting at different points on this water particles.

Then as you move from one point or the other, then you will have the magnitude of force differing along with that, as you have places where the forces are acting outwards and places where the forces are acting inwards at the forces where the, places where the forces are acting outwards, you have the bulge in the water and that results in the origin of tides.

What is the origin of tide? Very quickly, the tidal force. Now, if I have force, I have movement. If I go back to my earlier discussion in wind or water-based systems, we had a flowing fluid and if we were able to ensure that there was a condition where the turbine was able to interact with this is flowing fluid and what was happening, we were able to extract power.

We have the same condition now here, we have the waves, force they are flowing, the only question is, can we now extract power from these tides which are coming in and this is what is called as tidal power. This is the power produced by the strong movement of the ocean waters during the rise and fall of the tides. Obviously, you are using water from the ocean, it is a renewable source of energy.

We can see that, if you have conditions where the flow of water is through narrow channels or bay, then they can also lead to the appearance of tides and once I have tides, if I am able to extract power from these tides, then it is called as tidal power and similar to wind turbine methods of harnessing power, water turbines will have to be used to extract this tidal power. And in the next lecture, we will focus more on the use of water-based turbines to extract this power.

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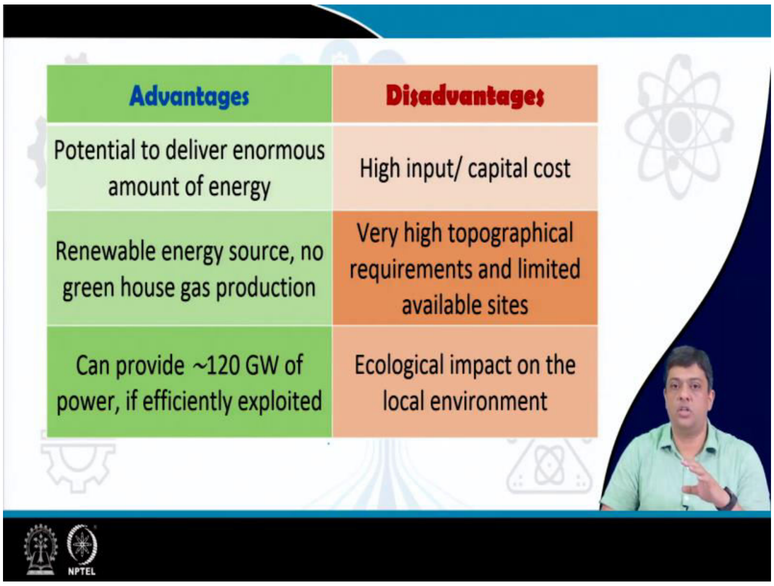

The major advantages and disadvantages associated with tidal power, which you should remember at this point and they will become clear after the next lecture are the advantages are very clear, you have potential to deliver enormous amount of energy. It is a renewable source, which is continuously available at places and can provide extremely large amount of power.

Disadvantages, you are venturing into technologies which are yet to get commercialized and have large scale implementation. So, a lot of new research and understanding has to be developed, before they become economically viable and their capital cost becomes acceptable to the society. The places where they can be installed are topographically quite different from the kind which we discussed for water or wind-based systems.

And because you are installing these technologies in places which are maybe inside the ocean or at the base, then the ecological impact could be quite serious to the local environment and hence, lot more understanding has to be developed before this technology becomes useful for large scale implementation. Off grid implementation and small-scale electricity generation could be the way forward for these technologies.

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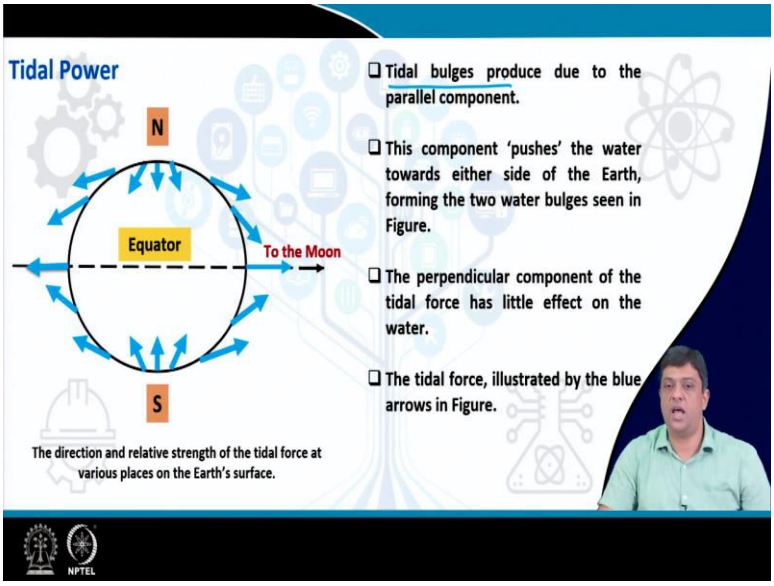

So, as we have seen, what are we going to do, we are going to talk about the appearance of bulge which is coming in because of the inward and outward forces experienced by water particles at the surface of the earth and driven by the fact that Moon's gravitational forces are acting on it.

