Coal Extraction in the United States

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Introduction

The amount of coal that can be extracted in the United States as a function of time (the depletion curve or function) is a crucial part of the future of the country. This article does the math to arrive at an estimate of the U.S. coal-depletion curve and coal-depletion curve for several states.

Also, depletion curves for the main states in which coal is extracted are presented.

Crude-Oil-Extraction, Recoverable-Reserves and Reserve-Base Data for the United States

The Energy Information Agency of the United States government has annual extraction data (they call it "production", which is incorrect verbiage; natural resources are extracted, not produced): http://www.eia.gov/coal/data.cfm#production .

The Energy Information Agency has estimated recoverable-reserves data: http://www.eia.gov/coal/annual/pdf/table14.pdf

The Energy Information Agency also has estimated reserve-base data: http://www.eia.gov/coal/data.cfm#reserve .

Depletion Function for Fitting to Extraction Data

The depletion function used to fit the data is the Verhulst function (http://www.roperld.com/science/minerals/VerhulstFunction.htm):

$$P(t)=\frac{Q_\infty}{n\tau}\frac{(2^n-1)\exp\left(\frac{t-t_{\frac{1}{2}}}{\tau}\right)}{\left[1+(2^n-1)\exp\left(\frac{t-t_{\frac{1}{2}}}{\tau}\right)\right]^{\frac{n+1}{n}}}.$$

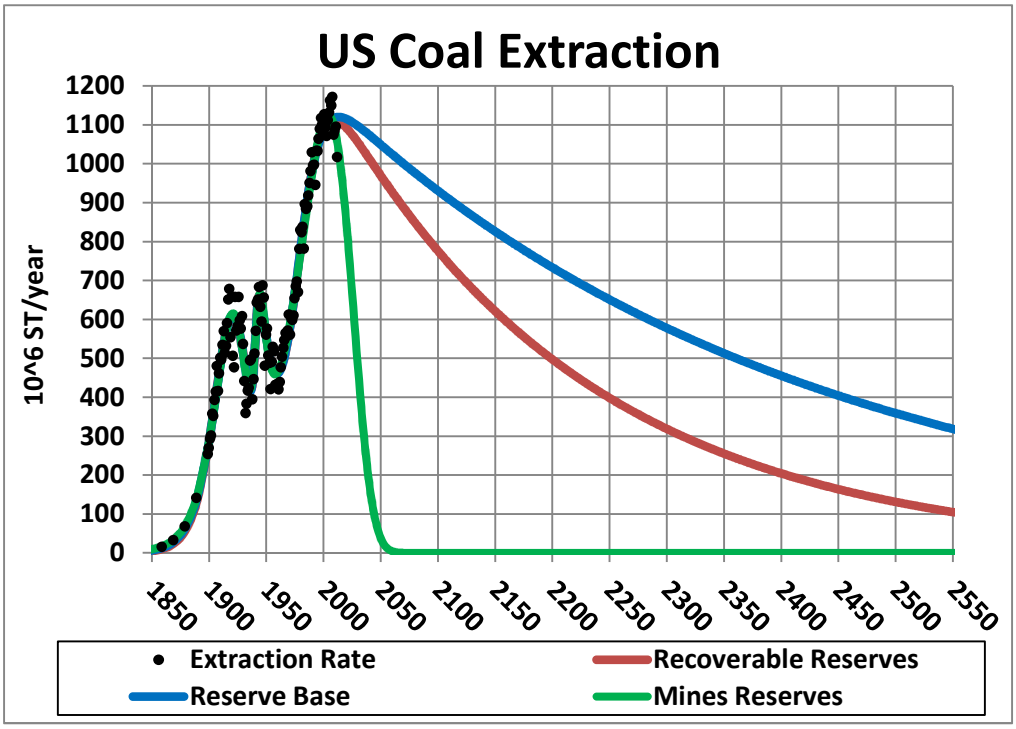
Q_∞ is the amount to be extracted eventually, τ is the rising exponential time constant, $n\tau$ is the falling exponential time constant and $t_{1/2}$ is the time at which the resource is one-half depleted. The parameter n determines the amount of skewing at large times; it must be greater than 0. For n = 1 the extraction curve is symmetrical and the peak occurs at $t_{1/2}$. The deviation of the peak time from $t_{1/2}$ is negative for n > 1 (skewed toward higher times) and is positive for 0 < n < 1 (skewed toward lower times).

The maximum of P(t) occurs at $t_{\max}=t_{1/2}+\tau\ln\left(\frac{n}{2^n-1}\right)$, which yields $P_{\max}\left(t_{\max}\right)=\frac{Q_\infty}{\tau}\frac{1}{(n+1)^{\frac{n+1}{n}}}$.

The unit of extraction is 10^6 short tons (ST).

Depletion Fit to Total United States Coil-Extraction Data

Three-Verhulst- function fits to the U.S. extraction data are shown here:



The amount to be extracted (area under the **blue curve**) is 560,461x10^6 ST (481,385x10^6 ST reserve base in 2012 + ~79,425x10^6 ST already extracted by 2012). (I.e., about 14% has already been extracted. The peak is at year 2012. There might be later peaks instead of a smooth decline in extraction, which would be followed by a faster drop.

