Energy Resources< Economics and Environment
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Lecture 7 Part 2
Energy Resources- Part 2

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Let us look at the critic of the finite resource constraint and this is the critic which is given by an economics Adelman, he says the total mineral in the earth is an irrelevant non-binding constraint if expected, finding minus development costs exceed the expected net revenues, investment dries up and the industry disappears. Whatever is left in the ground is unknown, probably unknowable, but surely unimportant geological fact of no economic interest.

So, it is not just, the reserves that we are talking of, only when it is economic and if it is viable then only it will be extractable. So, this whole calculation of the, this is a critic which says that the calculation of the reserves should not be necessarily then it depends on the costs and we will define that.

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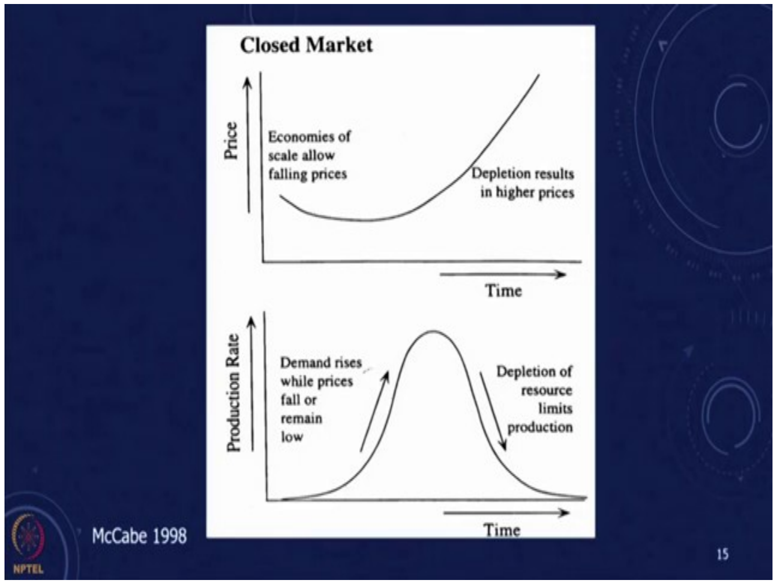

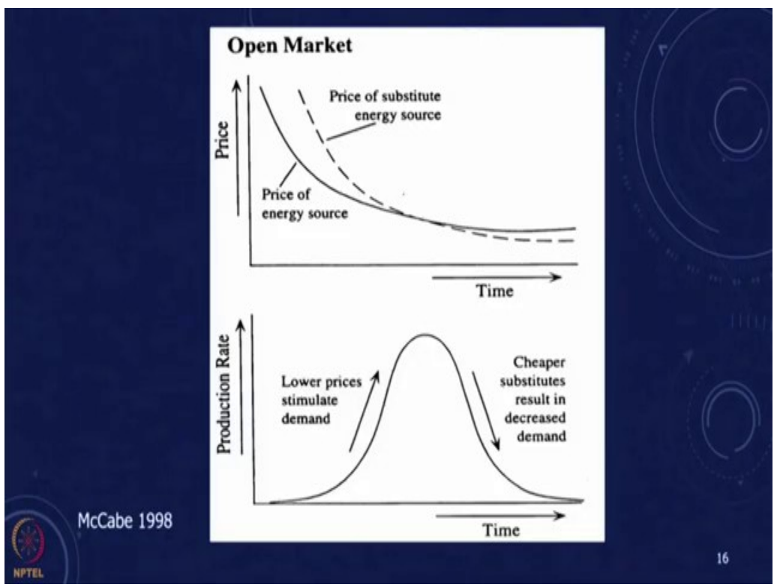

But just historically when we look at it, the static R by P ratio, the exponential ratio is something which is interesting to see. In the McKelvey's paper, he talks about two different models of any resource and you have a close market where initially because of the economies of scale, the prices can go down and then and depletion results in higher prices and as a result of this the demand rises while prices fall and then as the depletion goes up and then the production rate goes down. So, we expect a curve which will go through a maximum and come down and similar kind of thing is expected even in a case of an open market.

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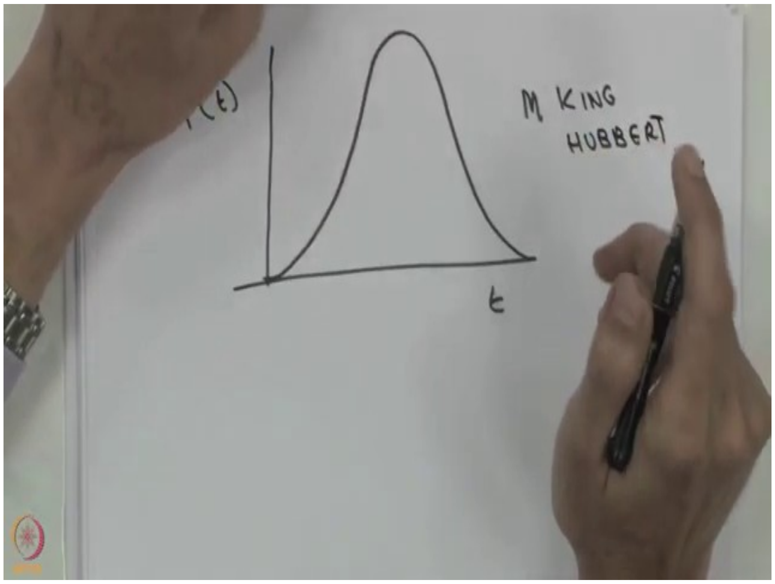

So, in all the cases, what we expect is that, we will have a bell-shaped curve Pt versus t, we will start from 0. Go to an oximum and come down and this is similar, this is essentially similar to the initial analysis which was done by M. King Hubbert, M. King Hubbert way back in the 1950s, 1960s was a geologist with the Geological Survey. This was a time when there was no concept of finite resources, and we were talking of coal and oil and gas being the main source where we are going to have a lot of innovation and development and growth and but he was the first person who talked in terms of a limit and a reserve and looked at this kind of a shape of curve.

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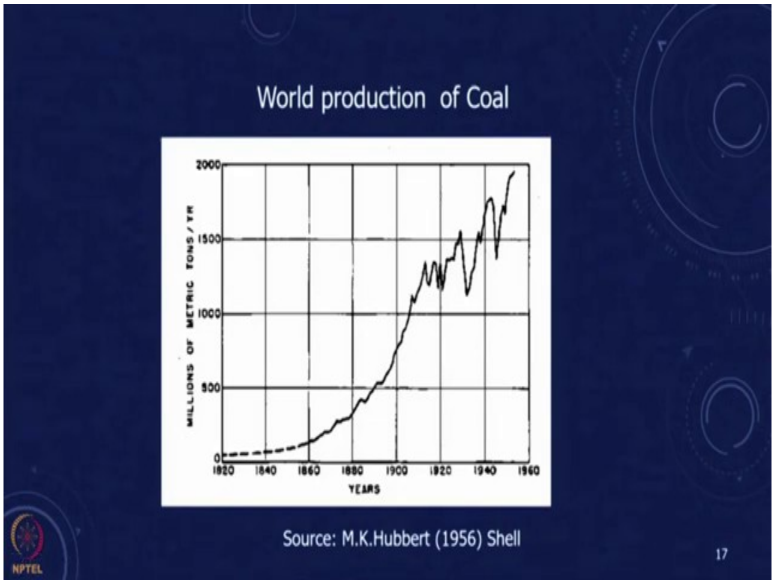

So, let us look at, we will upload for you the original paper and you can take a look at that. But his analysis showed, he made these kinds of plots with this was. So, if you see the plots, these plots all follow. This was the trend which was there in the till the 60s. We were looking at an exponential growth in all the resources. So, where we look at this is the world production of coal and you can see it start from a small amount and then it is been growing is fluctuation, but it is been growing exponentially.

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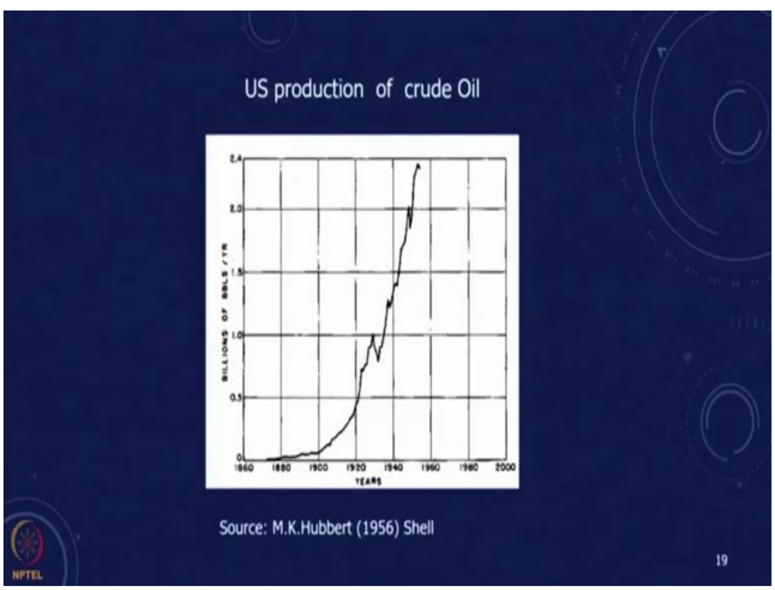

