Fossil Fuels: Examination and Prediction of Future Trends

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Abstract

The accumulation of fossil fuels is a process that took hundreds of millions of years, yet in just the last few hundred years we have depleted a large percentage of the total amount formed. The future trends of fossil fuels are difficult to predict because of the many different factors that affect the production and consumption of each fossil fuel. To present accurate predictions about coal, oil, natural gas, and other energy sources like uranium, factors such as human population growth, the energy requirements in developing countries vs. developed countries, use of comparable fossil and renewable fuels, and environmental concerns and responses must be considered. By using conversion factors, the numerical energy values for each resource are equalized based on the thermal energy of oil. By this conversion the total amount of energy producible from the total reserves of each resource can be compared against one another. Taking into account these many variables, predictions results may accurately reflect the trends these fossil fuels will take in the future.

Definitions of Terms Used

Proven reserves - The quantities of hydrocarbons estimated with reasonable certainty to be commercially recoverable from known accumulations under current economic conditions, operating methods, and government regulations. Current economic conditions include prices and costs prevailing at the time of the estimate. Estimates of proven reserves do not include reserves appreciation.

Reserves - The quantities of hydrocarbon resources anticipated to be recovered from known accumulations from a given date forward. All reserve estimates involve some degree of uncertainty.

Reserves appreciation - The observed incremental increase through time in the estimates of reserves (proven and unproven) of an oil and/or natural gas field as a consequence of extension, revision, improved recovery, and the additions of new reservoirs.

Resources - Concentrations in the Earth's crust of naturally occurring liquid or gaseous hydrocarbons that can conceivably be discovered and recovered.

Undiscovered resources - Resources postulated, on the basis of the geologic knowledge and theory, to exist outside of known fields or accumulations.

Undiscovered technically recoverable resources - Oil and gas that may be produced as a consequence of natural pressure, artificial lift, pressure maintenance, or other secondary recovery methods, but without any consideration of economic viability. They are primarily located outside of known fields.

Undiscovered economically recoverable resources - The portion of the undiscovered technically recoverable resources that is economically recoverable under imposed economic and technologic conditions.

Unproven reserves - Quantities of hydrocarbon resources that are assessed based on geologic and engineering information similar to that used in developing estimates of proven reserves, but technical, contractual, economic, or regulatory uncertainty precludes such reserves from being classified as proven.

Introduction

In 1956 M. King Hubbert published a theory discussing the trend of oil production he expected to see in the future. His theory, referred to as the “Peak Oil” theory or “Hubbert's Peak,” predicted that at some point 50% of the world’s easily accessible fossil fuels would be depleted, the production of these fossil fuels would peak, and then begin to decline as the resources became less abundant. Other sources and independent studies have advanced this theory and there have been many predictions made estimating when this peak will occur based on the proven reserves and global consumption rates of the various fuels. Most predictions show that peak oil will be reach in the next ten years if it has not already been reached today.

The fuels examined in this paper include uranium and the fossil fuels oil, natural gas, and coal. Uranium, (U), is not technically a fossil fuel in the sense that the term fossil fuel applies to coal, oil and natural gas. However, since it does exist in a fixed quantity and is a nonrenewable resource, it will be included when discussing fossil fuels. These fossil fuels are the result of buried carbon over the last 500 million years. As ancient plant and animals were buried and, under appropriate depositional conditions preserved, their carbon based material were slowly transformed and stored as chemical energy. The process has taken hundreds of millions of years to accumulate the total reserves of fossil fuels on the planet. Due to the extremely slow nature of this process, it can be assumed that the amount of fossil fuels that are being produced now and over the next few hundred years is negligible and will not contribute to the total quantity.(Hubbert 1956) With that in mind I will exclude any current formation of additional fossil fuels in this paper, and consider the total amount of fossil fuels on Earth to be in fixed quantities that are not being replenished. Since the formation of life on Earth, up until the later part of the 18th century, the total amount of fossil fuels on the planet were rising as they slowly accumulated through geologic processes. I consider this to be the growth period for the fossil fuel. Since the beginning of the Industrial Revolution in the later part of the 18th century there has been a decline in the total amount of fossil fuels available. (Figure 1)

Compilation of Data

The data were compiled from various sources such as British Petroleum's statistical reviews, UN statistics and other mineral resource group websites. Once the numbers were collected they needed to be equalized so each unit was converted to Btu (British Thermal Units) using these conversion factors:

1 short ton Coal	=	19,988,000 Btu
1 cubic foot Natural Gas	=	1,027 Btu
1 US barrel Oil	=	5,800,000 Btu
1lb. 3.2% uranium by weight	=	1,250,000,000 Btu

The numbers were then converted to Barrels of Oil Equivalent (BOE) so that they could be viewed in terms of oil consumption using the conversion factor:

1 BOE =5,800,000 Btu

By using these conversion factors, the numerical values for each resource are based on the thermal energy of oil. This conversion facilitates comparing the resources against each other in terms of the total amounts involved. The comparison, in turn, allows us to critically evaluate the remaining amounts of the nonrenewable resources, to compare and contrast human dependence on them, and predict near-future trends in consumption and production.

Geologic and Economic Background

Coal is used in the United States and in rest of the world as fuel to produce electricity. It is also used in great quantities in the production of steel, cement, and other products used on a daily basis around the world. It is estimated by the EIA that there are more than 800,000 million tons of coal in