The amount to be extracted (area under the **red curve**) is 336,516x10^6 ST (257,648x10^6 ST reserves in 2012 + ~79,425x10^6 ST already extracted by 2012). (I.e., about 24% has already been extracted. The peak is at year 2009. There might be later peaks instead of a smooth decline in extraction, which would be followed by a faster drop.

The amount to be extracted (area under the **green curve**) is 98,089x10^6 ST (18,664x10^6 ST mines' reserves in 2012 + ~79,425x10^6 ST already extracted by 2012). (I.e., about 81% has already been extracted. The peak is at year 2004.

It appears that "peak coal" has arrived for the United States. http://en.wikipedia.org/wiki/Peak_coal

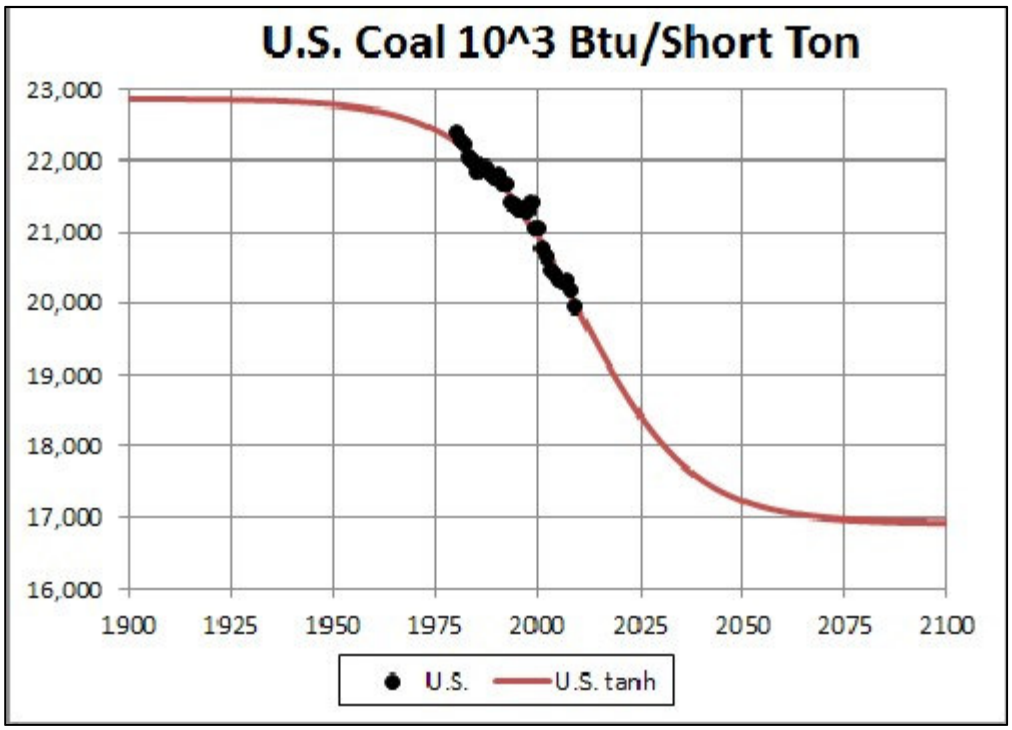
Some Interesting Facts about Coal

Energy Content of Coal

The energy contents of the three different classes of coal are (1 MBtu/ST = 0.8598 MJ/kg):

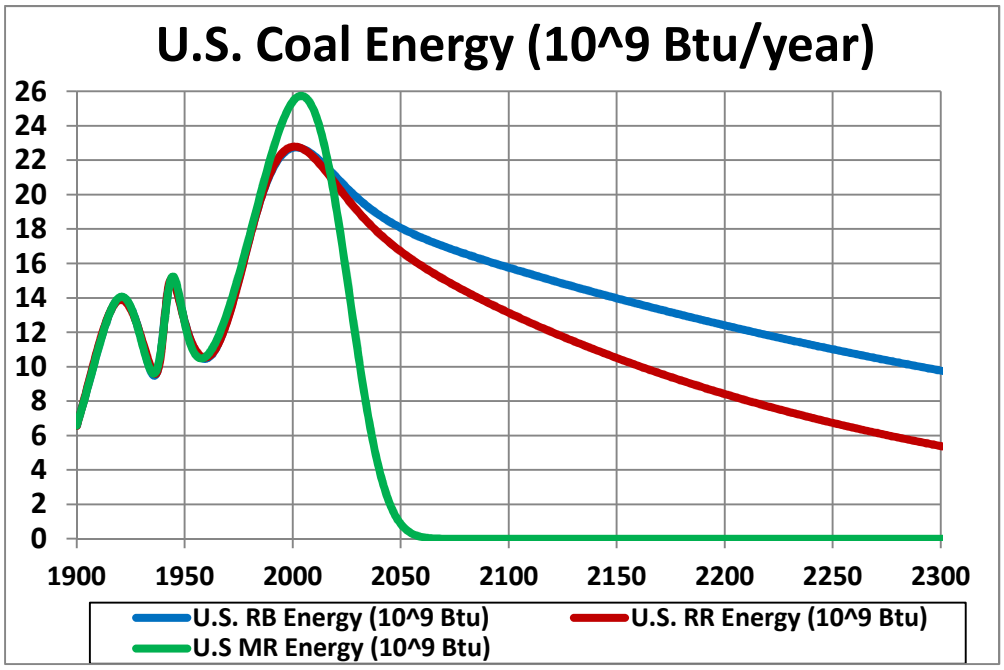
Coal energy density	**MJ/kg**	MBtu/ST
Anthracite:	32.50	28.0
Bituminous:	24.00	20.5
Lignite:	16.50	14.0