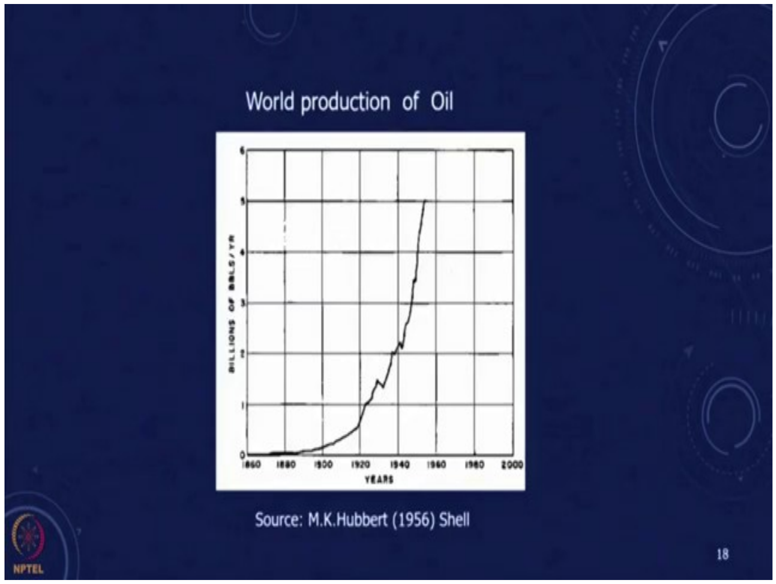

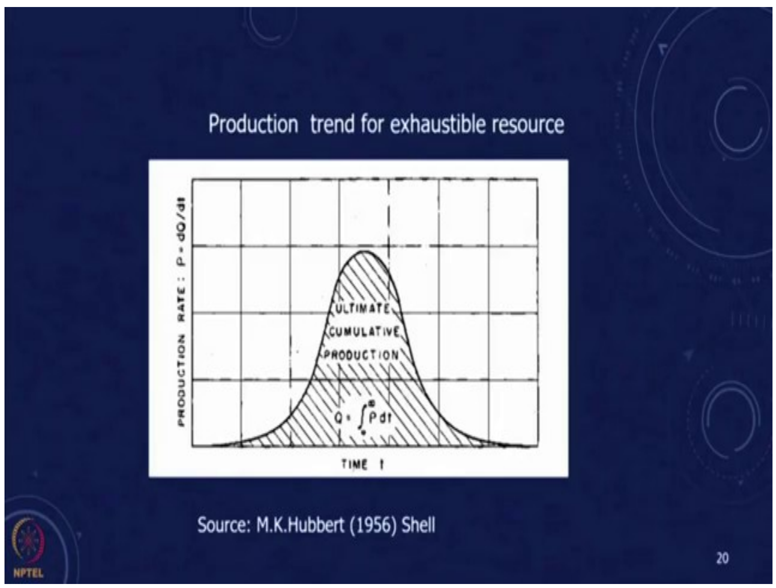

Similarly, the world production of oil, US production of crude oil and he postulated that the overall production trend for any exhaustible resource will follow this kind of a curve and then he said that let us take the total amount of reserves which is there which is called as skew infinity.

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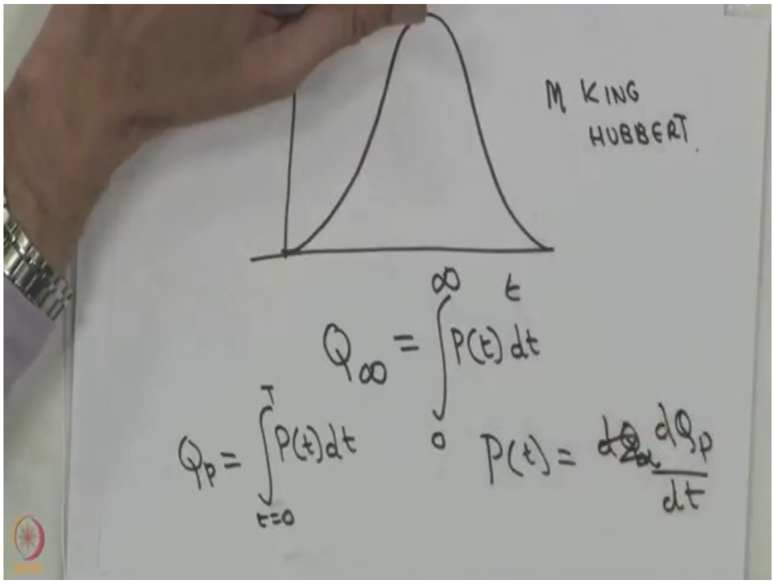

And if we take 0 to infinity of pt dt. This will give us the total amount of cumulative amount of reserves that we have and the production rate at any point of time pt will be dQ, dQp by dt. This is the Qp is the cumulative production from time t is equal to 0, t is equal to 0, to some time t.

So, it is the cumulative production and that cumulative production. When we look at that cumulative production the rate of the dQp by dt will be the production in the dt here. And what he did was this was in the period when we did not have the computers and the modelling capability.

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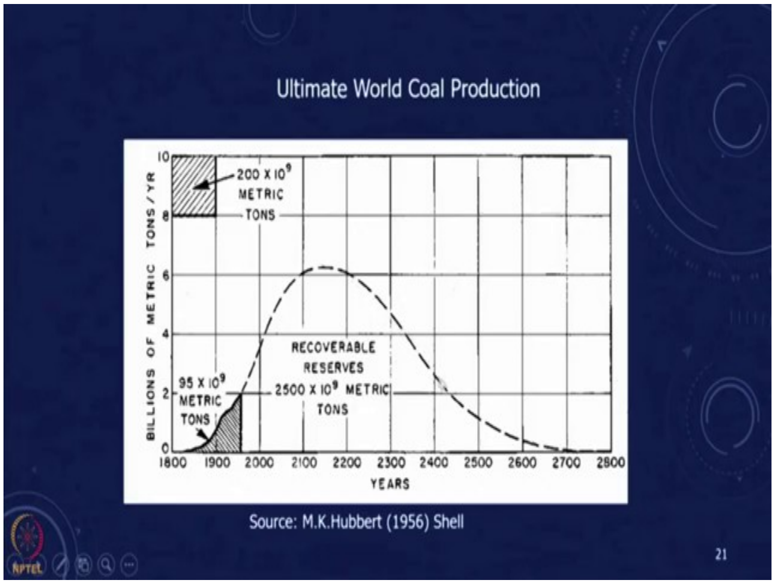

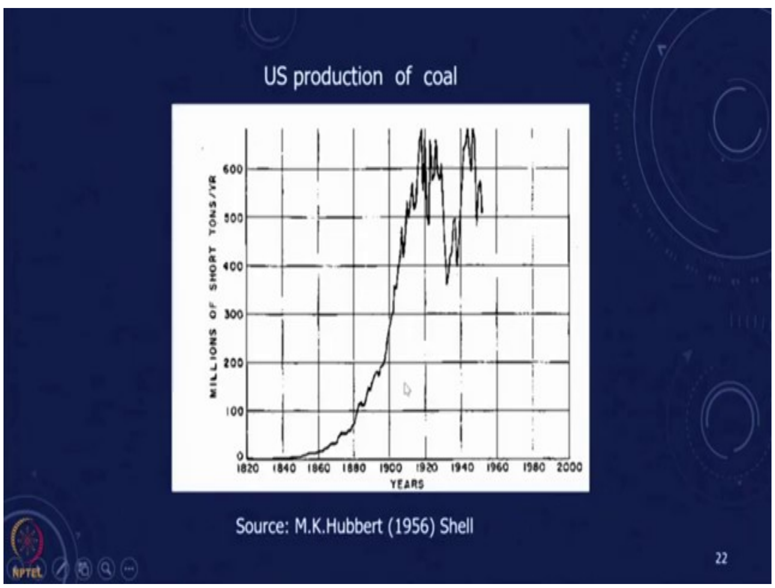

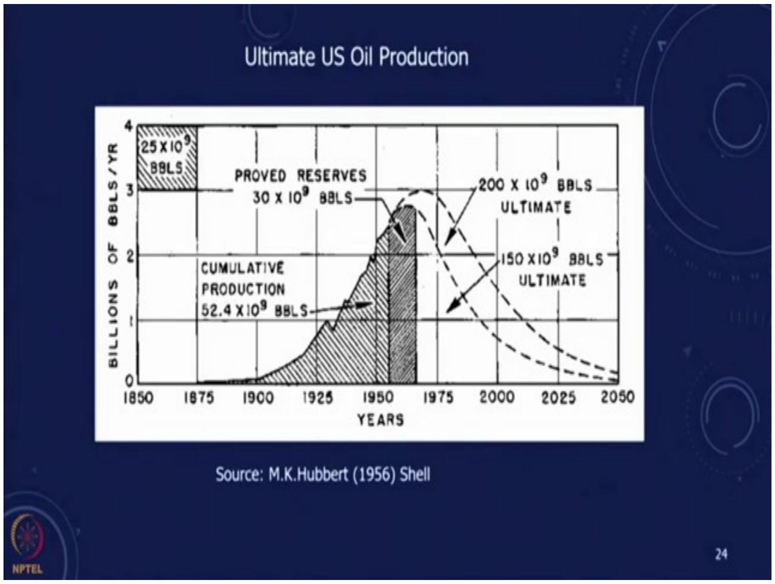

And so, he took essentially looked at these world fossil fuel reserves and he plotted the production and used it on a graph paper where the area under the curve would be the reserve and he estimated, based on the recoverable reserves estimate with this production fitted a curve of this type. And this is this is what he had done for world coal. And he had done this for US and he had done this for the world coal, world oil production. Interestingly, he projected the year in which the US. oil will peak.