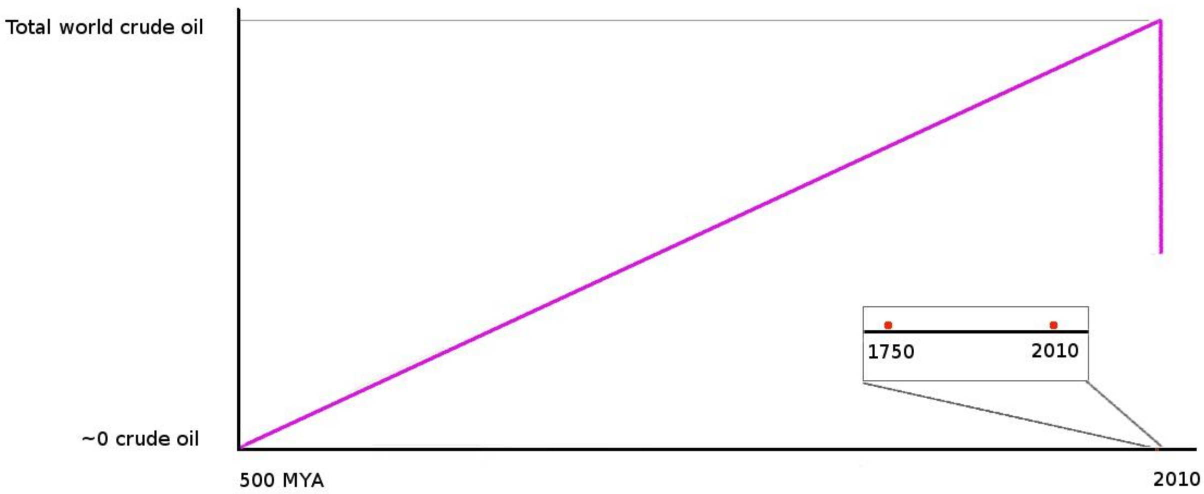


Figure 1: This is a representation of the easily accessible crude oil on Earth over the last 500 million years. The "peak oil" theory referrers to the point in time when 50% of the Earth's easily accessible oil has been depleted. The consumption of ~50% of the world's oil over the last few hundred years is a nearly vertical line when viewed on this time scale.

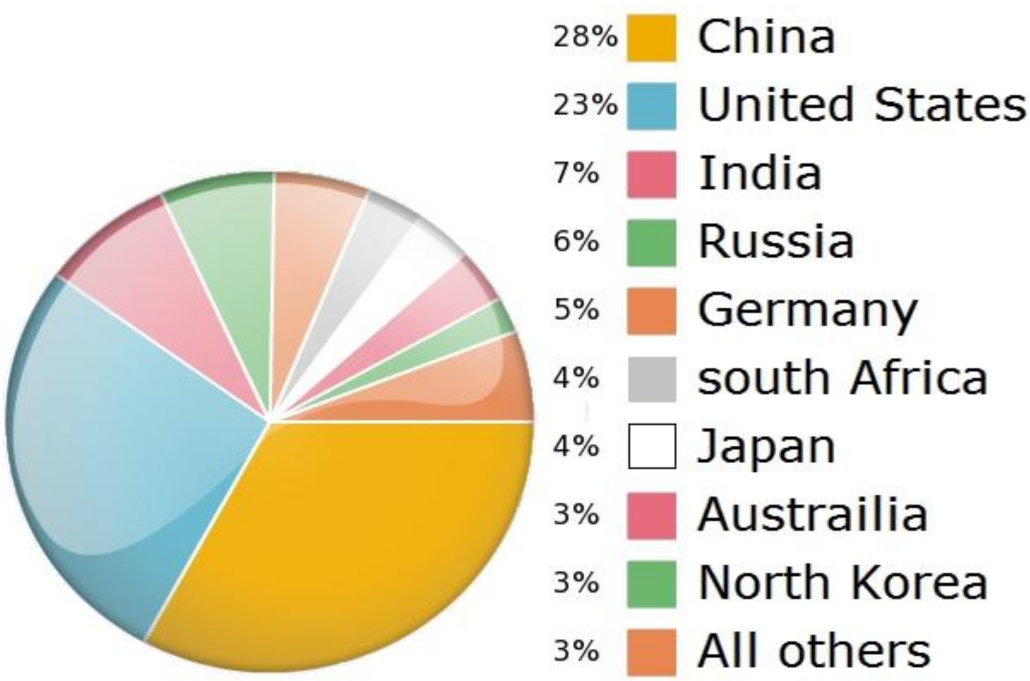


Figure 2: The consumption of coal by region in 2010. Together China and the United States consume more coal then the rest of the world combined.
Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library

the world's reserves. There has been a significant increase in the use and production of coal in developing countries throughout the world. This is because it is relatively easily converted to electricity compared to other methods and coal is accessible worldwide.

Coal is formed through a process called coalification. This most commonly occurs in areas with dense plant life and an abundance of water, such as a swamp environment. As plant life dies in a swamp the organic material is covered by water. The overall process of decay is much slower in a swamp water environment compared to dry environments. In an organic-rich water environment all of the free oxygen is used up by the decaying plant life which slows down the growth of bacteria causing the overall decay process to slow down drastically. The delay in the decay process is important because it makes it far more likely for the organic material to be buried by sediment. As the pressure increases due to continued sediment burying the material deeper and with the addition of heat the organic material has most of the water squeezed out of it and the compounds in the materials begin to break down. As the process continues the material becomes more carbon rich and the energy content or grade of the coal increases.(Monahan 1952)

Coal is one of the most abundant fossil fuels on Earth and although it is used in very high amounts for the production of electricity it is not expected to reach peak production for more than 100 years. Both consumption and production of coal has more than doubled in the last 50 years however the total amount of coal reserves is still many orders of magnitude higher that the production rate. The total estimated reserves of coal are sufficient to support production at the current production level for approximately 460 years. There has been a fairly steady increase in production over the last fifty years.(Figure 3) It is unlikely that the production rate will stay constant if the growth patterns in the past are indicative of trends in the future.

The production and consumption rates of coal in the past are valuable when trying to determine the trends that will occur in the future, however there are many other factors that must be accounted for as well.(Figure 3) In order to make plausible predictions, factors such as human population growth,

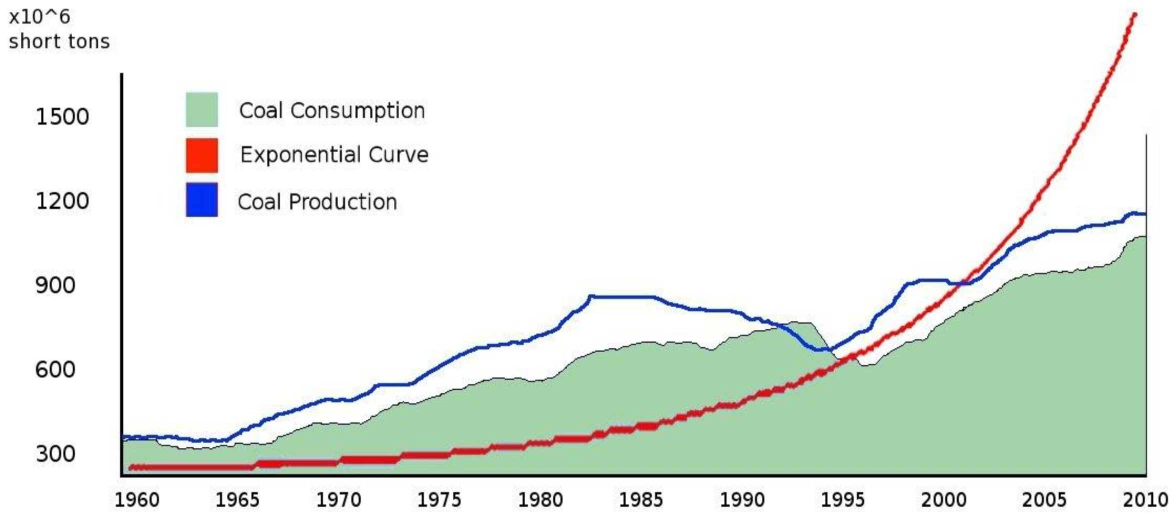


Figure 3: The consumption of coal viewed in million short tons. The figure above is a graphical representation of the coal consumption vs production from 1960 to 2010
Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library

