Energy Resources< Economics and Environment
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Lecture 7 Part 1
Energy Resources- Part 1

So, we have seen the overall energy scenario. We have also looked at different ways in which we can do the energy economics calculations for projects. Now we are going to look at energy resources.

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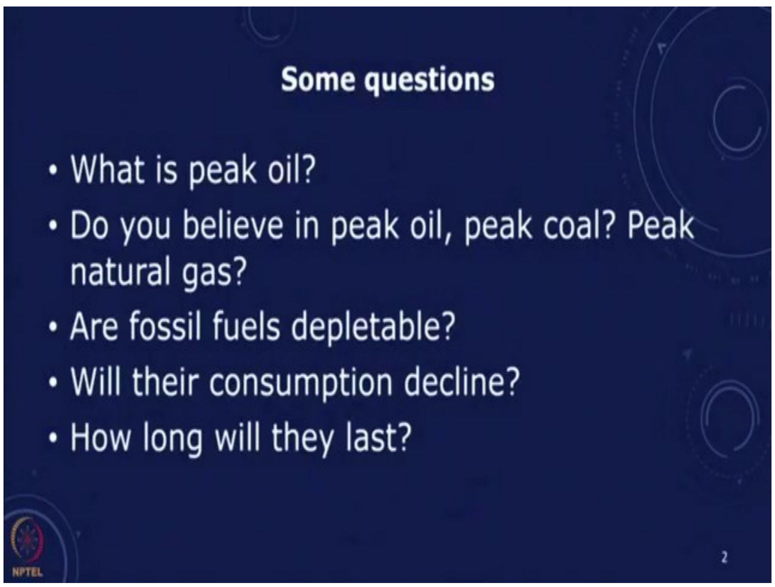

So, when we talk about energy resources, there are some questions which you may want to think about. We have heard you might have heard the term peak oil. So, what is this peak oil? Do we believe in peak oil, peak coal, peak natural gas? We all know and we have seen in our overall energy balance where we look at India or we look at the world.

That predominantly today our energy use is based on fossil fuels. So, the question that we want to ask is, are fossil fuels depletable, will their consumption decline? How soon will they decline? How long will the fuel fossil fuels last? And so, this is some of the things that we will consider. We will when we talk about resources, resources can be energy resources can be stocks or flows.

And in the initial part, we are going to talk about resources, which are stocks. Stocks mean that they will be, they can be stored, they can be transported. And then you have an estimate of how much we have, how much we have in terms of the resource and how long how much are we using annually. So, we want to get an estimate of how long that fuels would last.

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So, if you see, there is this interesting quote from the Saudi Arabian oil minister who said that the Stone Age did not end for lack of stone and the oil age will end long before the world runs out of oil. So, the estimation, the earlier calculations were where we would try to see how much stock is there.

At what rate are we using that stock and estimate how much time it will take and what has been said here is that it is all about dynamics, prices, substitutes, and it is not necessarily about these estimates. However, it is still worthwhile to see. Traditionally, we have this concept of the geological resources and reserves. How do we characterize it? How do we estimate how much time it will last if we have a certain consumption rate?

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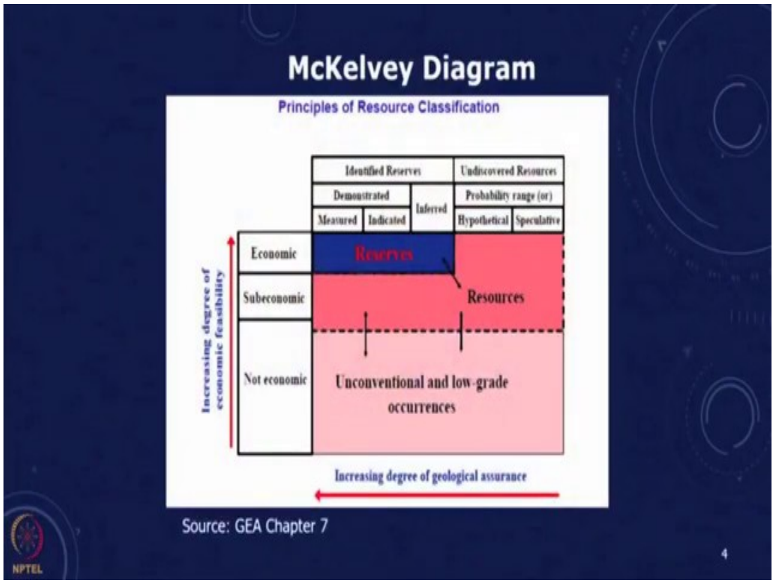