And this is the whole concept, the beginning of this peak oil. And we projected it as happening in a particular year. And it actually happened within a few years of that. So, this is where his analysis in future showed that this is the kind of things. But this represents one of the earliest analysis where you have this limit. And today we can use this and we can plot a curve and we will do this. We will take this analysis, we will derive a curve for this and this will be like a logistic curve and we will see what is the year in which the peak occurs.

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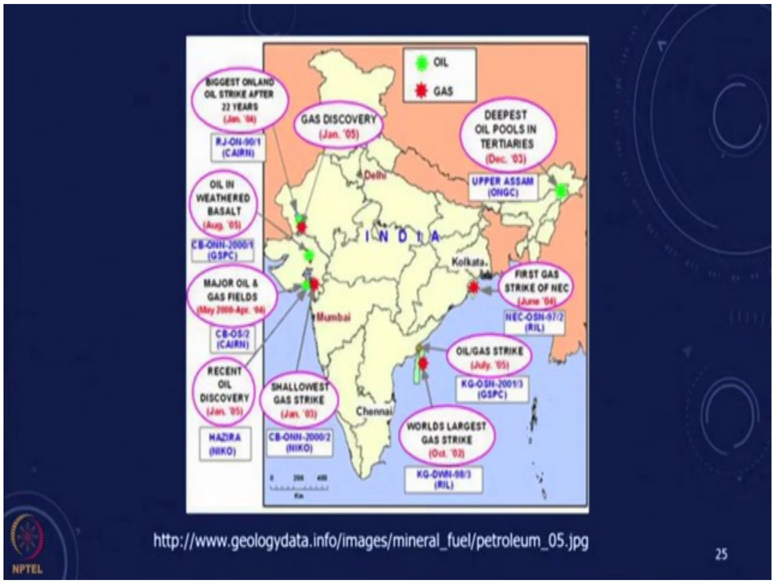

When we talk about oil, you will see that oil that we have is. Some of it is offshore and about half is onshore and we have certain needs distributed in certain areas. We of course, have relatively less amount of oil and production only met a small proportion of our total.

So, the R by P ratio, if you take the R by P ratio or the R by C where if you take the oil consumption, the R by C ratio, if you see it is really, really small and we do we really do not have oil for even more than a decade. If we are to meet the total consumption from the Indian resources. But of course, most of our oil comes in terms of imports.

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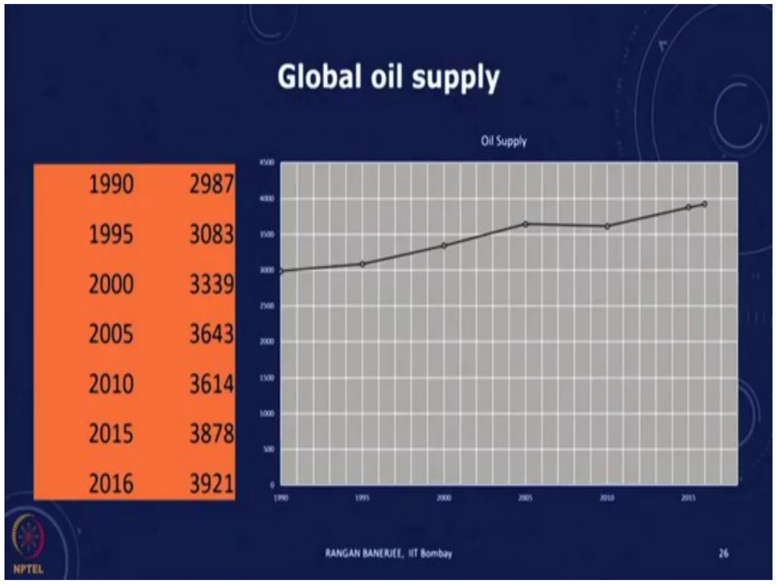
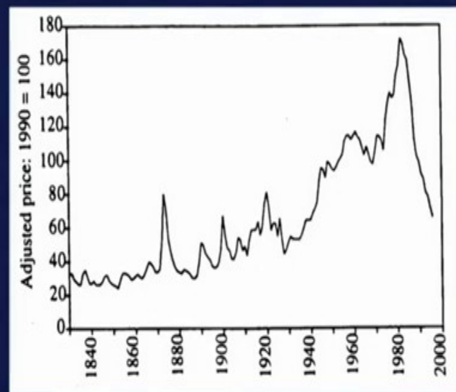


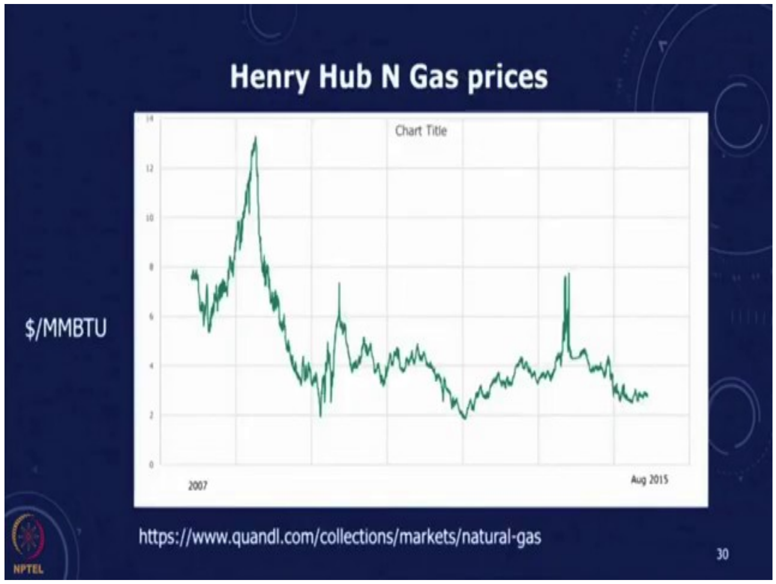
Coal Price Trend UK



McCabe 1998

Price Variations (Ngas- Germany)

https://www.destatis.de/DE/Publikationen/Thematisch/Preise/Energiepreise/EnergyPriceTrendsPDF_5619002.pdf?__blob=publicationFile


Henry Hub N Gas prices
Chart Title
$/MMBTU
2007
Aug 2015
https://www.quandl.com/collections/markets/natural-gas
30


US Coal Prices
COAL PRICE IN USD
$/short tonne
120
100
80
60
2010
2012
2014
https://www.quandl.com/collections/markets/coal
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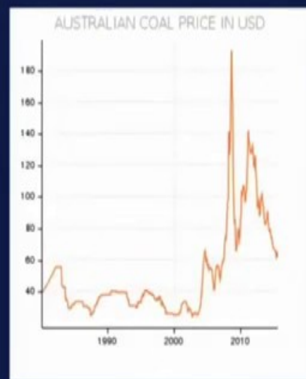
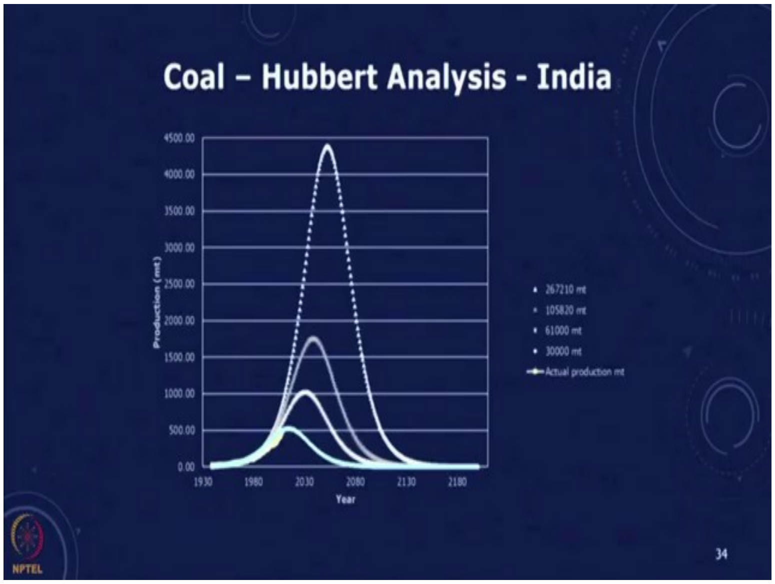
Australian coal Price

$/ metric tonne



https://www.quandl.com/collections/markets/coal

https://tradingeconomics.com/commodity/coal



Similarly, in the case of oil supply also you can see globally oil supply has been increasing. We can just take a look at some of the trends in prices of some of these fossil fuels. So, we look at the coal price trend. In UK, you can see the price variations in Germany, price variations in natural gas. So, there are fluctuations in these and then not showing much trend there. Of course, some of them have increased and decreased and we will now try and replicate the analysis which the, which was done by Hubbert and we will try and do this in terms of the logistic growth curve.