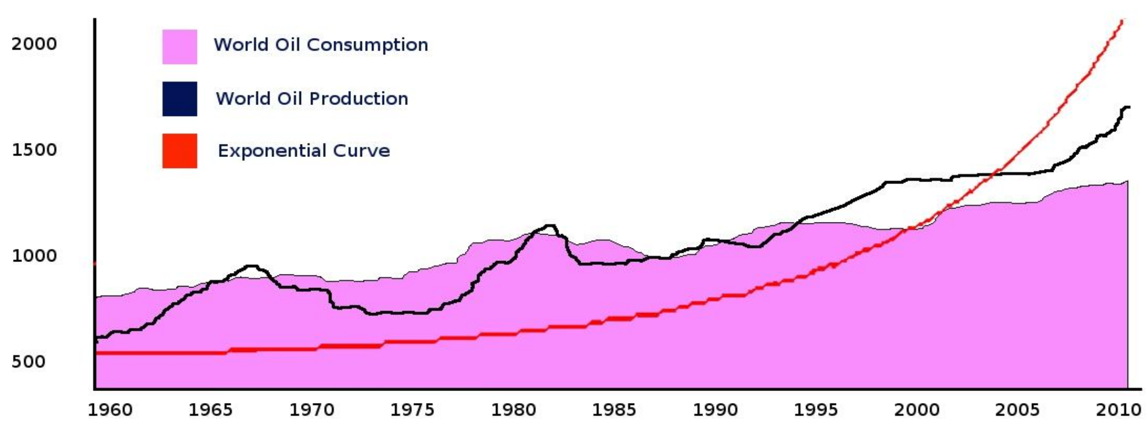


Figure 4: Consumption vs production of crude oil over the last 50 years in billion barrels.
Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library

coal usage in developing countries vs. developed countries, use of comparable fossil and renewable fuels, and environmental concerns and responses must also be considered. The first aspect of this I will address is the percentage of worldwide coal usage by region. This is an important aspect to consider because the potential for large growth in some regions is different than in others. The majority of the world's coal consumption is in the United States and China (Figure 2). This means that although there is room for growth in these counties the potential for growth in other counties such as India is significantly higher. As the population of developing countries such as China begin to rely more heavily on electricity, the consumption of coal in those areas rises significantly. China has been an example of this and it is predicted that development and reliance on coal will follow similar trends in India and other developing countries.

Crude oil is a combustible liquid made up of a variety of hydrocarbons. Oil is the most heavily and widely used fossil fuel. The global usage is estimated to be 3.12x10^10 barrels per year. That is nearly 90 million barrels consumed every day. Oil is formed in a similar fashion to coal where organic carbon is buried by sediment and then transformed due to the addition of pressure and temperature.(Libbin 1977) This is a very slow process that takes millions of years, so any new additions of recent or future oil formation is negligible. The production of oil has followed a rapid upward trend, but varies some due to exploration and new discoveries prompting increases in production. (Figure 4)

Natural gas is a highly combustible mixture of hydrocarbon gasses. It is made up primarily of methane but can also contains propane, butane, ethane and in some cases carbon dioxide (CO_2). The purest forms of natural gas are almost entirely methane. When a natural gas is very nearly all methane it is considered “dry,” where as if it has significant quantities of other hydrocarbons in it, it is considered “wet.”

Natural gas forms through the same process as coal and oil. However, natural gas is lighter that either of those fuels, so at geologic formations where hydrocarbons are trapped, natural gas is the closest to the surface. Extraction of natural gas found in geologic traps such as anticlines is considered the conventional method of extraction. Natural gas is also abundant in shale formations but it requires more energy to release it from the rock. A process called hydraulic fracturing is used to release natural gas from these unconventional shale deposits. This is done through a combination of special drills that can be turned horizontally into a geologic formation, pumping a high pressure fluid into the wells to induce fracturing of the layers, and then injecting a "proppant" either quartz or a ceramic material to keep fractures open.

Natural gas is used widely for heating purposes so the annual consumption varies seasonally. Production however can continue year round and natural gas can be stored for future use. The production of natural gas has been constantly rising for the last 50 years. The overall trend is fairly linear but new discoveries in unconventional shale gas are expected to push production to a higher rate than the trends in the past would suggest. (Figure 5)

Uranium U is a fairly common element in the Earth's crust. It is present in small amounts in the majority of rocks on Earth and can be found in ore deposits in very high concentrations. Uranium is used to power nuclear power plants in order to produce electricity through fission reactions.(Deffeyes 1980) Uranium is not formed through the same process of deposition and burial as the hydrocarbon fossil fuels discussed in this paper, however it is a nonrenewable resource that can be viewed as a fixed amount on Earth. Because uranium exists in a fixed amount the rates of its production and consumption are comparable to the other fossil fuels. The current global usage of uranium is approximately 68,000 tU/year. This is equal to 2.913x10^9 barrels of oil equivalent. At the current consumption rate uranium reserves are expected to last approximately 160 years. This is based on a total reserve that is continually growing due to new mineral discoveries so the projection of 160 year at current rates is likely to grow.