So, we have this is the McKelvey diagram. This is the diagram which was used and this is shows, this is the basics by which we classify the resources. So typically what happens is when we talk about fossil fuels or we are looking at materials which are stocks, we look at some areas where we have done some extractions and we know that these are the we have the in the case of oil, you will have a oil well dug and you will find that there is this percentage of concentration and it is viable to take the oil out.

So that would be something where you have actually conducted explorations. And we know that this is the kind of in this situation, we have the reserves. That means the reserves are known quantities and this could be which have been already measured. So, this is called proven. And then there is a second portion where you have done some sample wells and you know that; whole area has similar kinds of rock formations. So those will be called indicated and the third one is in similar areas, in similar formulations we expect that though we have not done any exploration, we think that it could be inferred that these will also help.

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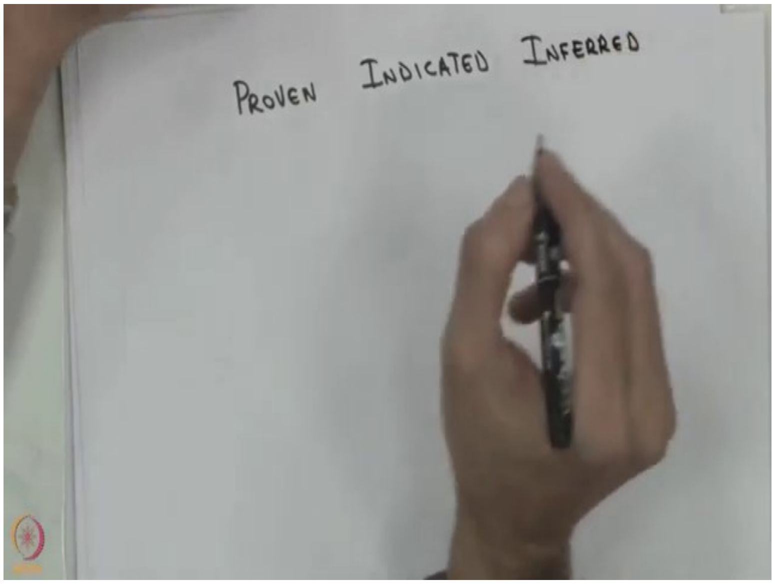

So, whenever we have these estimates, it is given in terms of proven, indicated and inferred. And the probability of occurrence is highest in the case of proven, we have actually measured and quantified, so we are quite sure that this is existing indicated with some lower probability and inferred with a, with even a lower probability.

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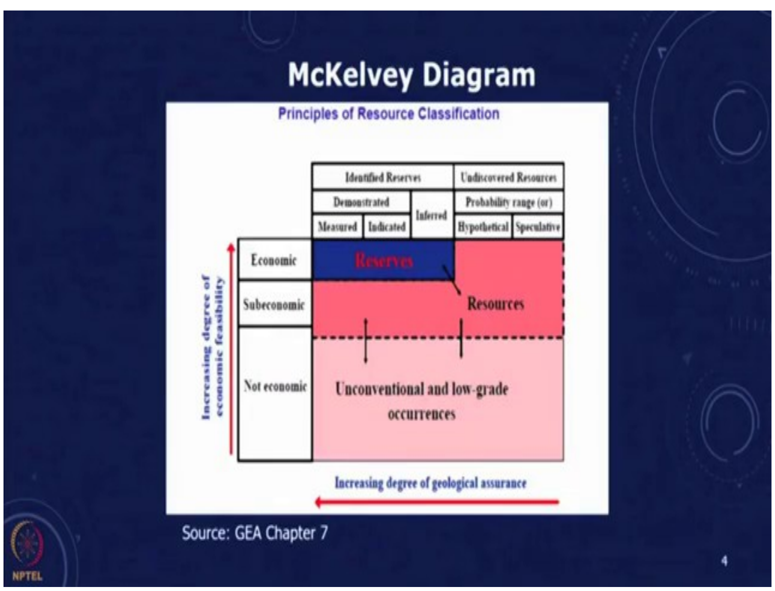

So, this is in terms of the resource, now there are also other undiscovered, there is this whole set where there are other undiscovered resources and which are hypothetical, speculative. And also, in these there are two axis. One axis is in terms of the probability, and the second one is in terms of the economic. So, reserves which are easily extractable with higher concentrations, the cost of extraction would be much lower.