The energy/weight of coal extracted in the U.S. as a function of time; the data are from (http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=1&pid=1&aid=10&cid=&syid=1980&eyid=2009&unit=TBTUPST) and a hyperbolic-tangent function (http://www.roperld.com/science/Mathematics/HyperbolicTangentWorld.htm) fit to the data is:



As seen in the table above the final asymptote is somewhat above the energy content of lignite (14 MBtu/ST), as it should be. The initial asymptote is equivalent to mostly bituminous (20.5 MBtu/St), as it should be.

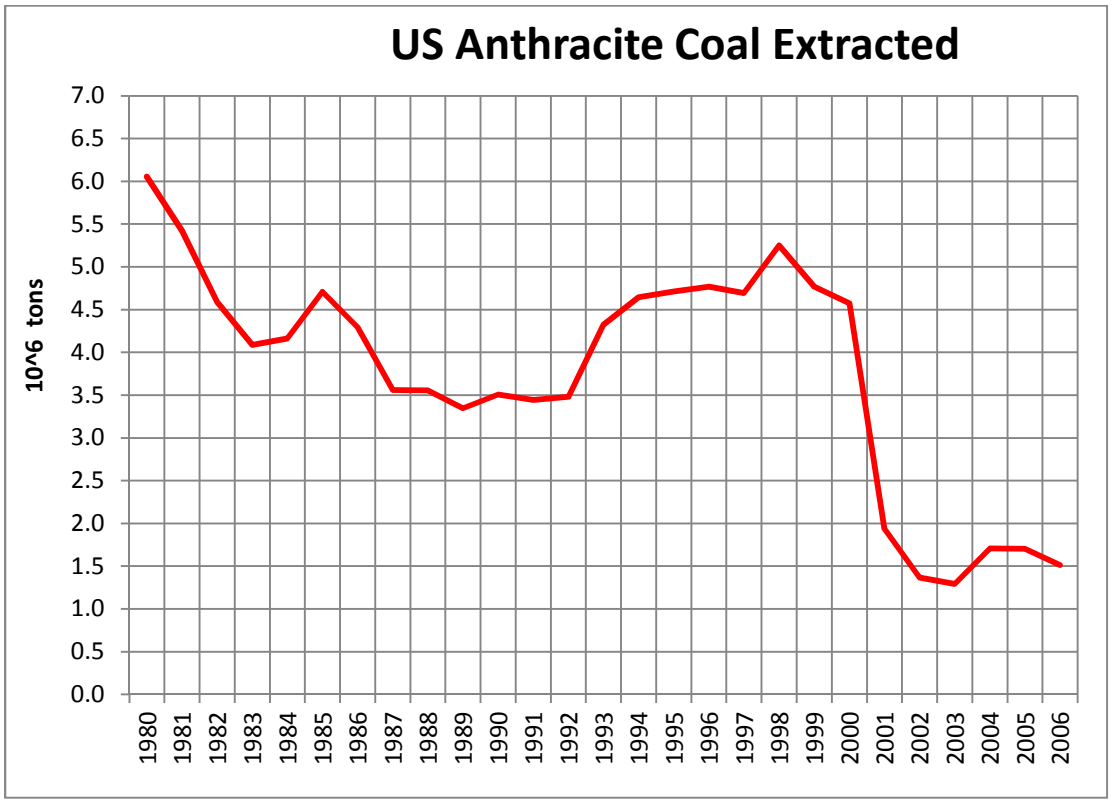
Putting the last two graphs together, the energy available from coal in the U.S. is



Although U. S. coal extraction peaks at ~2004-2012, U.S. coal energy peaks at ~2000-2004.

Coal Types Mined in the U.S.

Most of the coal mined in the U.S. is bituminous (http://www.eia.gov/emeu/international/coalproduction.html), with lesser lignite. Anthracite extraction is very small:

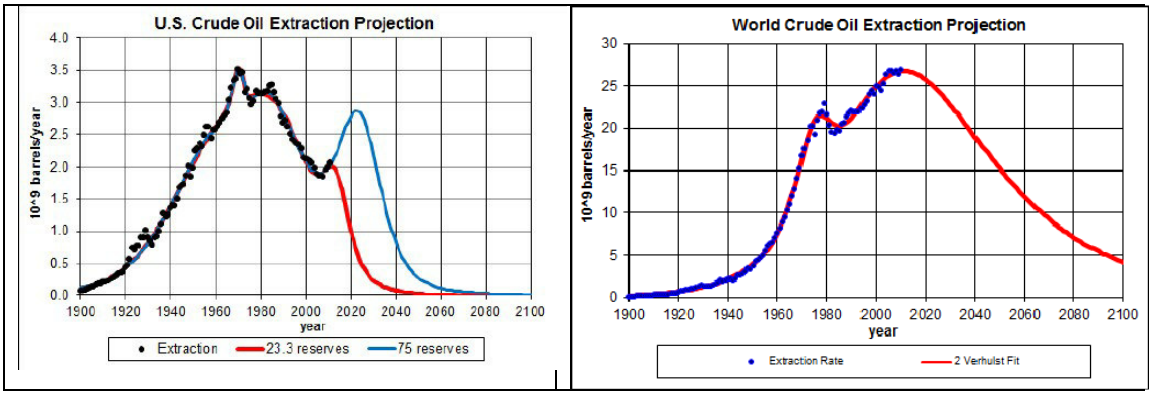


Coal Prices Prediction

http://www.roperld.com/science/minerals/coalpricesprediction.htm

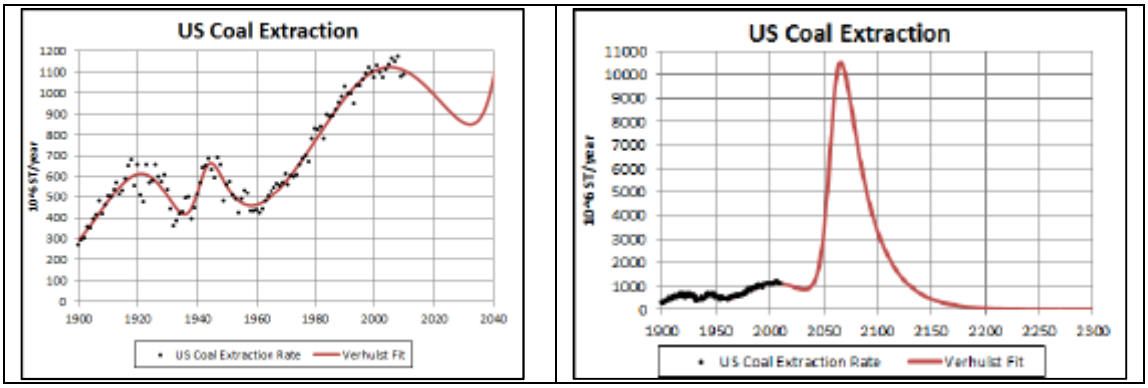
What if Liquid Fuel from Coal becomes Viable?

Because of the rapid depletion of crude-oil extraction in the United States and the world, a time may come when producing liquid fuels from coal becomes viable. Here are graphs of the probable future of crude-oil extraction in the U.S. and the world:



From these graphs 2050-2100 appears to be a time when liquid fuel production from coal might peak.

Here are graphs showing how producing liquid fuels from coal in the U.S. might affect coal extraction:



Because of environmental concerns, coal extraction might drop for a decade or longer and then rise rapidly as liquid-fuels production from coal occurs. Of course, it then has to fall rapidly after peaking because of depletion.

Better Use of Coal

Burning coal is the main cause of increasing carbon dioxide in the atmosphere, the main cause of global warming. If disastrous effects of global warming are to be mitigated in the future, burning coal must be curtailed.

Future generations will rue the burning of coal by current generations, because a much better use of it is to make useful objects. Making useful objects of coal (and other fossil fuels) sequesters the carbon instead of putting it in the atmosphere. Also, the material in the objects can be recycled to make other objects in the future.

U.S. States Coal Extraction

The United States is divided into five regions with regard to coal extraction:

Central Appalachia 12,500 Btu/lb, 1.2 SO_2/lb	Northern Appalachia 13,000 Btu/lb, <3.0 SO_2/lb	Illinois Basin 11,800 Btu/lb, 5.0 SO_2/lb	Powder River Basin 8,800 Btu/lb, 0.8 SO_2/lb	Uinta Basin 11,700 Btu/lb, 0.8 SO_2/lb

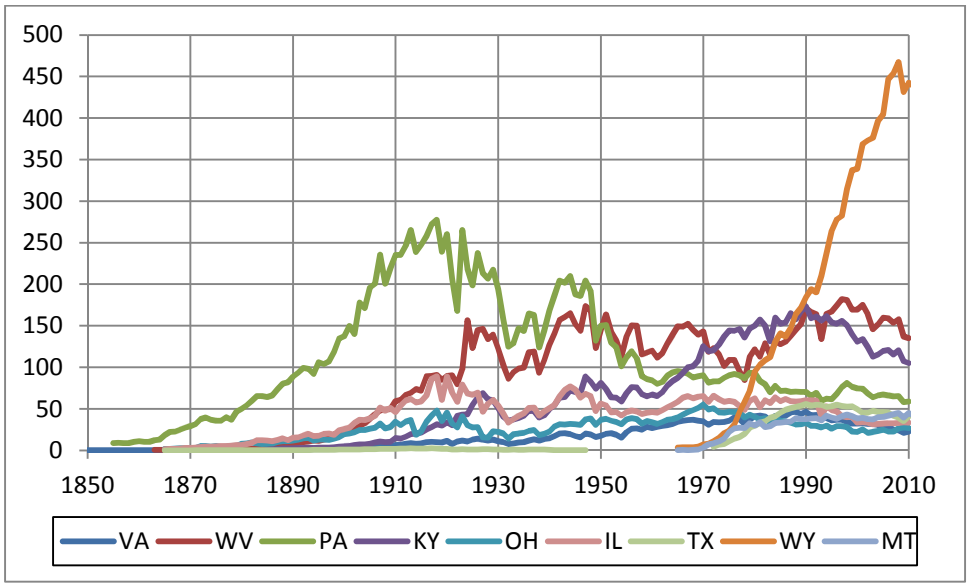
1 Btu = 1055.056 joules = 2.930711×10^{-4} kWh
1 lb = 0.45359237 kg
1 MJ/kg = 429.9226 Btu/lb

Below are given the historical coal-extraction data for the states that have yearly rates of 50×10^6 tons/year for some years and projections of extraction into the future.