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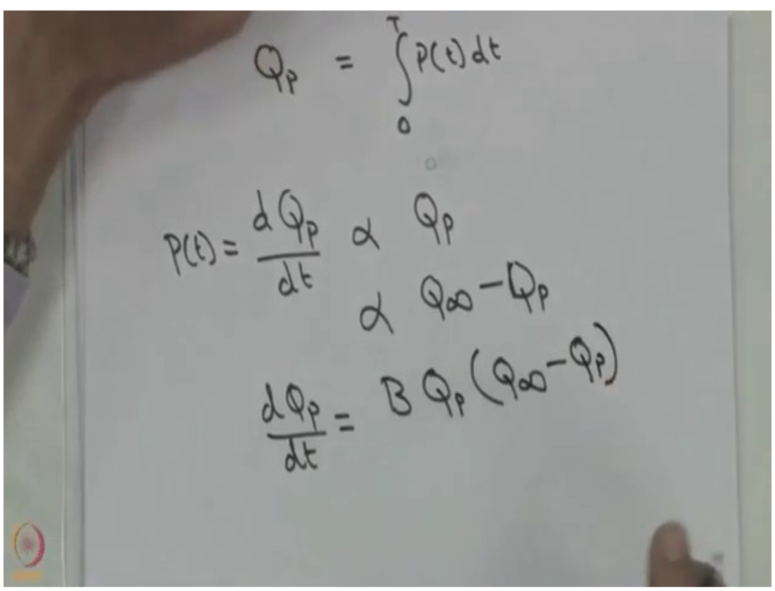

So, the we talked about Qp, being the cumulative production from time t is equal to 0 to T. That means 0 to T pt, dt. Now this Qp. Rate of change of Qp, dQp by dt. Is nothing but Pt. The rate of change up is proportional dQp dt is proportional to Qp. That means the demand for coal will be proportional to the cumulative amount of coal that has been used because that would result in more usage and people's see and as we go towards the limit then this if we are going towards Q infinity, that dQp by dt is constrained by the fact that we are near the limit. So, if we take this, we have a model which gives us dQp by dt is equal to B into Qp into Q infinity minus Qp. So, as we go towards the rate of change of the cumulative production, cumulative production Qp, which is the production in a particular year, in the initial case, it is exponential as we go towards the limit that decreases because we have this limiting term which is Q infinity minus Qp.

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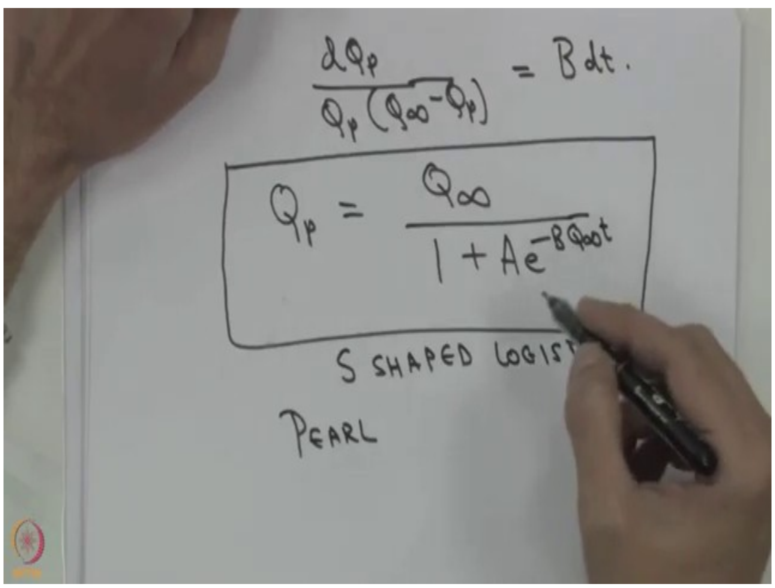

If we take this, we can then derive and we will get dQp by Qp, Q infinity minus Qp is equal to B dt. And you can show by integration that Qp is Q infinity by 1 plus AE raise to minus Q infinity dt. This is called an, S shape logistic curve. It is also called the Pearl curve, after the statistician Raymond Pearl, who initially proposed this as a curve which was used to show the growth in organisms in terms of height and the height and weight and this has been used in a whole host of applications.

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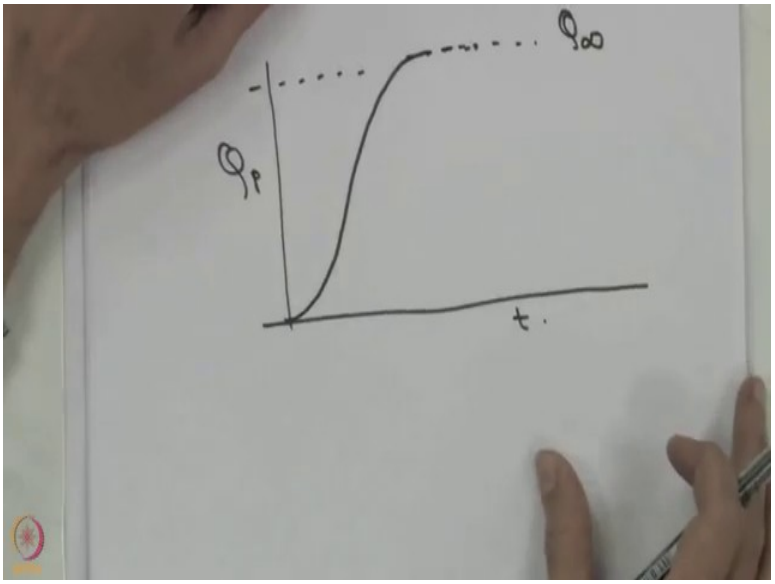

The way this works is that use. Start from here and then you go and it goes asymptotically to the limit. So, in this case this is Q Infinity this is Qp, this is t. And this is what is known as the S shaped curve. So, how do we get this curve? And I will give you a tutorial where we can look at the actual data for India and you can make this calculation. We have done this and based on this corresponding to this, then you get the production going to a maximum and coming down and this is the kind of thing that this is what was done for petroleum.

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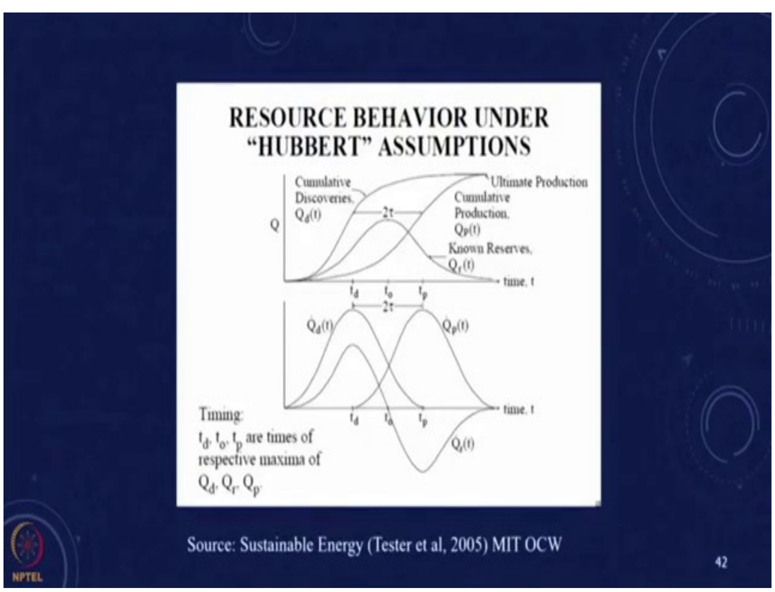

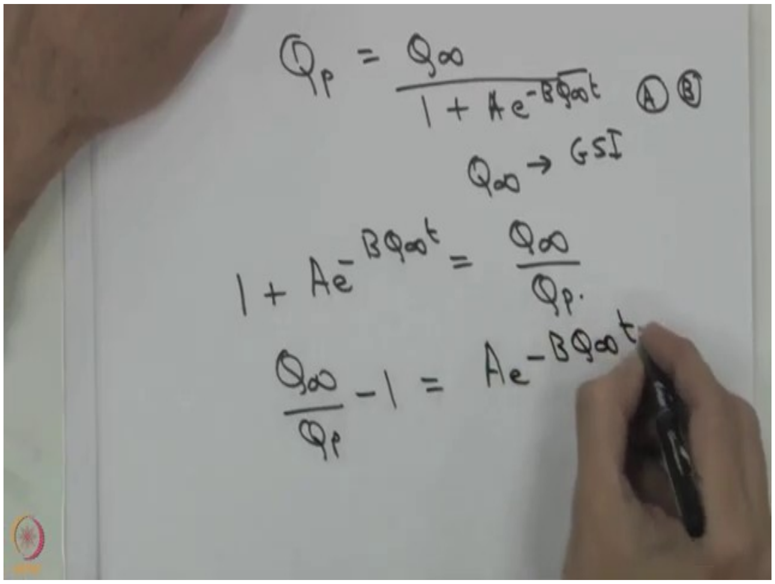

So, typically what happens in this is that we can take this curve Qp Q infinity by 1 plus A e raise to minus BQ infinity. We need to find these coefficients A and B. Q Infinity, we should be able to get an estimate from the Geological Survey, the Geological Survey of India.

If we are looking at Indian context, whatever estimate we have of the reserves we use as Q infinity and we can calculate we can modify this and see we can write this as 1 plus A e raise to minus B Q infinity t will be Q infinity by QP. So, Q Infinity by Qp minus 1 is A e raise to minus B Q infinity t.

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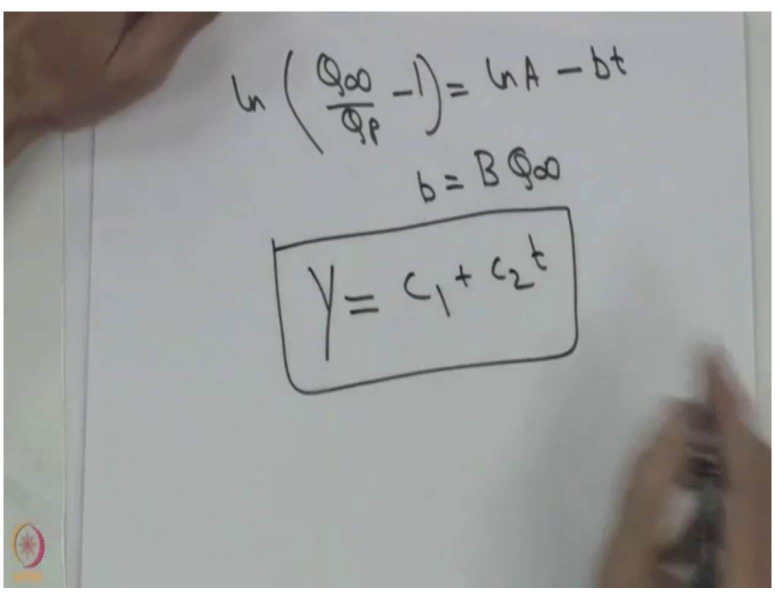

Now for this I can take ln on both sides and I will get a line of Q infinity by Qp minus 1 is ln A minus b t where B is equal to BQ infinity. Now, if you look at this, this is of the form. Y is equal to C1 plus C2t and this is amenable to linear regression. All that we can do is we can take. We can start with the time series data that we have of production and we can take a particular year in which we can get the initial value of Qp at starting ts.