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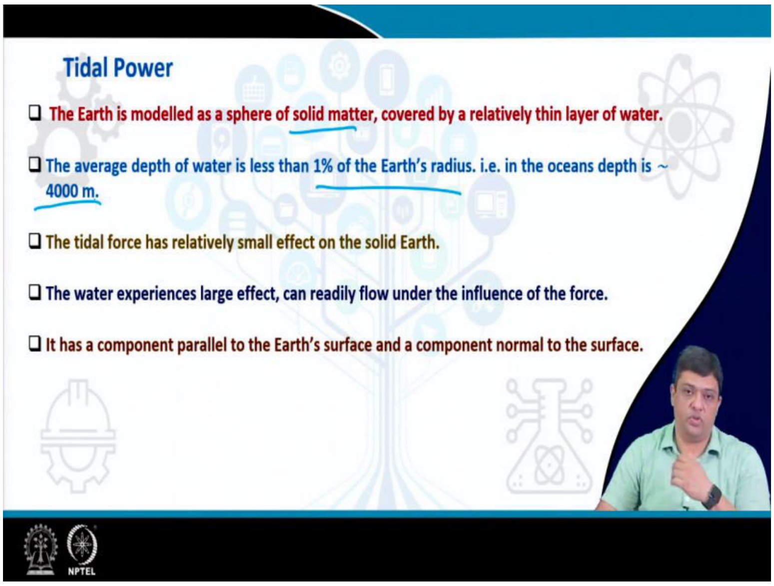

For extracting tidal power, what do we do? We model Earth as a sphere of solid matter covered by a relatively thin layer of water and the average depth of water is less than 1 percent of the Earth's surface. So, approximately 4000 meters. The tidal force has already relatively small effect on this order, because you are considering solid earth.

The water experiences large effect can be readily made to flow under the influence of a force and then you have various components which can be estimated, either component pattern or component normal to the surface of the earth.

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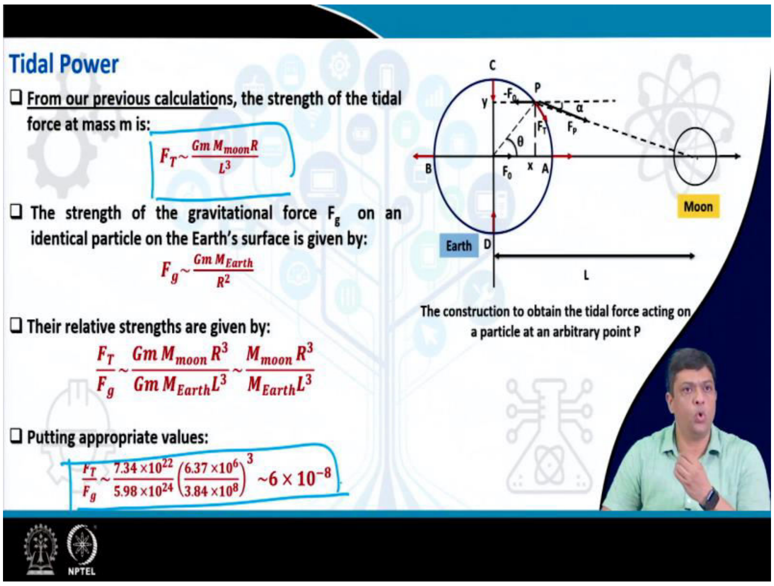

Similar to what we did in the earlier case, where we saw that F_T is equal to G m M moon into R by L cube, you can find out that the relative strengths or F_g an F_T is approximately equal to 6 into 10 raise to power of minus 8.

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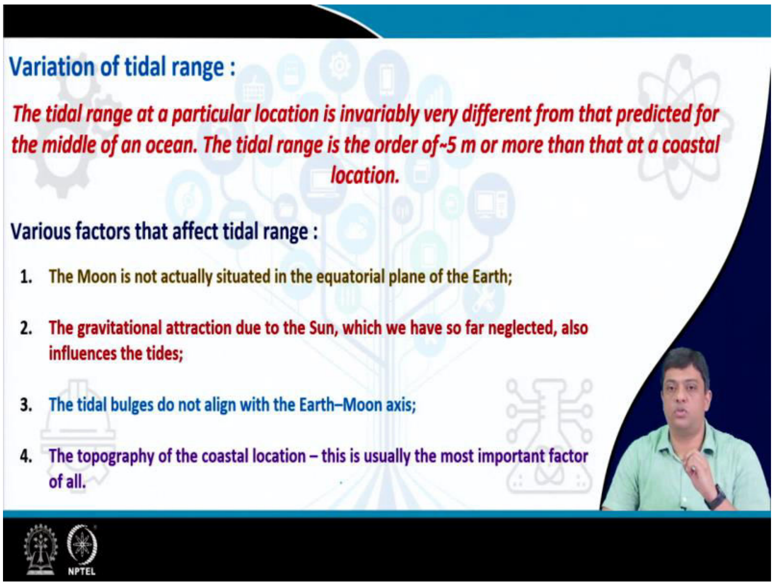

So, we have also now obtained the components which are there. As we move forward you should remember tidal force is negligible in magnitude compared to gravitational force. What we did just previous to this slide, we have estimated the ratio ft by F_T and what is the value you are getting? You are getting 6 into 10 raise to the power of minus 8.