So, they may be currently economic. As the technologies change, things which were not economic earlier can become economic. So, this, the between reserves there is this concept of reserves and resources, resources maybe known occurrences, but they are currently not economic to extract. So, resources is a slightly larger term which has a larger value and resources.

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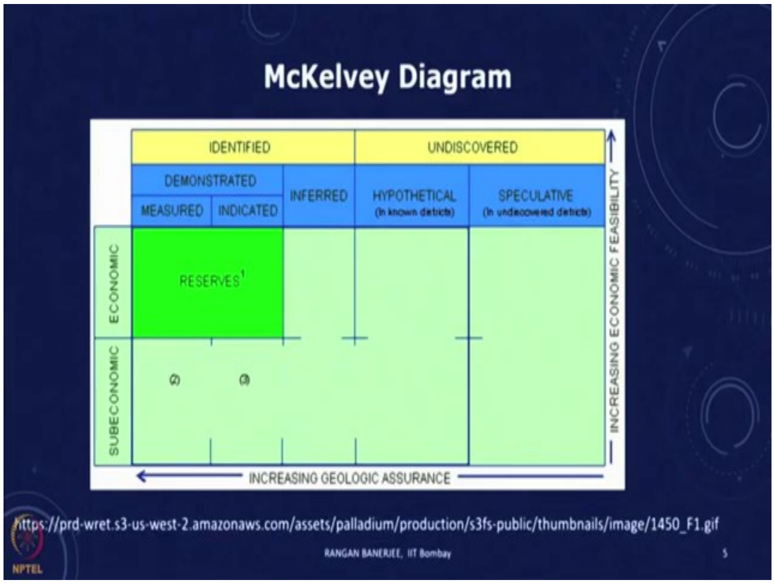

So, this concept of resources and reserves is shown in this classification, which is the McKelvey diagram and this is how it is plotted with the kind of increase as you go down, as you go up. It is the more economic the costs are lower and here this is the highest probability and lowest cost. And then you go for lower probabilities in this, on this side and you have higher costs going in this direction.

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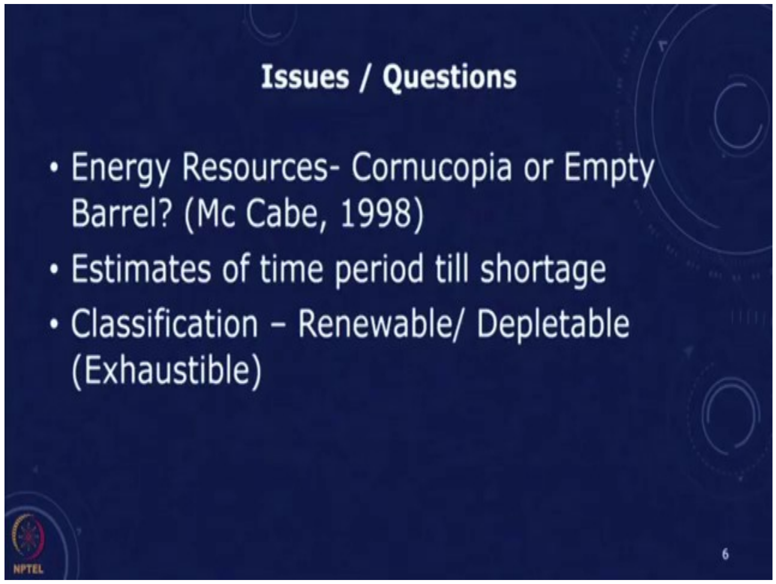

So, there are two kinds of beliefs about resources. One is that if we look at a finite amount of reserves, which is there in the ground and if we look at a finite amount of reserve and we know that we have a particular kind of extraction pattern, we can estimate then how much time that extraction will occur. So, if we have a finite reserve and we are talking of a stock.