Coal-extraction data are given in:

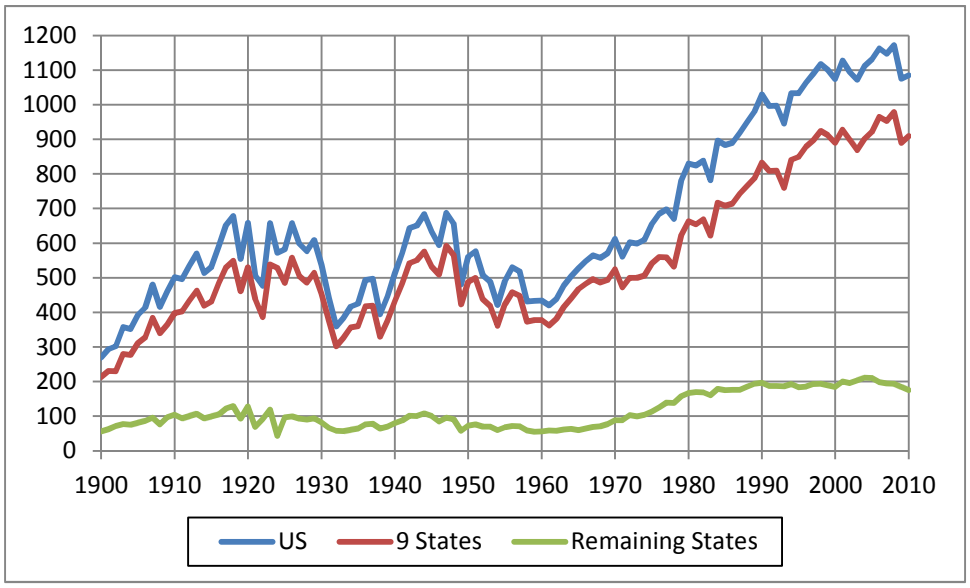
- 1700-1995: http://pubs.usgs.gov/of/1997/of97-447/
- 1985, 1990-4: http://www.eia.gov/coal/annual/archive/05841994.pdf
- 1994-7: http://www.eia.gov/coal/annual/archive/05841997.pdf
- 1997-2000: http://www.eia.gov/coal/annual/archive/05842000.pdf
- 2001-2: http://www.eia.gov/coal/annual/archive/05842002.pdf
- 2003-4: http://www.eia.gov/coal/annual/archive/05842004.pdf
- 2005-6: http://www.eia.gov/coal/annual/archive/05842006.pdf
- 2007-8: http://www.eia.gov/coal/annual/archive/05842008.pdf
- 2009-10: http://www.eia.gov/coal/annual/pdf/table1.pdf

Here is a comparison of the coal-extraction data for the nine states with the highest extraction peak:



The unit of extraction is 10^6 short tons (ST). Note that extraction rates for eight of the states are declining, with only Wyoming increasing, except for the last four years.

This shows the comparison of coal extraction for the nine states and the remaining states with the total U.S. extraction:

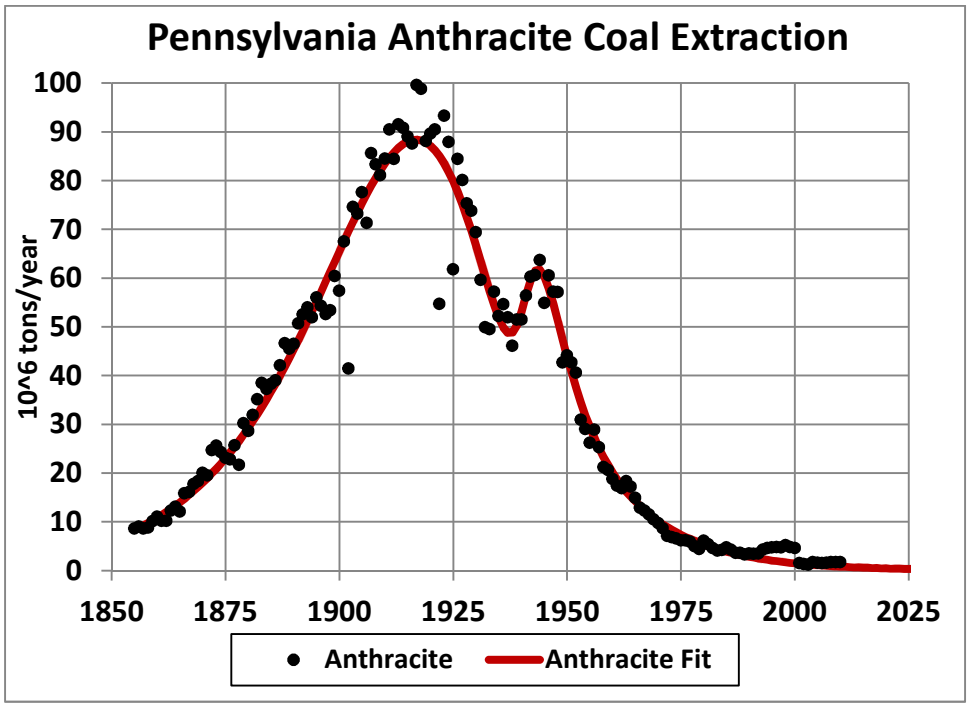


In the following the nine-states' extraction data will be discussed in the order of the highest to the lowest peaks before 1970: Pennsylvania, West Virginia, Kentucky, Illinois, Ohio and Virginia; followed by the states with the most recent peaks: Wyoming, Texas and Montana.

Pennsylvania Coal Extraction

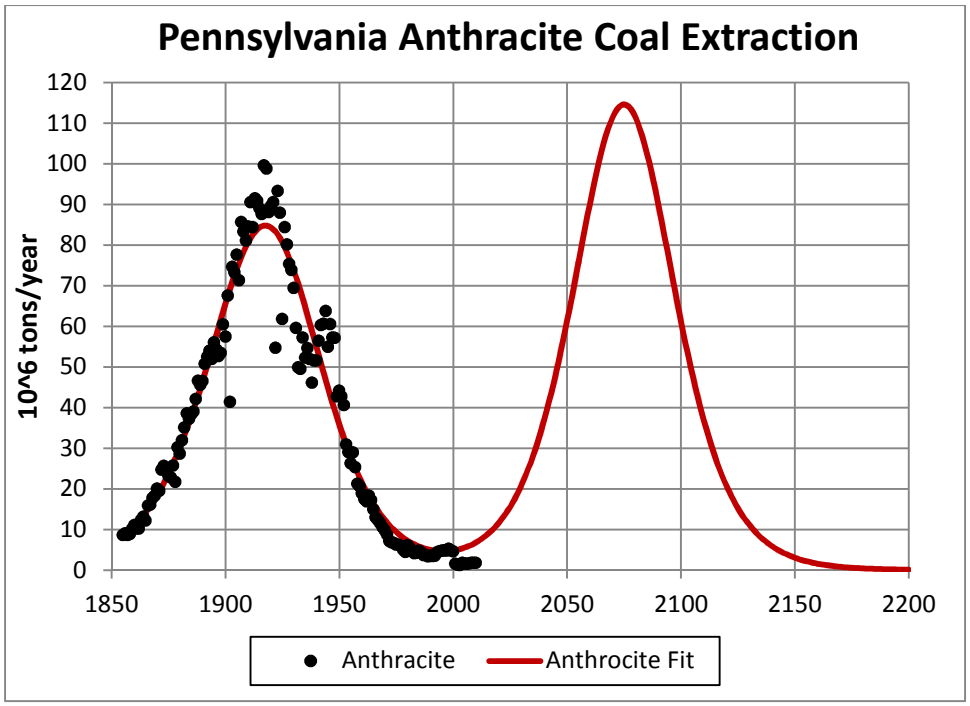
Pennsylvania is the main state where anthracite, the coal with the highest energy content, has been mined. (http://en.wikipedia.org/wiki/Anthracite) So, coal-extraction data for Pennsylvania is divided between anthracite coal and bituminous coal. (http://en.wikipedia.org/wiki/Bituminous_coal)

Pennsylvania Anthracite-Coal Extraction



The area under the red best-fit curve is the amount to be extracted eventually (5619x10^6 tons). The reserve-base number is estimated at 7100 x10^6 tons; much higher. The recoverable-reserves number is estimated at 39 x10^6 tons, much lower.

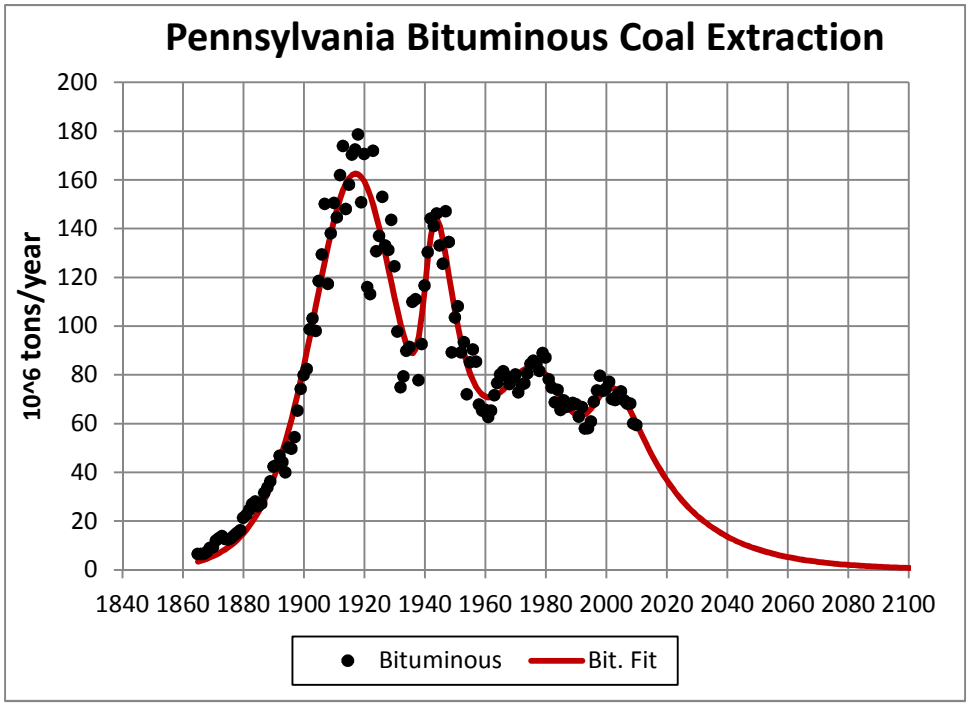
Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental.