There was a large increase in uranium exploration between 1970 and 1985 as well as an increase in consumption due to increases in nuclear power usage. (Figure 6) In 2005, the estimate of

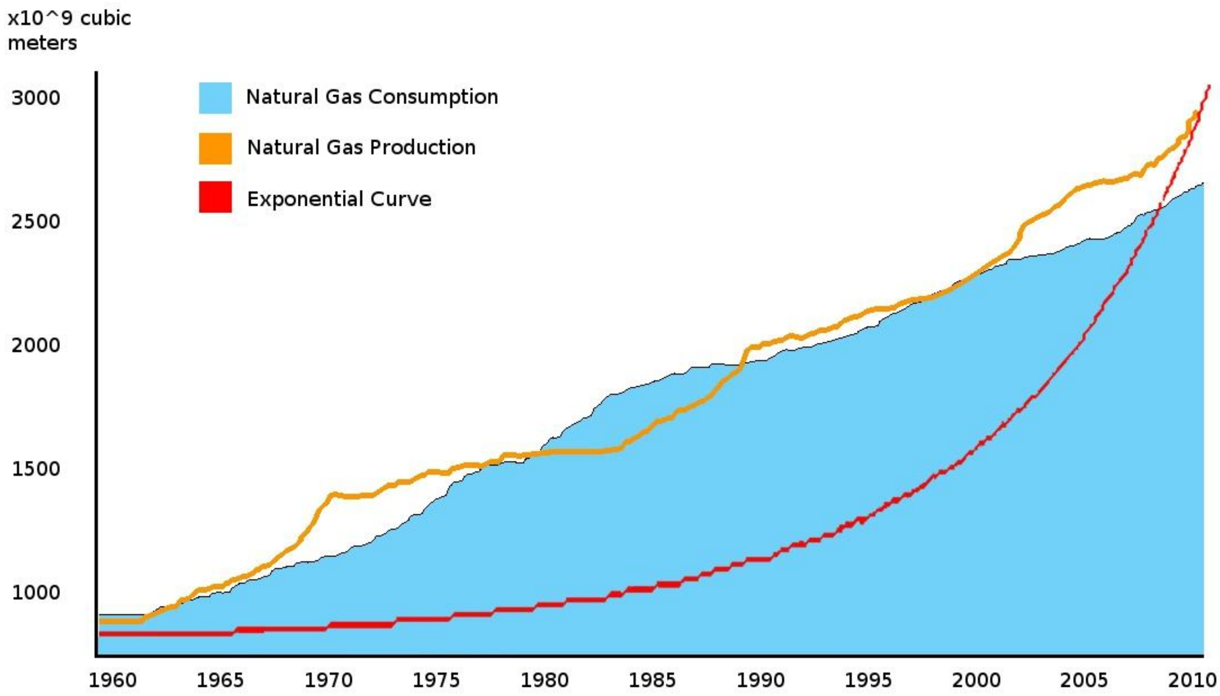


Figure 5: Consumption vs production of natural gas over the last 50 years in 10^9 cubic meters.Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library

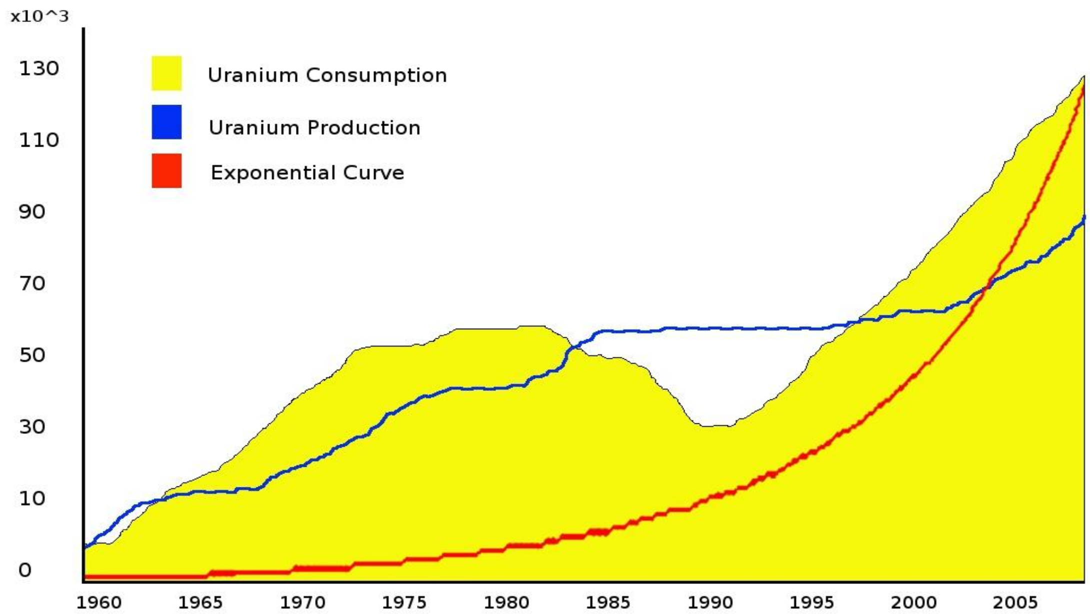


Figure 6: Consumption vs production of uranium over the last 50 years in 10^3 tones. Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library

total uranium reserves were increased by 15% due to mineral exploration.(eia.gov) The largest reserves of uranium are in Australia, which is estimated to have about 30% of the world's uranium reserves. The United States in comparison has only about 4% of the world's uranium. (Figure 7)

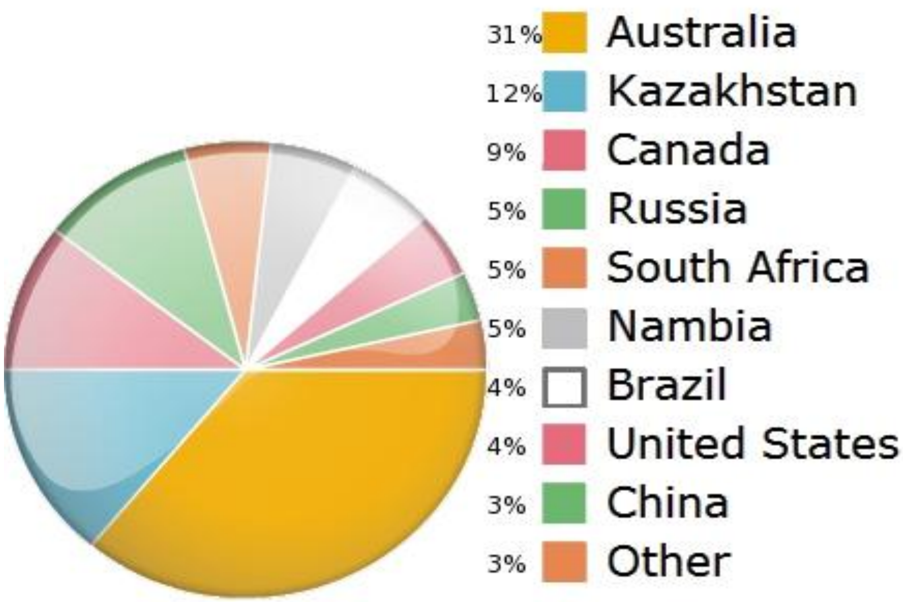
Discussion and Results

The total reserves of fossil fuels divided by the consumption rate per year of each fossil fuel yields the number of years each fuel can be produced at the current rate before the resource is exhausted. This is the simplest way to determine how long each fossil fuel will last. However there are some issues with this calculation that must be accounted for in order to make an accurate prediction. The first is the variability of the total reserves.