And then for each year, we can just add on the production so that we can get the Qp from that starting year till the recent years, as a obtain the estimate of Q infinity from the resource and then we can get ln, Q infinity by Qp minus 1 and get that as y and then get these coefficients ln and B from a regression. So, we can take this and make the calculations and get the coefficients A and B.

So, I would urge you to try this with the dataset that we have for India for Indian coal, and you can try and get the coefficient A and B and compare it with the results. Then once we have that, we can use it to find what is the year of peaking. So, we can. This is something that we can calculate. What is the year of peaking that we will have based on the fact that the peak production will happen in that year.

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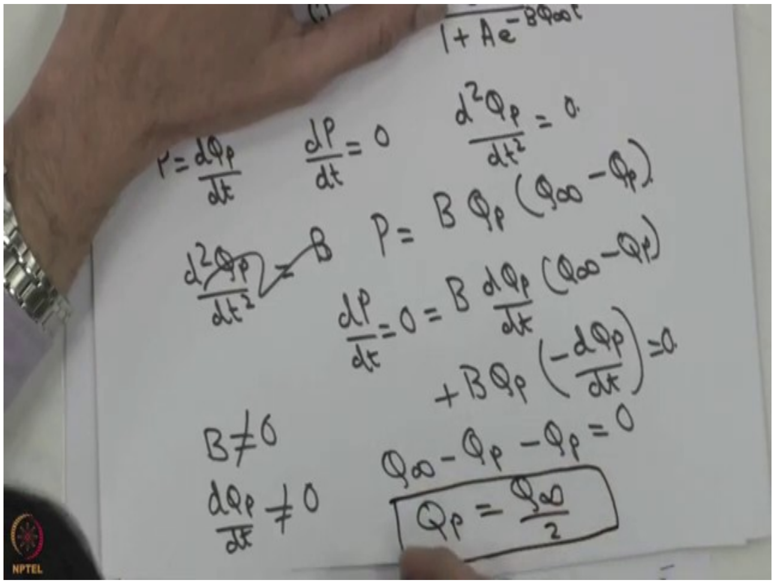

So, if we see the equation that we have Qp is Q infinity by 1 plus A e raise to minus BQ, infinity t. We want to find out the time when the production is maximum. When the production is maximum it will be a stationary point where dp by dt will be equal to 0. Now dp by dt is equal to 0 means that we are going to have dQp by, dpp is equal to dQp by dt. So, we will like to find the point of inflection when this will be maximum, where d square Qp by dt squared is equal to 0.

So, let us take this equation and differentiate it. You get d square Qp by dt square. We can take the equation where we have, let us start from the other point. Let us start from the point where we have p is B Qp Q infinity minus Qp. This is the starting point, so we can take this as dQp by dt which is going to be B dp by dt set it equal to 0 is going to be B dQp by dt into Q infinity minus Qp plus B Qp and differentiate Q infinity minus Qp, which is minus dQp by dt is equal to 0.

B is not equal to 0. Also, tQp by dt is not equal to 0 because that is the production. That is the maximum production so we can divide by these and what we will get then is Q infinity minus Qp minus Qp is equal to 0. Which means Qp is equal to Q infinity by 2. This is the point at which we will get a peak production, and this will happen at the point of inflection. It will happen at the midpoint of the cumulative production curve.

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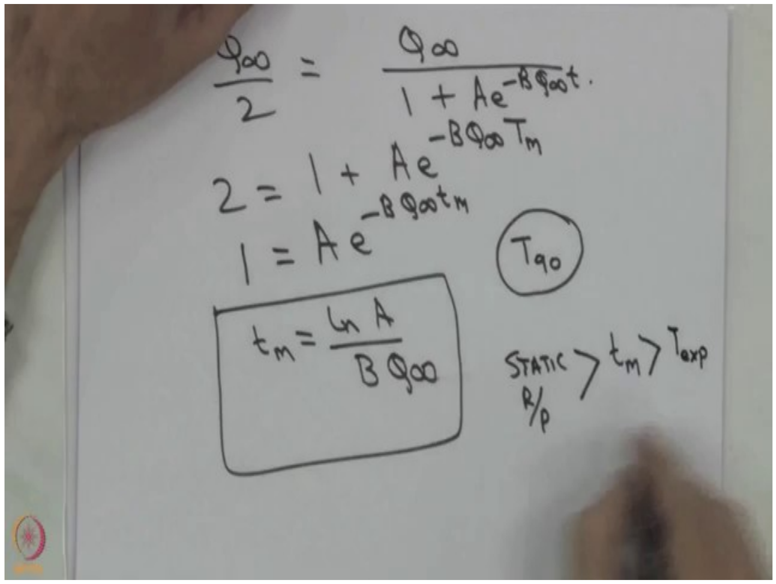

So, now we can calculate, we can substitute, we can say Q infinity by 2 is equal to Q infinity by 1 plus A e raise to minus B Q infinity t. We can then say 2 is equal to 1 plus A e raise to minus B Q Infinity Tm. Let us say Tm and then this becomes 1 is equal to A e raise to minus B Q Infinity Tm and then you get Tm is ln A by B Q Infinity. So, what are we calculated? We have calculated the time at which the peak will occur and this is in terms of these coefficients, A, B and Q Infinity, which we have derived. So, this is the year of peaking.

We can also find out instead of this we can find out the T 90 percent time at which 90 percent of the resources used up. So, we can take QP by Q Infinities point nine substituted and get the value of T. So unlike in the other case where it abruptly ends. In this case, if we have the S shaped curve where it goes asymptotically to the limit and so this can give you an estimate and you will find that this Tm will be in between.

You have the static R by P ratio, which is the highest and this will, you will have the Hubbert model or Tm. And the, this will be in between this and the exponential. T for the exponential growth model, which will be the smallest so it will be somewhere in between and this is one of the ways in which we can do this. This curve which we have is symmetric about the point of inflection.

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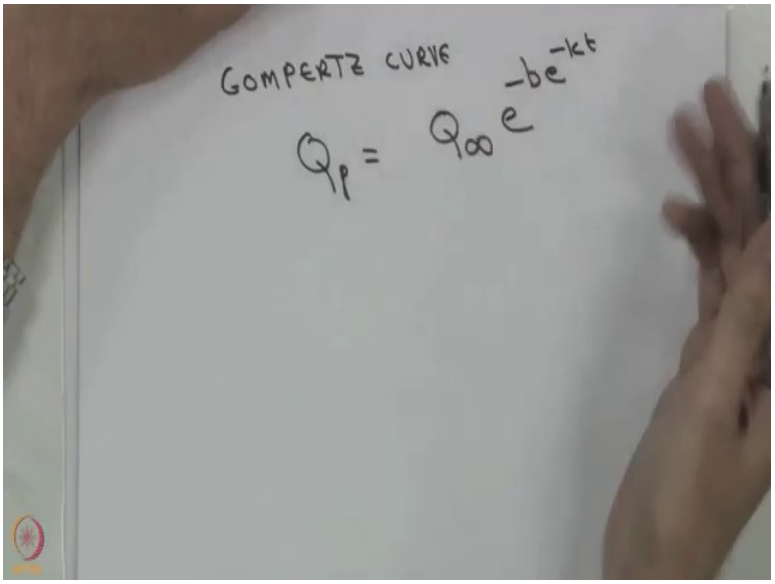

Instead of this, we can also have other curves, other logistic curves, not commonly used but there could be the Gompert's curve for instance and you can try this out. This is where Qp is Q infinity e raise to minus b, e rest to minus kt. So, we have Q infinity and you have these two coefficients b and k you have to take log twice and then you can you can get these coefficients by linear regression substituted here. The curve is not symmetric about the point of inflection. So, we have choices in and it has it. It has a different kind of characteristics.

So, we looked at the Hubbert's model and we just saw that we can calculate this point of inflection. We, this model has been used to estimate this is where the world oil when it will peak and in many of these estimations, what has happened is that technologies have changed and the reserve estimates have changed. So, sometimes this whole concept of peak oil has been questioned.