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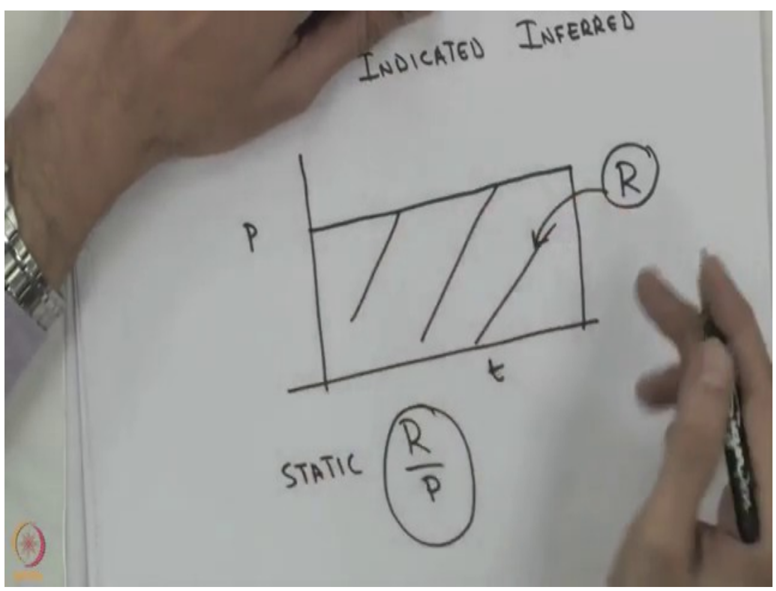

If we have a production in a particular year and we have t as a time and we have P and we say that, let the production be constant at the rate at which it is being consumed, then if we look at this area under the curve, this becomes a, the static we define a static R by P ratio or the R by P ratio, which is simply divide the total amount of known reserves and divide it by the production in a particular year, assuming that it is constant.

This will give us the number of years at which the resource will last at the current level at which we are consuming it. In many cases as we know where the population grows exponentially and the requirement for many of the fossil fuels, coal or natural gas, has been growing exponentially.

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1970	70 MILLION TONNES
2012	557 MILLION TONNES

For instance, if you take the example numbers, if you look at in India 1970, we use about 70 million tons of coal and in 2012, we used 557 million tons of coal. So, you can see very clearly that there is a exponential growth.

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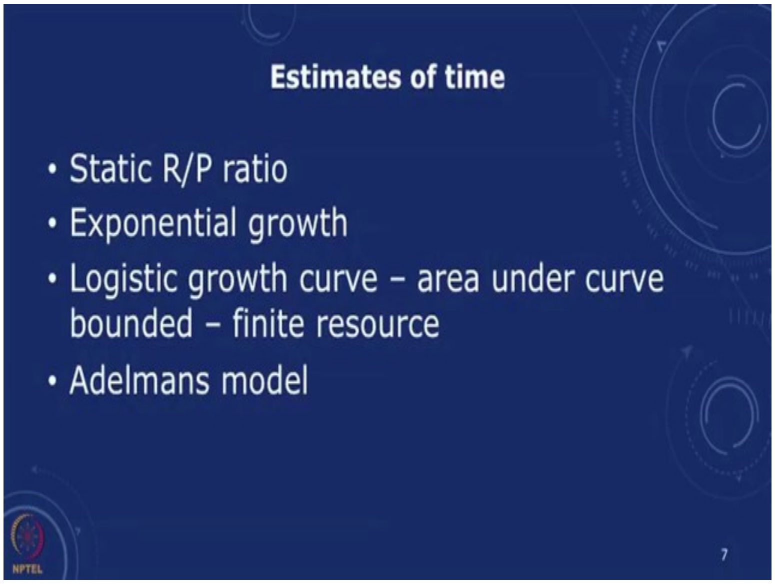

So, we are going to look at the following models. We will start with the static R by P ratio, which I have already discussed. We will look at the exponential growth model and then we will look at the logistic growth curve and where we take the fact that the area under the curve is bounded and yet there is a finite resource and then we look at Adelman's model.