Each of the fossil fuels has a different amount of total reserves.(Figure 8) These are based on estimates of proven reserves which are areas or formations where there is a relatively high level of certainty of recovering the resource. In order for an area to be considered a proven reserve it must meet some guidelines. There must be a high certainty of recovering the resource that is confirmed either by drilling or imaging methods. In order to be considered a proven reserve the resource must also be economically recoverable. By definition this means that the total amount of proven reserves will fluctuate with the price of the resource. As the price of a resource rises, it becomes economically viable to extract the resource at a higher cost so the amount of proven resources increases.

The extraction of resources is highly driven by economic conditions, and because of this many of the terms used to describe resources relate to economics. Economically recoverable resources, for instance, are areas where a resource is likely to be recovered, but the cost of extraction requires certain economic conditions. For example, there may be a bed of high grade anthracite coal that can be mined, but the cost of extraction would be higher than the current value of the coal due to its depth or difficult extract. However, as economic conditions change and the price of coal rises, it becomes economically

Figure 7: The known recoverable resources of uranium by region in 2010. Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library



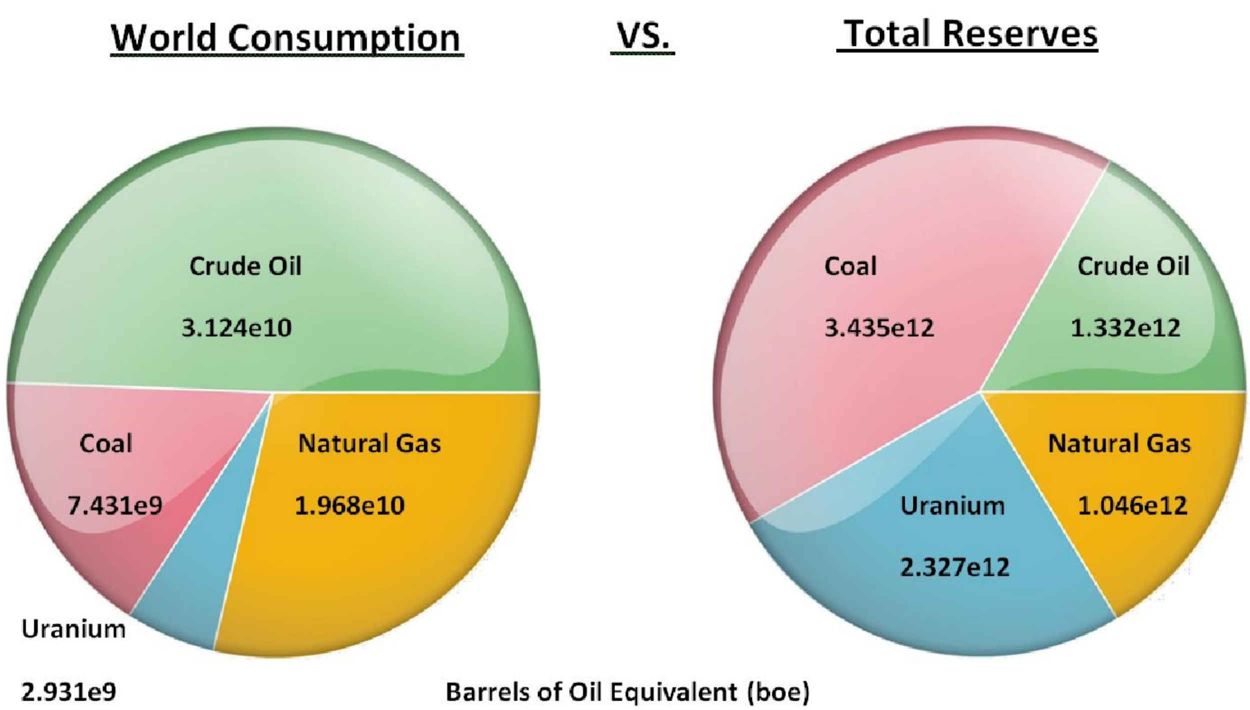


Figure 8: Representation of the worlds estimated total reserves of Oil, Natural Gas, Coal and Uranium. These are equalized to (BOE) barrels of oil equivalent so they can be represented equally in a pie chart.Source: U.S. Energy Information Administration - International Energy Outlook 2011www.eia.gov, BP Statistical Review of World Energy bp.com/statisticalreview, www.cia.gov/library

viable to mine the coal at the high price of extraction because the value of the coal exceeds the cost of mining. This principle also applies to undiscovered resources, which refers to areas where undiscovered but technically recoverable resources may exist that are recoverable under the right economic conditions.

The influence of economic growth will have one of the biggest effects on the production rate of fossil fuels in the future. In the past, basic supply and demand has dictated the rise and fall of production and prices. However, as fossil fuel reserves begin to decline while population growth and economic development rise, the need for resources will become greater.(Sibly 2002) This will become apparent with oil in the next 50 years. Oil is the most heavily used resource and offers the lowest total reserves. As economic growth increases, especially in developing countries with high potential for rapid growth, the need for oil will increase dramatically. The other fossil fuels are further from being depleted and are not relied on as heavily, so they will be affected less. Oil can be used to produce electricity, power motor vehicles, produce plastics and many other uses. Coal, natural gas and especially uranium have far more limited uses. Also, as of 2010 only about 8% of the world's energy consumption was from renewable resources.