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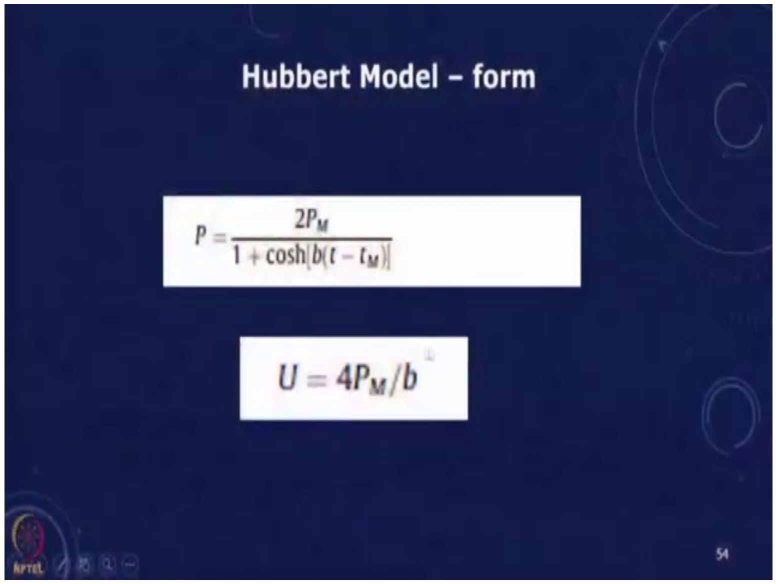

The cumulative production proven reserves and if you see some of these so you can also express this model in terms of this expression which has a cost component which is very similar to the model that we are talked of.

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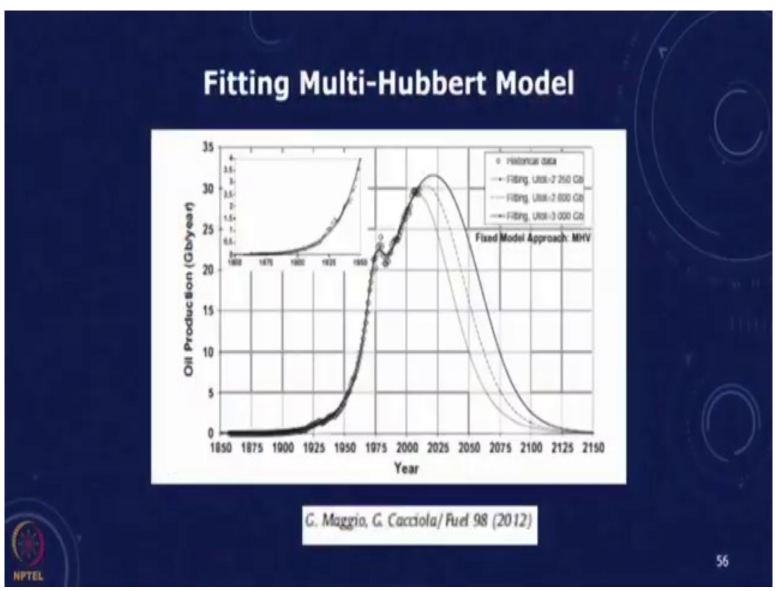

There also these models which have been used for different countries where you have a multi-Hubbert model which means that you start with one particular peak. And then if we find reserves for instance you use shale oil or you use some other things weather technology has changed you are going for the second peak.

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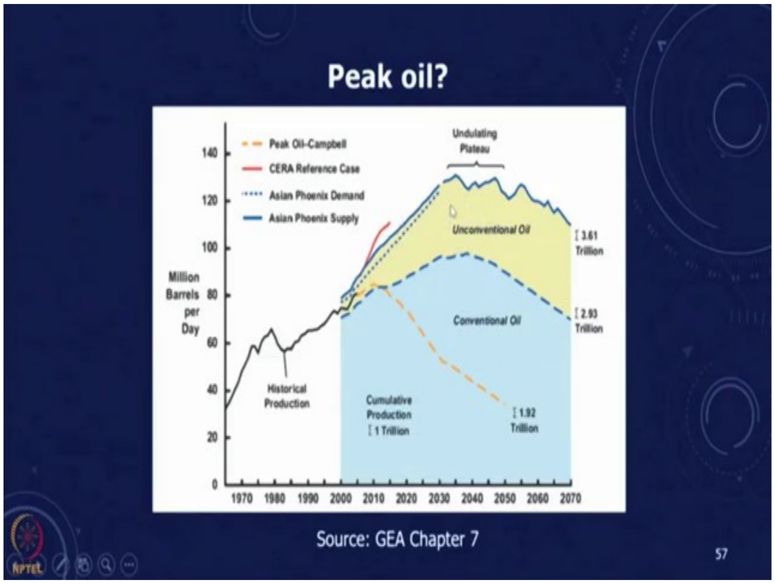

And there have been modifications of this. So, this has been sort of the history, historical production, cumulative production, but we have extended beyond conventional oil and gone into the unconventional and this is because in previous years we had certain technologies where which involved a certain amount of certain type of drilling. We now have the possibility of cost effective even horizontal drilling. And we have this concept of fracking where now we are using shale oil, unconventional resources.

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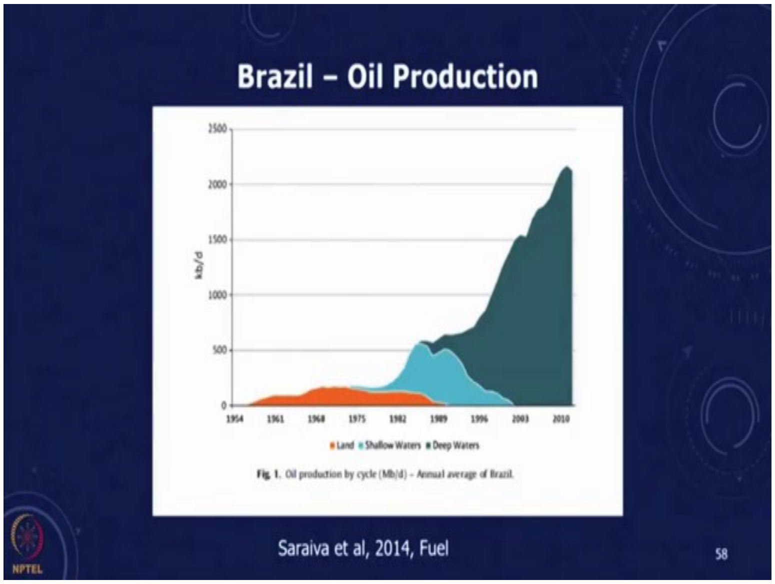

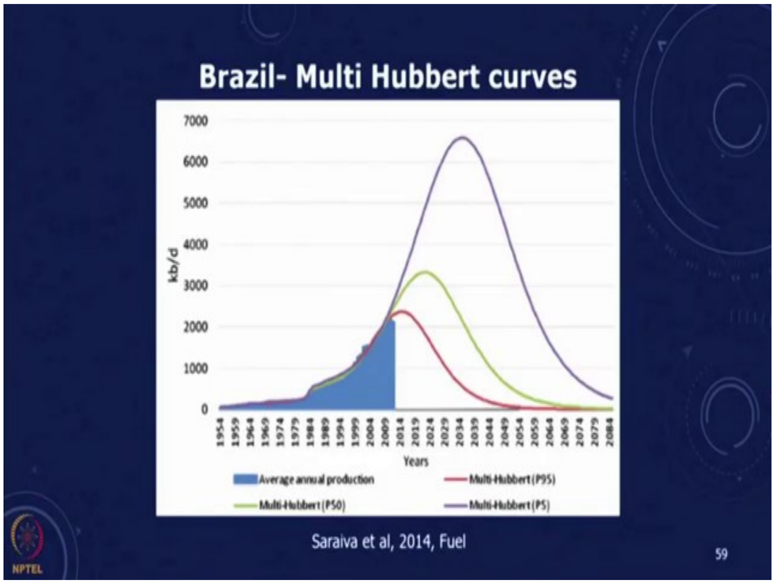

So, it is this paper which has shown in Brazil you had these multi, you had this first cut where we have a production and it goes down and then it goes to the next level and so basically, we have these kinds of multi Hubbert curve, you go to one peak. Then because of the technology improvement go to the next peak and so on. So, these are ways in which we try to understand how the technology and reserves consist. And there are many different studies where they are done this kind of Hubbert curve analysis.

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This is a news article which talks about the different kinds of oil drilling technologies over the years and you can see very clearly that there have been a lot of improvements in technology. So, essentially what happens is that earlier there were, there were resources which would not be considered economically economical as sources of oil, but today they will be considered as something which is economical and this is why we have different kinds of production.

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GEA – Reserve estimate

	Historical production through 2005 [EJ]	Production 2005 [EJ]	Reserves [EJ]	Resources [EJ]	Additional occurrences [EJ]
Conventional oil	6069	147.9	4900–7610	4170–6150	
Unconventional oil	513	20.2	3750–5600	11,280–14,800	> 40,000
Conventional gas	3087	89.8	5000–7100	7200–8900	
Unconventional gas	113	9.6	20,100–67,100	40,200–121,900	> 1,000,000
Coal	6712	123.8	17,300–21,000	291,000–435,000	
Conventional uranium[a]	1218	24.7	2400	7400	
Unconventional uranium	34	n.a.		7100	> 2,600,000

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There are if you look at the global energy assessment you will find that there are these estimates for conventional, unconventional oil, coal and you have the reserves and resources and you find that we have significant amount of stock if you add up the resources and reserves. And so that is not currently a constraint based on the present thing. But of course, there is the problem in terms of the carbon dioxide which makes it problematic to use the fossil fuels.