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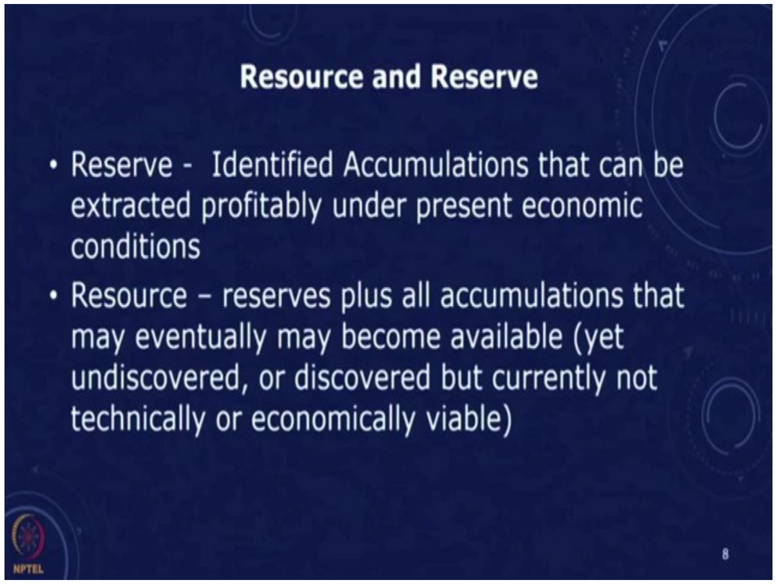

Again, this is the definition of the Geological Survey. The identified accumulation that can be extracted profitably under present economic conditions, that is the result and resources are the reserves, plus all accumulations that may eventually become available. They are, they may be today undiscovered but discovered but currently not technically or economically viable.

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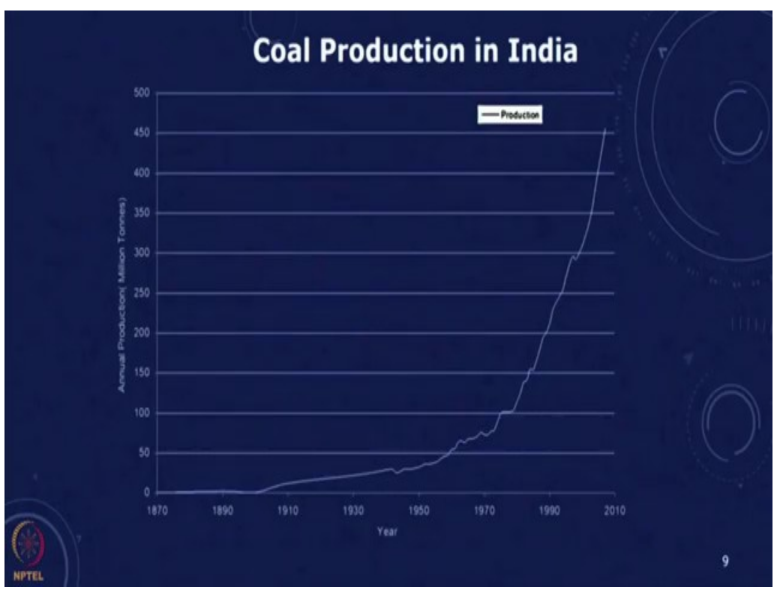

1970	70 MILLION TONNES
2012	557 MILLION TONNES

$$\frac{557}{70}=(1+g)^{42}$$

$$g \quad 5\%(0.05)$$

$$6-7\%/year$$

So, resource is greater than the reserve and if you see, this is you, I told you that we are going for an exponential growth rate for coal. It is been growing exponentially and if you see from the early years and this is the kind of growth, just to give you an example, as we said, if you take 1970 and 2012, we can find out what is the growth rate. We can just take 557 divided by 70 and calculate the compound annual growth rate, now 70 to 2012 is 42 years.

And you will find that this G corresponds to roughly 5% or 0.05. In the recent past, you will find that coal has been growing at 6 to 7% per year. So, the question is that if we think in terms of an exponential growth, then obviously that static R instead of the static R by P ratio, the number of years for which the coal will last would be much lower and we can do that calculation.