Future trends in natural resources can be difficult to model because there are so many factors effecting future projections. It is also difficult to determine which of these factors will be first order variables and which will have a limited effect on the overall consumption and production. With the current estimates, as with any estimate of a numerical amount, there is a range between high and a low estimates.(Figure 11) This means that the projections of how long each resource will last will be within a varying degree of error. The next set of variables that must be considered are those that effect the consumption rate. These include: development of unconventional methods, advances in technology, economic trends, population growth, reliance on oil, coal, gas, and uranium, as well as the effect of increased use of renewable resources.The first three factors will likely push a graphical model of peak production in the positive direction with the peak further to the right. (Figure 10)

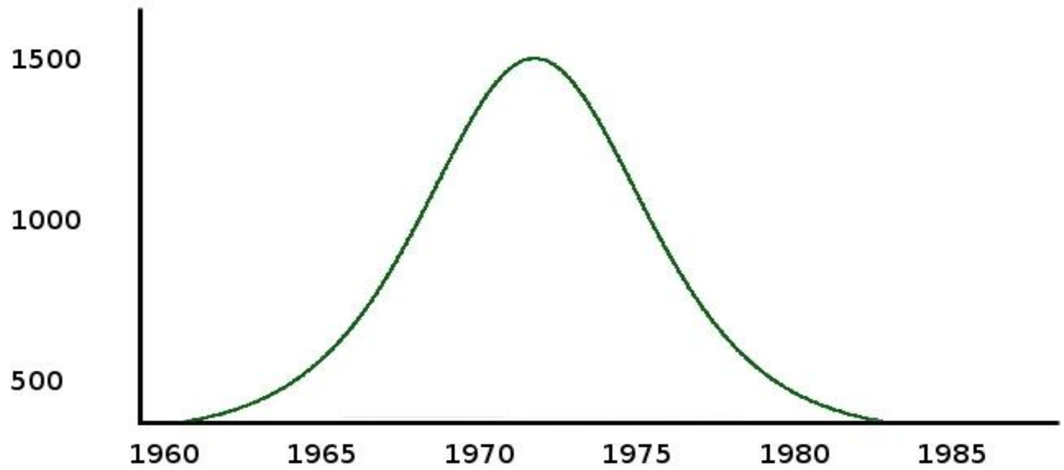


Figure 10: M. K. Hubbert's initial graph demonstrating the idea of the peak production of oil repented as a curve. He initially estimated that production of oil would peak around 1975.(Hubbert 1956)

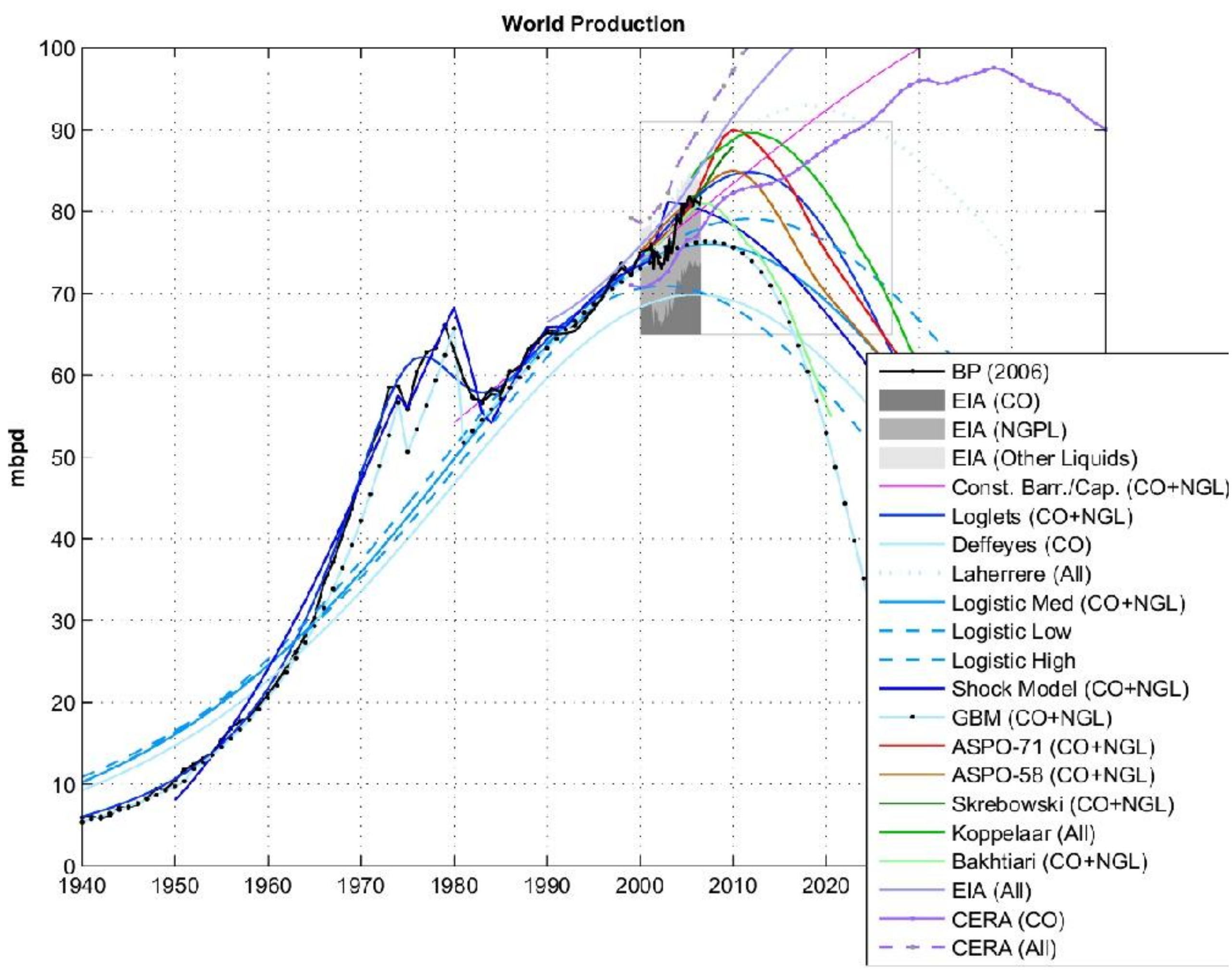


Figure 11: Models of peak oil production made by many different sources. These estimates are based on the amount of easily accessible oil and do not account of unconventional methods.

Development of unconventional methods for extracting resources opens up the possibility for huge growth in the total amount of resources estimated to be recoverable. If new unconventional methods prove to be productive they could push peak oil production well into the future.(Decora 1979) Hydraulic fracturing and horizontal drilling in order to extract natural gas from shale formations is an excellent example of this. By incorporating these techniques production companies have been able to produce large quantities of natural gas that was not recoverable with conventional methods. Some estimates have predicted that shale contains enough natural gas to meet the United States current consumption for 100 years. Unforeseen advances in technology would also greatly affect the curve in the positive direction. They could lead to areas that were once thought to be thoroughly drained of resources being productive again.(Lincoln 2005) For example, there are areas where depressurization has caused oil fields to become unproductive when a large amount of oil may still remain in the subsurface. If new technology were created to economically pump oil from depressurized well fields there could be a huge increase in the total amount of recoverable oil.