Hence, the tidal force is negligible in magnitude compared to gravitational force. Therefore, the gravitational force does not have any parallel component. The parallel component of the tidal force is effective and results in the production of tides and these tides will therefore, be affected by different factors and they are that the moon is not situated in the equatorial plane of the earth.

So, you do not have a straight line which is coming in and you have additional angle considerations. The gravitational attraction due to the sun, which we have so far neglected also influences the tides, please remember and this has not been included in discussions till now. Because of the earlier conditions, the tidal bulges do not align with the earth moon axis.

So, what we saw that we took a straight line connecting the center of the moon to the center of the earth, this is a simplified picture and hence, the tidal bulges do not align with the earth-moon axis and the fourth point which affects the tides or the tidal range is the topography of the coastal location, how the topography changes and if you do not have the channels, which are small, then the nature of the tides will also change.

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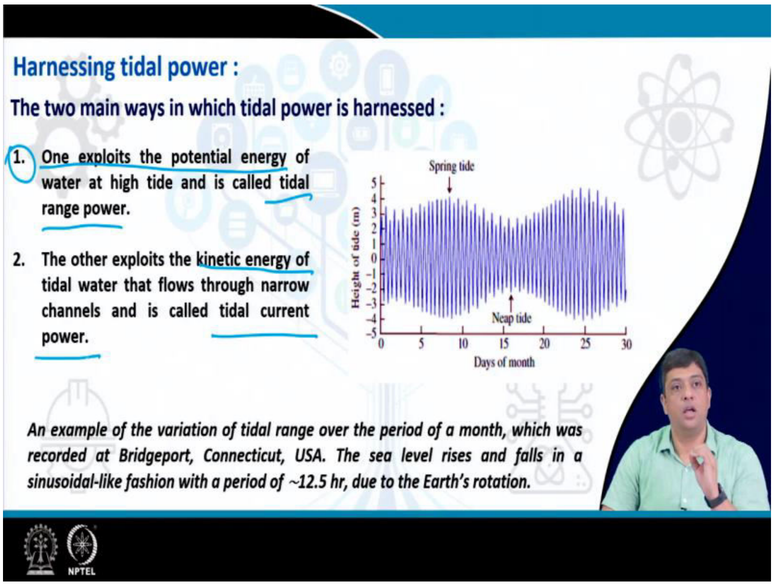

There are two main ways of harnessing tidal power, one exploits potential energy of water at high tide and that is called tidal range power. The second exploits the kinetic energy of the tidal water that flows through the narrow channels and is called the tidal current power. So, you have two components, one using the potential energy and second the flow. So, one using the potential energy height and second is related to the flow. So, two types tidal range power or tidal current power.

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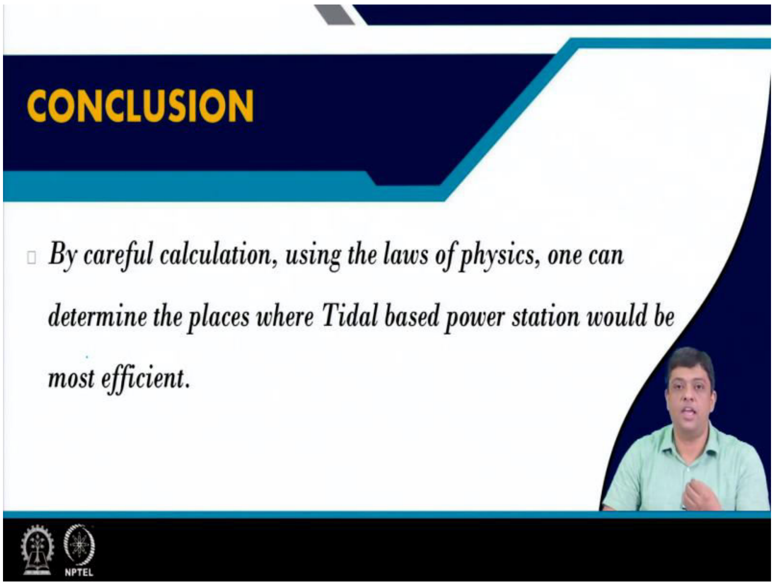

We will discuss these two more in detail in the next lecture and what we have done in today's introductory lecture is that we have shown you the calculations which are based on laws of physics and they prove that you can use tidal based power stations for electricity generation and they can be installed in places along the coastal line of our country. If the efficiencies of these tidal based power stations are increased and they are made economically viable and environmentally friendly.

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This is the major reference which was used to prepare today's slide. I thank you for attending today's introductory lecture on tidal power and in the next lecture, we will talk more in detail about this technology and we will finish the energy generation modules by giving you a brief introduction on geothermal power. Thank you very much and have a nice day.