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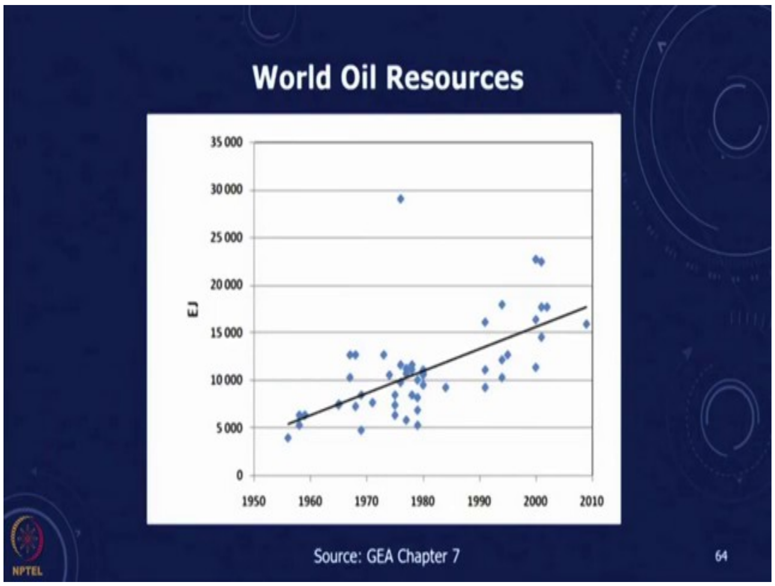

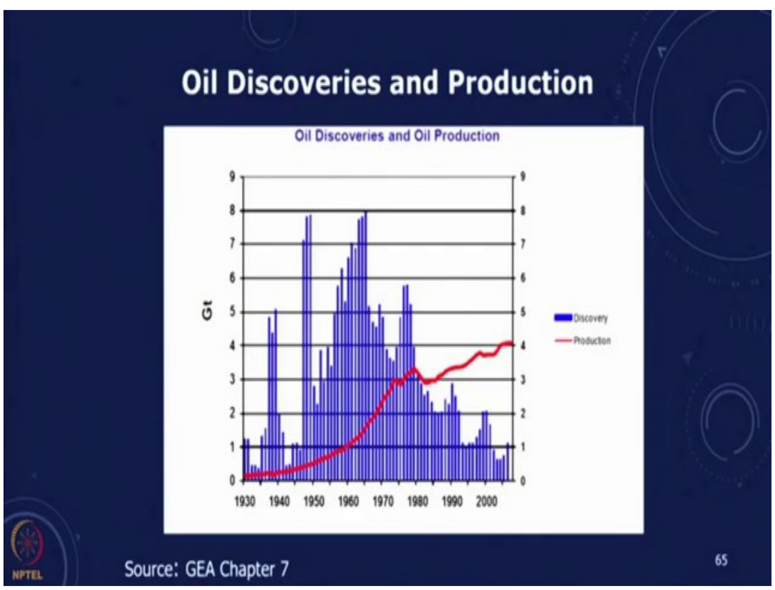

And you can see clearly that the oil resources also over time if you plotted you see that there has been an increase. And this shows this is an interesting sort of image which shows the kind of discoveries and production. And you can see that oil discoveries have been now declining. Production of course is increasing.

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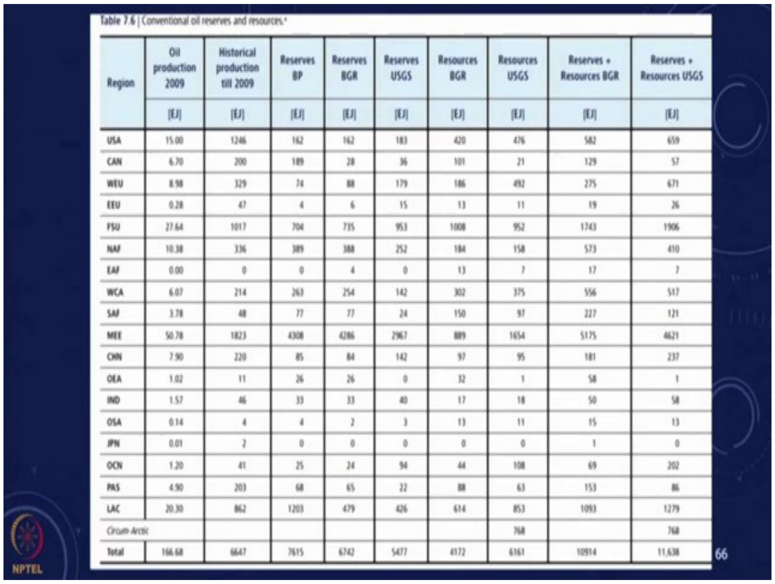

Table 7.6 | Conventional oil reserves and resources.[a]

Region	Oil production 2009	Historical production till 2009	Reserves BP	Reserves BGR	Reserves USGS	Resources BGR	Resources USGS	Reserves + Resources BGR	Reserves + Resources USGS
	[EJ]	[EJ]	[EJ]	[EJ]	[EJ]	[EJ]	[EJ]	[EJ]	[EJ]
USA	15.00	1246	162	162	183	420	476	582	659
CAN	6.70	200	189	28	36	101	21	129	57
WEU	8.98	329	74	88	179	186	492	275	671
EEU	0.28	47	4	6	15	13	11	19	26
FSU	27.64	1017	704	735	953	1008	952	1743	1906
NAF	10.38	336	389	388	252	184	158	573	410
EAF	0.00	0	0	4	0	13	7	17	7
WCA	6.07	214	263	254	142	302	375	556	517
SAF	3.78	48	77	77	24	150	97	227	121
MEE	50.78	1823	4308	4286	2967	889	1654	5175	4621
CHN	7.90	220	85	84	142	97	95	181	237
OEA	1.02	11	26	26	0	32	1	58	1
IND	1.57	46	33	33	40	17	18	50	58
OSA	0.14	4	4	2	3	13	11	15	13
JPN	0.01	2	0	0	0	0	0	1	0
OCN	1.20	41	25	24	94	44	108	69	202
PAS	4.90	203	68	65	22	88	63	153	86
LAC	20.30	862	1203	479	426	614	853	1093	1279
Circum-Arctic							768		768
Total	166.68	6647	7615	6742	5477	4172	6161	10914	11,638

And you can have details of this in terms of different regions what are the production reserves and you can if you are interested in you can look at this global energy assessment the resources chapter and you can look at some of these details.

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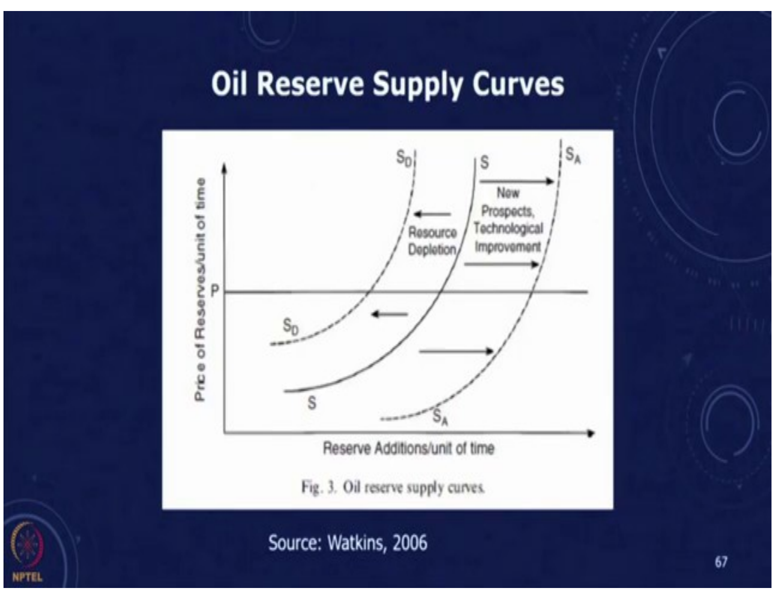

The other approach which is the approach which has been proposed by Adelman and others is where they were talking in terms of not a static estimate of reserves. So, the idea is that based on what is known technology you can have different kinds of and the prices at which one can get one can get different kinds of supply. So, as technology improves you can have the increase in the resources and reserves and on the other hand there is a resource depletion. So, there is these two kinds of trade-off.

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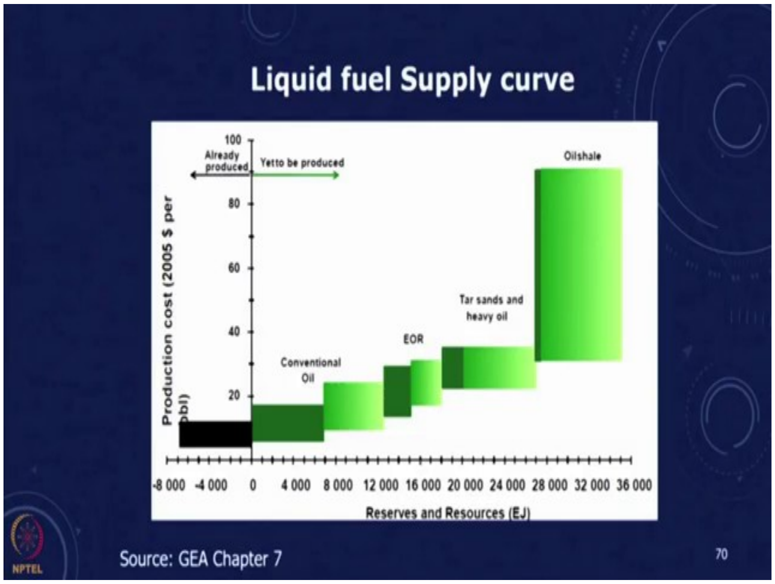

So, there is this approach which is now call the supply curve approach, where we estimate at with different kinds of technologies what kind of reserves are available. So, this is the kind of this is showing for conventional oil enhance oil recovery, tar sands and others and so on. So, one can have essentially different element of it, which relates to price and supply and for each of these, when we talk about stocks, we talk about a supply curve at different price levels and the kind of costs which are available.