Economic trends will cause short term ups and downs in the price of resources however as resources become more depleted and the demand for resources continues to grow the increase in prices will be inevitable. This will be an interesting process especially in the case of oil. The price of oil will have to rise as it becomes less available in order to facilitate further exploration and production in difficult regions or through unconventional methods. This comes back to the idea of economically available resources. If the price of gas rises to ten dollars a gallon at the pump then the increase in price of oil will lower the demand for oil. It is a question of how long oil can stay an economically recoverable resource once it is no longer easily accessible through conventional methods.

On the other hand, population growth, economic trends, and reliance on oil, coal, gas, and uranium vs. an increased use of renewable resources would all likely be factors that pushed the curve in a negative direction. An increase in population would very likely mean an increase in the rate of resource consumption. This has been the case in developing countries since the Industrial Revolution began. As more countries begin to develop and the overall world population continues to grow, the strain on fossil fuel will increase. The variation in the reserve estimates is not especially important when it comes to making projections about the trends that resources are likely to have in the near future. This is because whether a resource is projected to last for 100 years or 150, the trends in production in the near future are related to current and near future consumption rates. The effects of production being strained by lack of resources will not begin to really effect consumption until the resource extraction prices begin to dramatically affect the consumer price.

Production and consumption of fossil fuels can be graphically modeled by curves to express the trends that they have taken and to predict what they will do in the future. The first thing that must be considered is what type of curve the general trend follows. The three curves I will use to compare and contrast production rates are a linear curve, a cubic or quadratic curve, and an exponential curve. (Figure 12) For these models I will use oil as the fossil fuel because it is the closest to being depleted. The first model that will be examined is the production of oil following a linear trend.(Figure 13) This seems very unlikely because the trends in the past have been increasing at a higher rate.

For the second model I have predicted that as population, development and the need for fossil fuels increase the production of each fossil fuel will follow an exponential growth curve with a measurable doubling time.(Figure 14) This would mean that at the point where peak oil is reached, it is just one doubling time away from being depleted. This model does not take into account the effects of resource availability and human limitations to continue production at an exponential rate. This is what would likely happen if production of oil did not have any limitations. Most estimates predict that peak oil has already been reached or will be in the next few years. If the growth rate is exponential then the doubling rate should be constant and the duration of oil reserves can be calculated. (Figure 14) The production of oil has doubled worldwide from 1968 to 2010; this is a period of 42 years. If the doubling time is constant then this model would predict that in 2052 almost all of the world's easily accessible oil will be depleted. This may be a little faster than is likely to happen because of limitations in

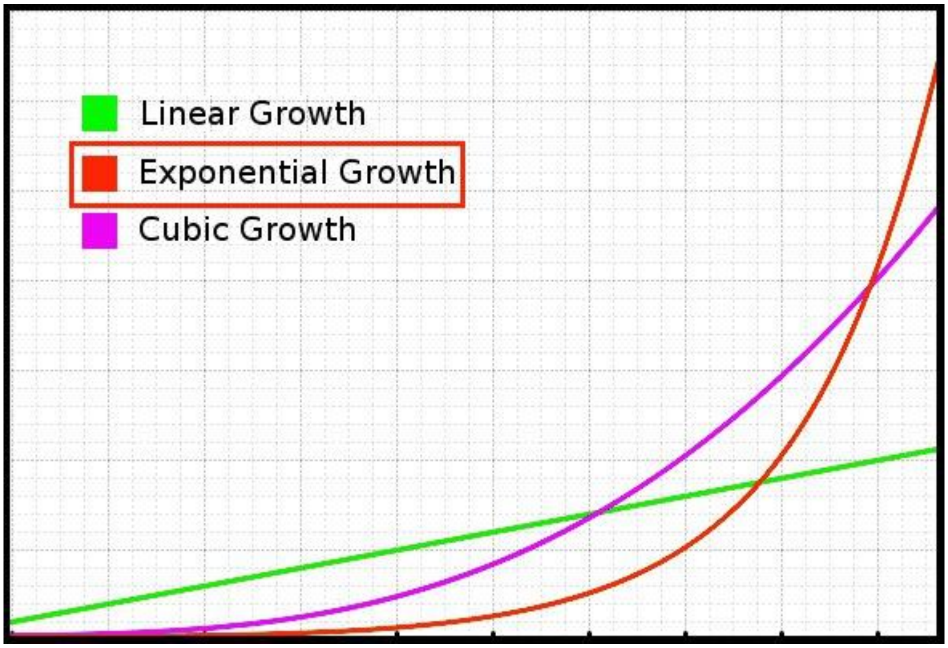


Figure 12: This is an example of three types of growth expressed as a curve. Exponential growth is outlined because it is the curve that will be discussed in the most detail.

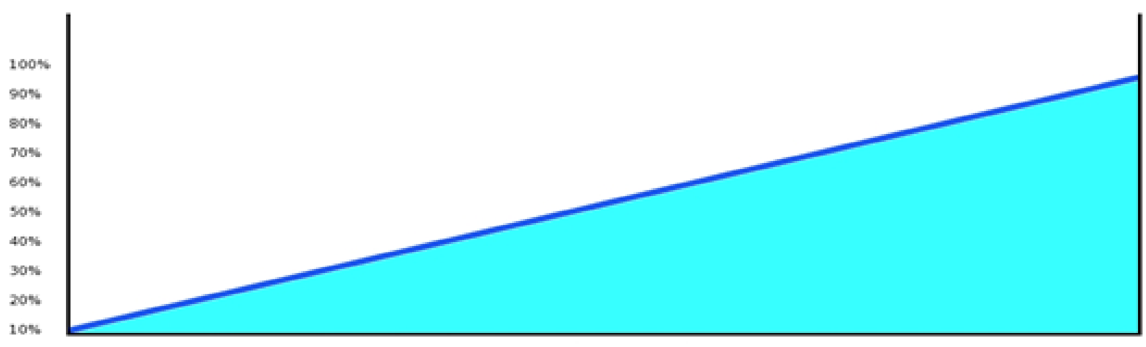


Figure 13: This is graphical representation of oil following a linear growth rate.