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Just to give you a sense of it, if you look at the coal mines and the coal resources, you find that most of our coal little bit in the central area and significant proportion in the east. These are where the coal mines are there, there are some in the north east, there are some lignite here in Tamil Nadu and some other. But this is where the distribution of the coal is.

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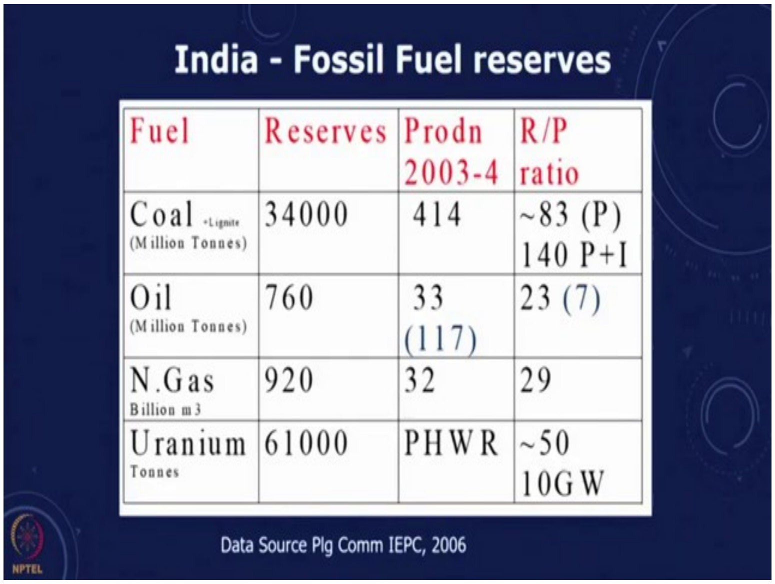
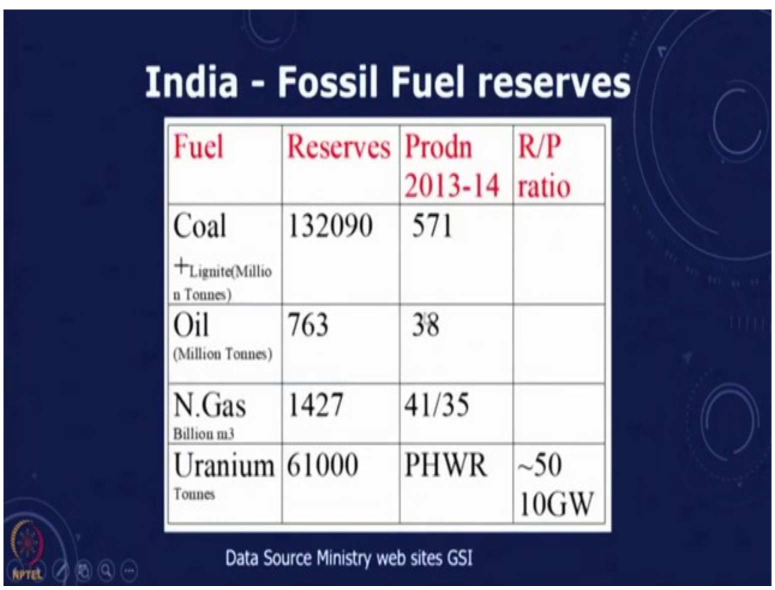


India - Fossil Fuel reserves

Fuel	Reserves	Prodn 2003-4	R/P ratio
Coal +Lignite (Million Tonnes)	34000	414	~83 (P) 140 P+I
Oil (Million Tonnes)	760	33 (117)	23 (7)
N.Gas Billion m3	920	32	29
Uranium Tonnes	61000	PHWR	~50 10GW

Data Source Plg Comm IEPC, 2006



India - Fossil Fuel reserves

Fuel	Reserves	Prodn 2013-14	R/P ratio
Coal +Lignite(Million Tonnes)	132090	571	
Oil (Million Tonnes)	763	38	
N.Gas Billion m3	1427	41/35	
Uranium Tonnes	61000	PHWR	~50 10GW

Data Source Ministry web sites GSI

Also, from the integrated energy policy document, this gives us a sense of what were the reserves which was there in 2003-4. You can see that the reserves were talking of 34000 million tons and the production was 414. If you divide these two, you get the R by P ratio of about 80. If we took proven plus indicated that R by P ratio goes up to 140.