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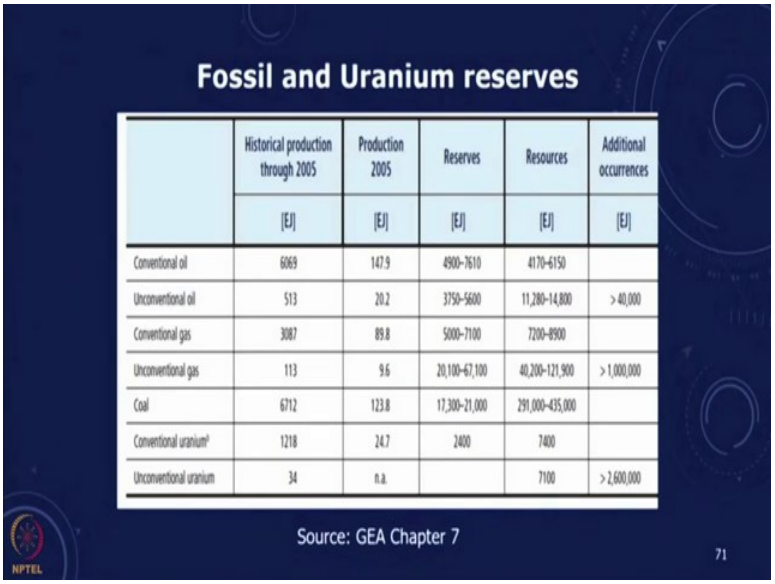

Fossil and Uranium reserves

	Historical production through 2005 [EJ]	Production 2005 [EJ]	Reserves [EJ]	Resources [EJ]	Additional occurrences [EJ]
Conventional oil	6069	147.9	4900–7610	4170–6150	
Unconventional oil	513	20.2	3750–5600	11,280–14,800	> 40,000
Conventional gas	3087	89.8	5000–7100	7200–8900	
Unconventional gas	113	9.6	20,100–67,100	40,200–121,900	> 1,000,000
Coal	6712	123.8	17,300–21,000	291,000–435,000	
Conventional uranium[a]	1218	24.7	2400	7400	
Unconventional uranium	34	n.a.		7100	> 2,600,000

Source: GEA Chapter 7

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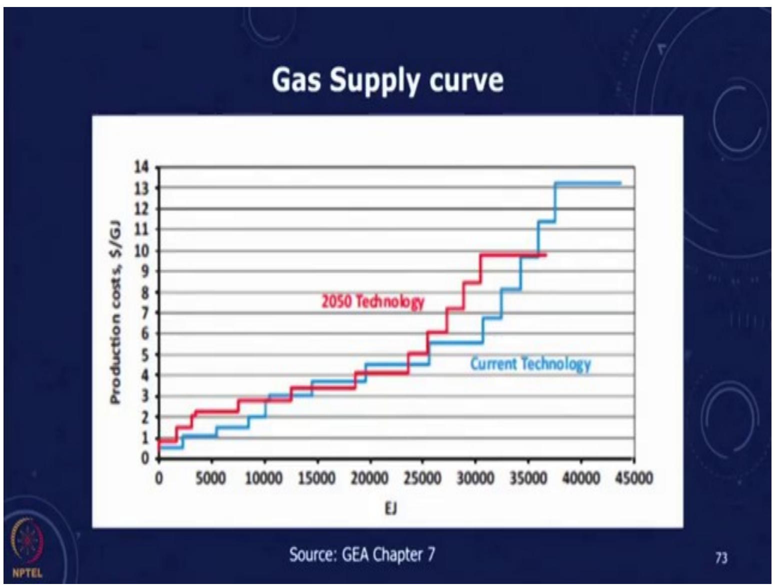

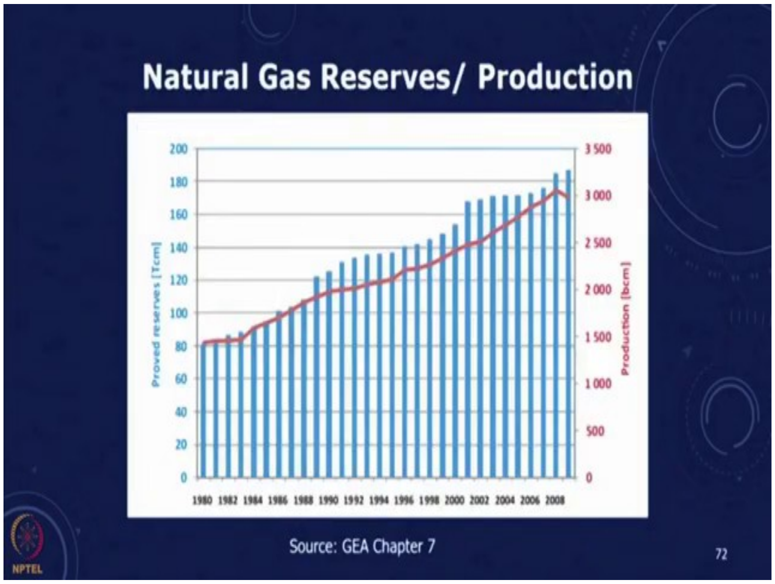

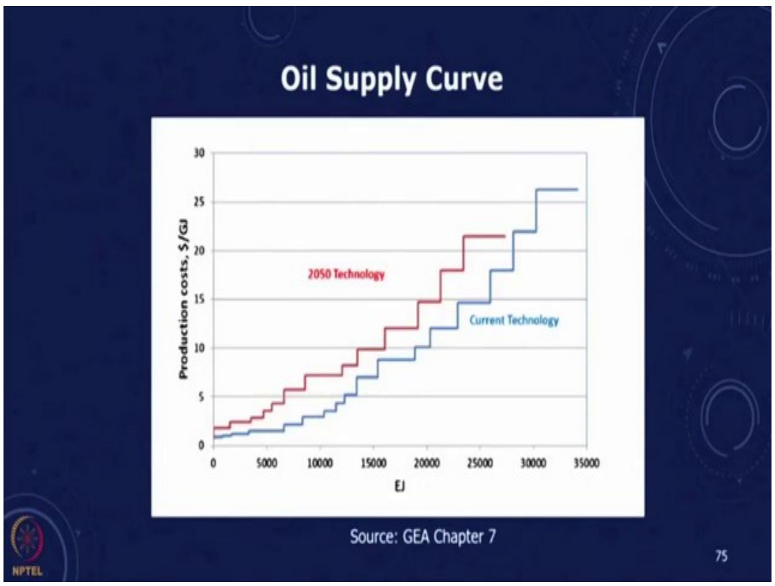

And similar things are done for fossil and uranium for instance in the case of uranium there is there could be a certain amount of reserves similar things for natural gas. You can have this for a gas supply curve, you can see different amounts at different kinds of prices.

So, that adds a different dimension and you can see the sources and put the kind of values which are there. So, this is this is the different approach. Unlike the, we have seen this static R by P ratio, the exponential and then the Hubbert curve the logistic growth and then we have the supply curve option. In the supply curve option, we are basically saying that it is not a static amount the, it is not a fixed finite resource but there is a resource which is a function of technology and costs and a different cost there will be different amounts of supply. So, this is one of the ways in which you can do this.

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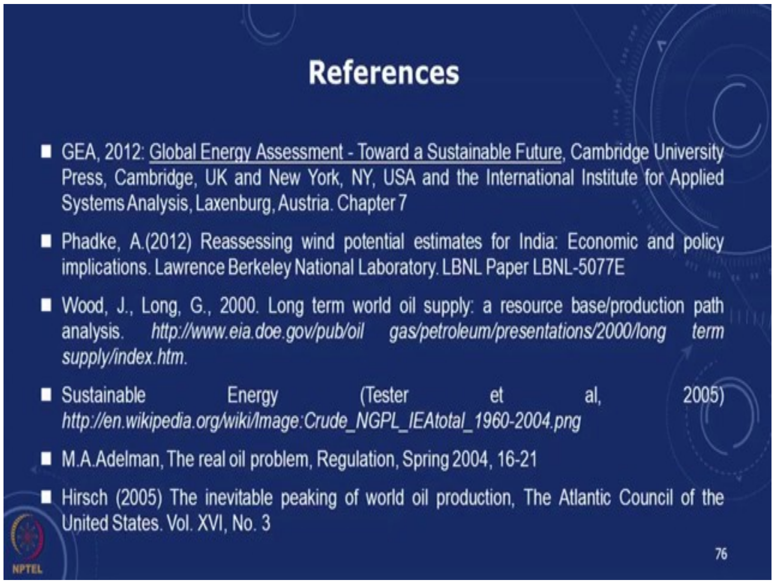

You can look at details of this through some of these references, the global energy assessment and some of the papers Adelman's paper and the peak oil concept. So, what we have done is we have looked at essentially resources, which are stocks and which are considered to be non-renewable or depleted, we should remember that in all of these cases coal, oil, natural gas is also renewed.

They are formed over natural processes where vegetation is comes under pressure and it comes under some sets of changes and over thousands of years, you have these resources and reserves formed. However, the rate at which we depleted is at much faster rate than the rate at which it is renewed. So, for all practical purposes, these are known as depleted, in the case of these resources which we are considering as stocks, there are different ways in which we can classify based on the probability of occurrence, based on the economics of it and we talked about the Mckelvy diagram.

We then said that given a certain estimate we can have different estimates of the time for which it would loss. We looked at the static R by P ratio. We looked at the exponential and we looked at the logistic growth curve or the Hubbert curve model. We also said that there are limits, there are problems with these kinds of approaches and may be what we can look at supply curve at different kind of prices. So, this is all in terms of stocks. There are also whole set of resources which are renewable resources which are going to be flows and that is the next thing that we will take. Thank you