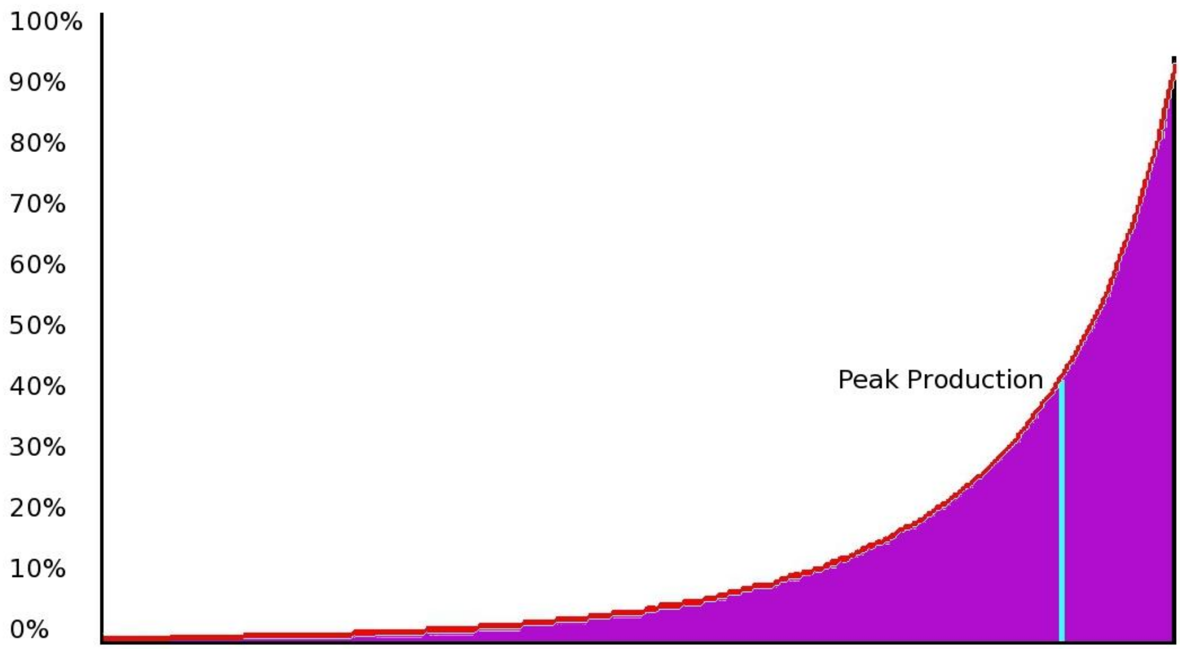


Figure 14: A graphical representation of the production of crude oil following an exponential curve

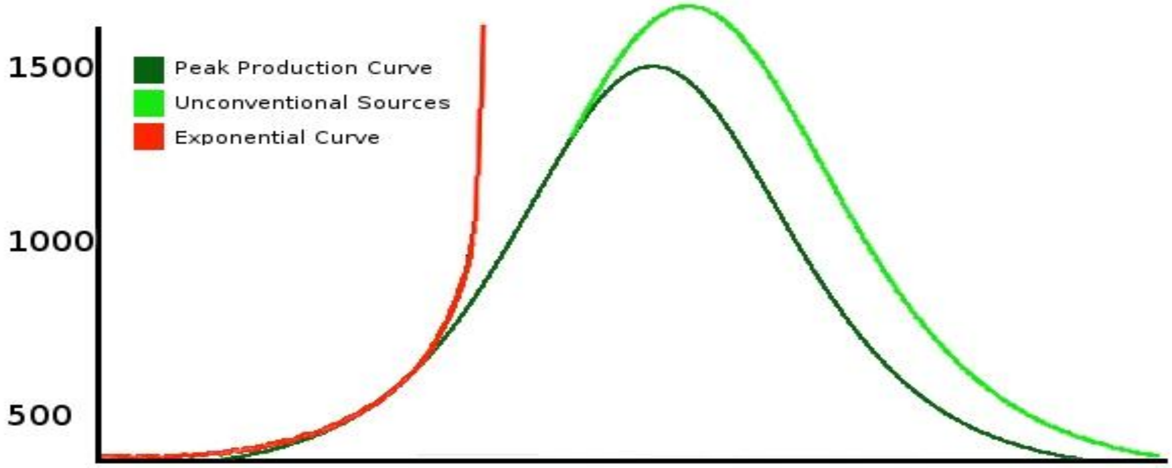


Figure 15: This is an example of Hubbert's peak curve, an extended prediction of the curve due to unconventional extraction of resources, and an exponential curve.

drilling speed and exploration. It is however the closest estimate to the three models of the trends oil will follow in the future.(Figure 15) When you divide the current consumption rate with the estimated total reserves the number of years that easily accessible crude oil reserves will last is 46. This means that if the current rate of production stays the same, in 46 years all of the world's easily accessible oil will be depleted. In reality it is unlikely that the production rate will stay at the level it is today. It is also safe to assume that consumption will continue to increase at an exponential rate. This means it will not fit any curve exactly so there will be a degree of uncertainty in any projection made.

Conclusions

The accumulation of the fossil fuels was a process that took hundreds of millions of years. In the last few hundred years, especially in the case of oil, we have used a high percentage of the total amount formed. The future trends of fossil fuels are difficult to predict because of the many different factors that affect the production and consumption of each fossil fuel. Coal, natural gas, oil and uranium will always remain in small quantities or in low concentrations on Earth but their ability to produce energy and mankind's dependence on them means they will be heavily extracted and refined. The factors controlling this are the key to understanding how long these resources will be available. If consumption increases then production must increase as well. With no signs of stopping we have, or will in the near future, reach a point where 50% of the easily accessible oil in the world has been extracted. The other resources still have larger amounts but the peak for coal, natural gas and uranium is in sight. Despite the variation and error in any model, it is undeniable that these resources exist in a finite amount and that they are running out. Whether oil lasts another 50, 100, or even 150 years we will have to face the fact that it will soon be gone and begin to adjust our society to reliance on other fuels. We are so heavily dependent on fossil fuels, between out power plants, motor vehicles and heating our homes that it will be difficult to reduce our dependence on them. However, it is something that must be done soon if a mad rush for the remaining quantities of fossil fuels is to be avoided. As of today only about 8% of the world's energy is produced from renewable sources. This must increase significantly in the next few decades if we are to break our dependency on fossil fuels. There are many options for producing energy through renewable methods such as: hydroelectric, geothermal, wood, wind, and solar power. Time will tell which of these, or some new alternative fuel, will prove to be capable of meeting the world's energy demands.

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Definitions of terms taken from U.S. Department of the Interior, Survey of Available Data on OCS Resources and Identification of Data Gaps, Report to the Secretary, OCS Report MMS 2009-015, compiled by Congressional Research Service