That means that at the, at that level of production, this will last for about 140 years and similar things can be done for oil and natural gas. If you update these numbers, you can see that this is the number that you have in 2013-14 and we can calculate the R by P ratio for this.

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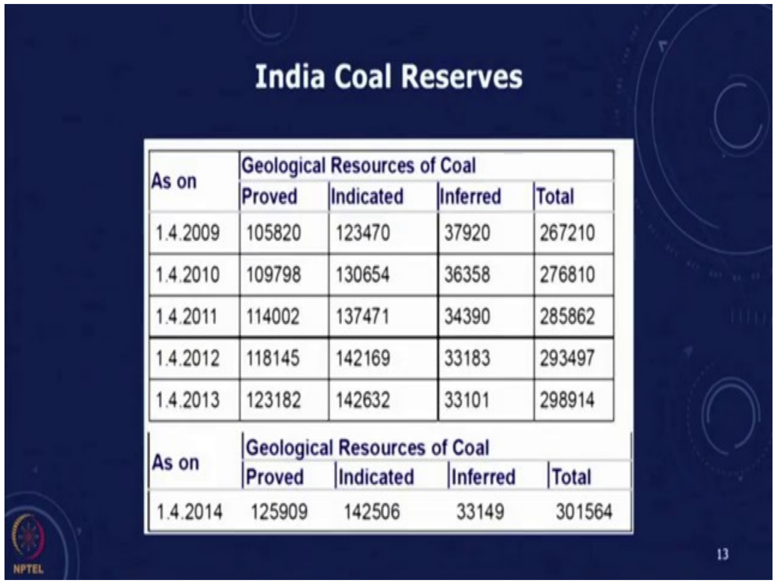

India Coal Reserves

As on	Geological Resources of Coal			
	Proved	Indicated	Inferred	Total
1.4.2009	105820	123470	37920	267210
1.4.2010	109798	130654	36358	276810
1.4.2011	114002	137471	34390	285862
1.4.2012	118145	142169	33183	293497
1.4.2013	123182	142632	33101	298914
1.4.2014	125909	142506	33149	301564

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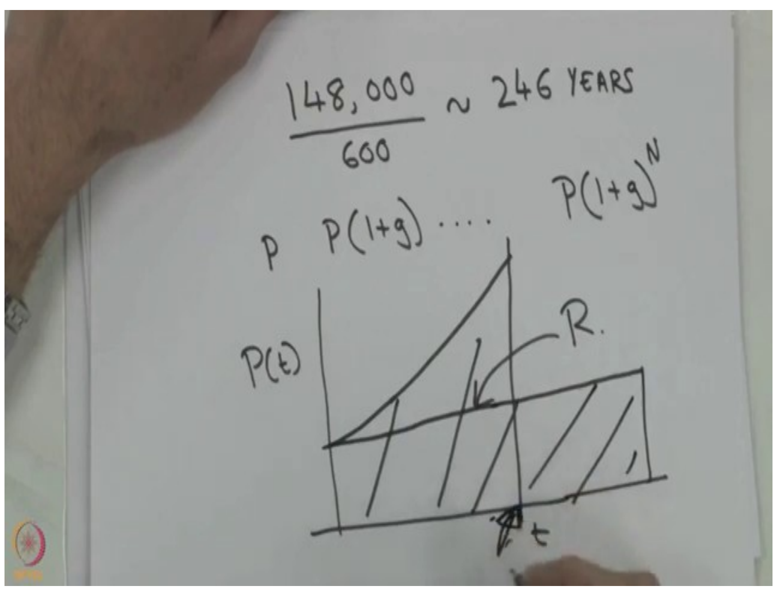

From the GSI if you look at it, you will find that over the years the proven reserves also keep increasing and today, if you see in 2018 values, I think it is of the order of about 148000 million tons. So, if we took 148000 million tons and if you look at this number of 148000 million tons and you divide that by the annual production, 148000 million tons of coal annual production roughly about 600 million tons of coal.

The number that we get static R by P ratio is about 200 years. So, we have a reasonable amount of coal, though, it is low grade coal. And of course, as we have seen, there is a problem in terms of the CO_2 emissions and so people we are talking about not using the coal. So, we would like to see now if we have an exponential growth rate, how do we make this calculation. So that means we are talking of let us say that this is growing at 5%.

Then what will happen is in the first year we use P, next year we use P into 1 plus G and so on. The P into 1 plus G raise to n. We want to find out n, the number of years in which the resource will get depleted. So that means here instead of that static we have P, and this is Pt by T. So, of course, you know that, you know, area under the curve for an exponential curve is not bounded.

But if we have a finite reserve then, this is R and we want to find out, what is the time, when this gets sort of cutoff. So, we have already calculated if it was a static, then it lasts for much longer. This is 246 years is what we had calculated. We want to now calculate what is this value.

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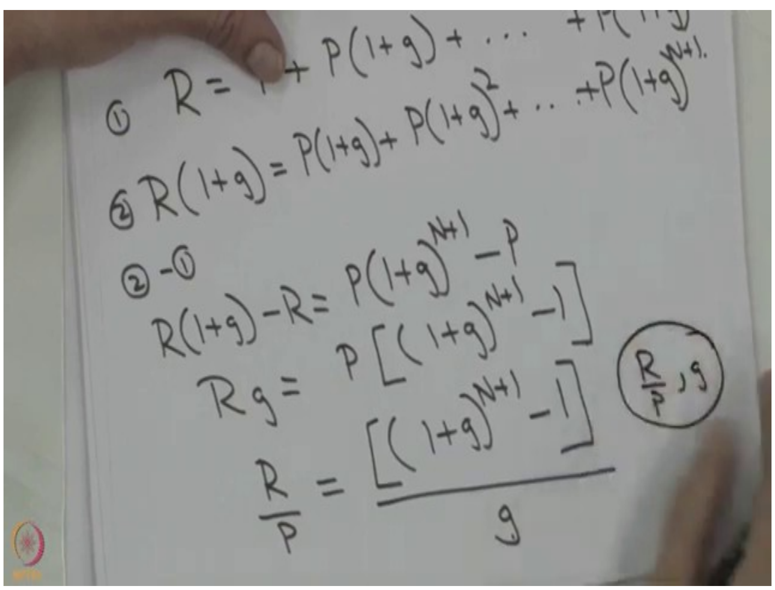

So, in order to do that calculation, we will take total reserve will be P, P 1 plus G raise to n so we can multiply this R into 1 plus g. The simple actually this is just a geometric progression. 1 plus g raise to n plus 1, we can take 2 minus 1 and we get R one plus g minus R is equal to P 1 plus g raise to n plus 1 minus P and this is nothing but R g is equal to P into 1 plus g raise to n plus 1 minus 1. So, R by P is equal to 1 plus g raise to n plus 1 minus 1 by g, if you look at this, we want to calculate n, this is what we want to calculate. We want to calculate n, we know R by P and we know g.

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$$g\left(\frac{R}{P}\right)=(1+g)^{N+1}-1$$

$$(1+g)^{N+1}=1+g\left(\frac{R}{P}\right)$$

$$(N+1)[\ln(1+g)]=\ln\left[1+g\left(\frac{R}{P}\right)\right]$$

$$N+1=\frac{\ln\left[1+g\left(\frac{R}{P}\right)\right]}{\ln(1+g)}$$

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We calculated for India for coal that R by P ratio was about was 246. And we said that let us consider the growth rate of 5%. We can of course take a higher growth rate so we can, suppose we take 5% then

$$N+1=\frac{\ln(1+0.05\times 246)}{\ln(1.05)}$$

$$¿\frac{2.59}{0.049}=53$$

$$N\quad 52$$

$$6\%\,N\quad 47\,YEARS$$

So, we of course, if we see the time, which we are talking of in this, is going to be lower than the time which we had calculated for the static R by P ratio. If we instead of 5%, if this is for 6 %, then you will find that the life will n will decrease and n turns out to be 47 years. So, remember we talked about a static R by P ratio and we also talked about the ratio if we are going at an exponential growth rate. Now, in actual practice, what will happen is we expect that the pattern will not be exponential and suddenly coming to 0.

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So, we expect this is similar to what Adelman had done but we have also this has been also done by Hubbert who was a geologist and he proposed the method, it is called the Hubbert model.