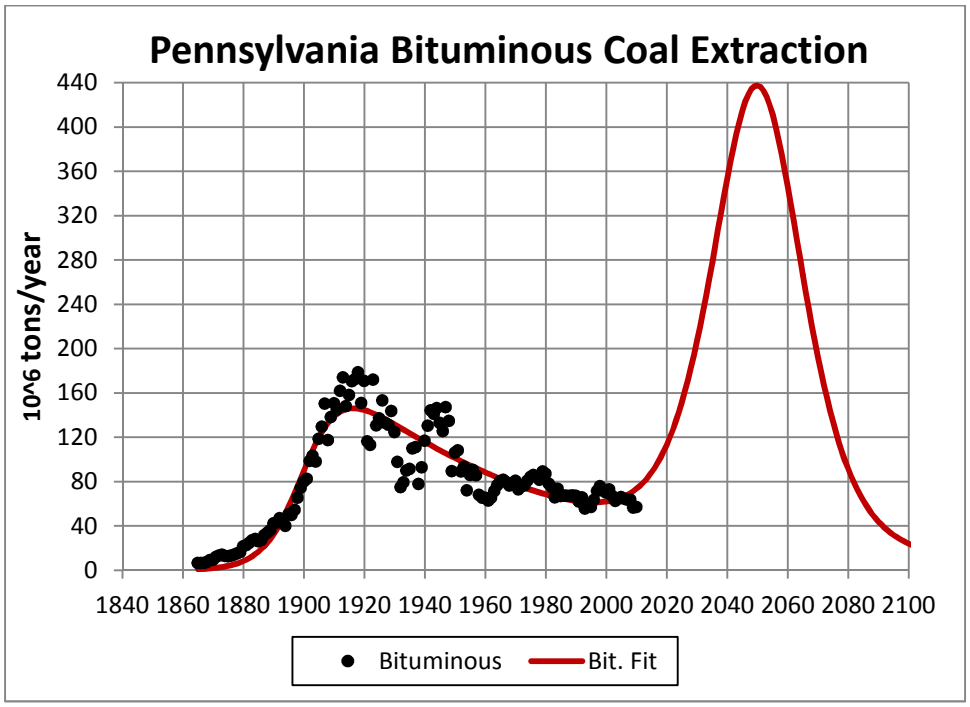
Since anthracite coal is the best coal for making objects and coal should be used to make useful objects instead of being burned, perhaps a strong effort should be made to mine more anthracite coal, but not to burn it.

Pennsylvania Bituminous-Coal Extraction



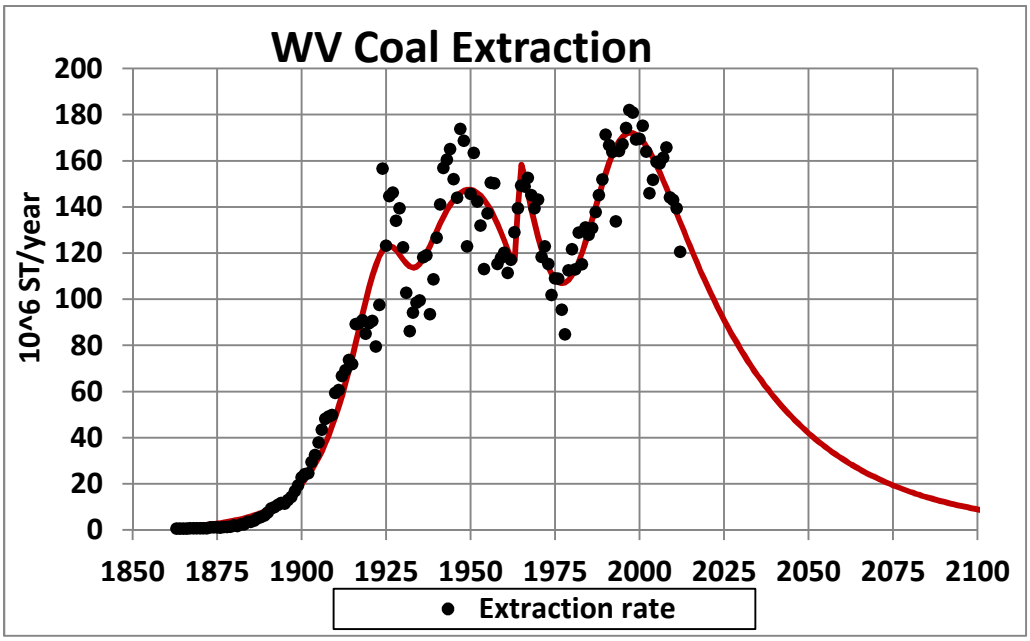
The area under the red best-fit curve is the amount to be extracted eventually (15,874x10^6 tons). The reserve-base number is estimated at 19,800 x10^6 tons; much higher. The recoverable-reserves number is estimated at 532 x10^6 tons, much lower.

Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



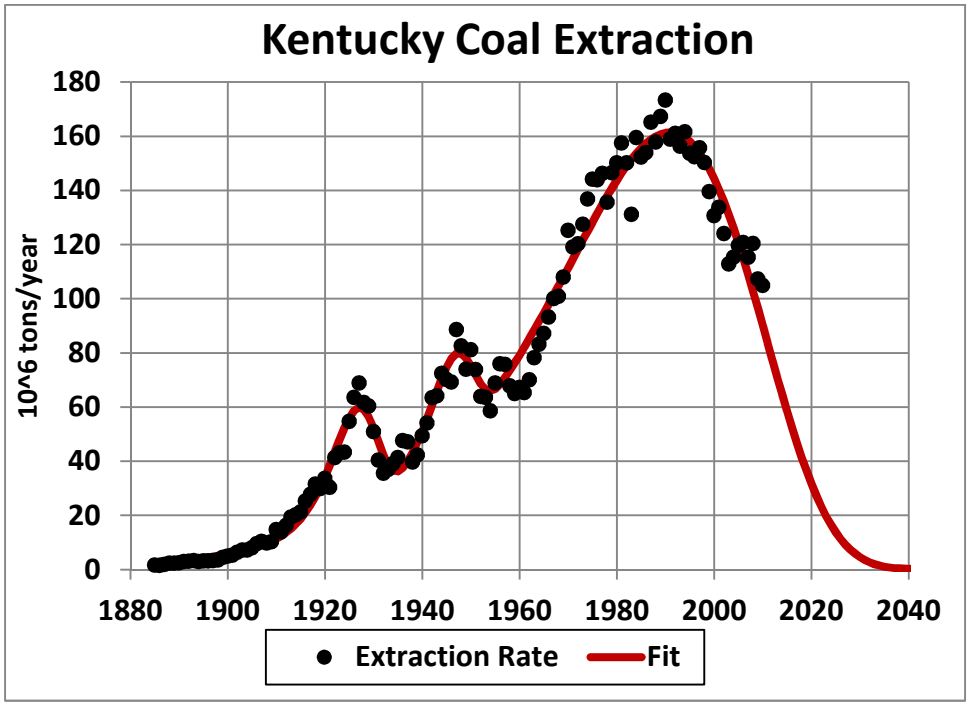
The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental.

West-Virginia Coal Extraction



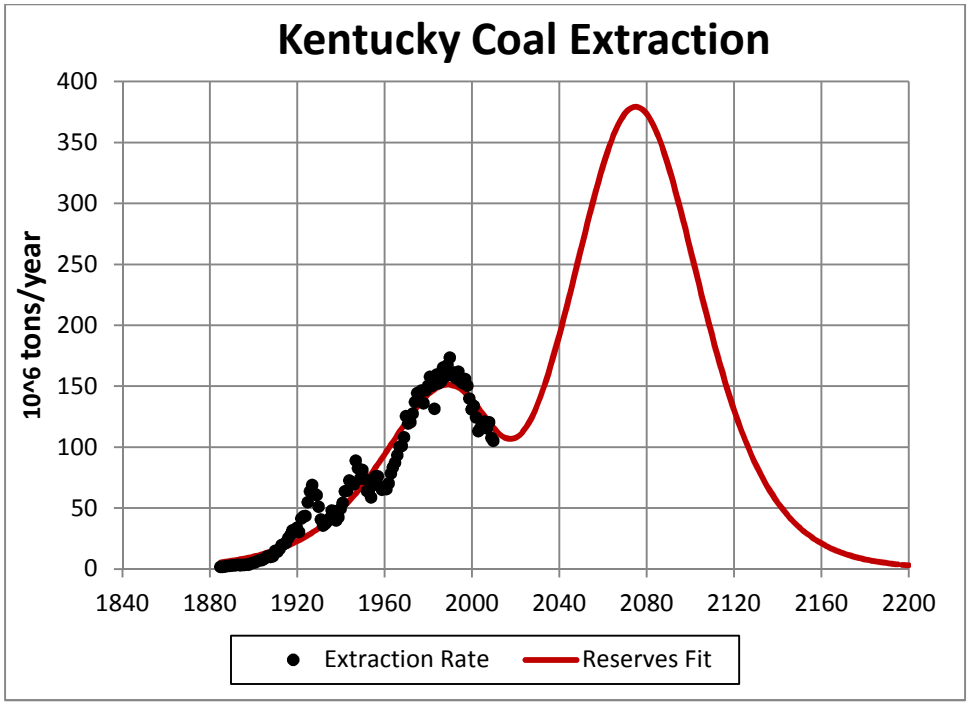
The area under the red best-fit curve is the amount to be extracted eventually (18,198x10^6 tons). There could be another peak in the future.

Kentucky Coal Extraction



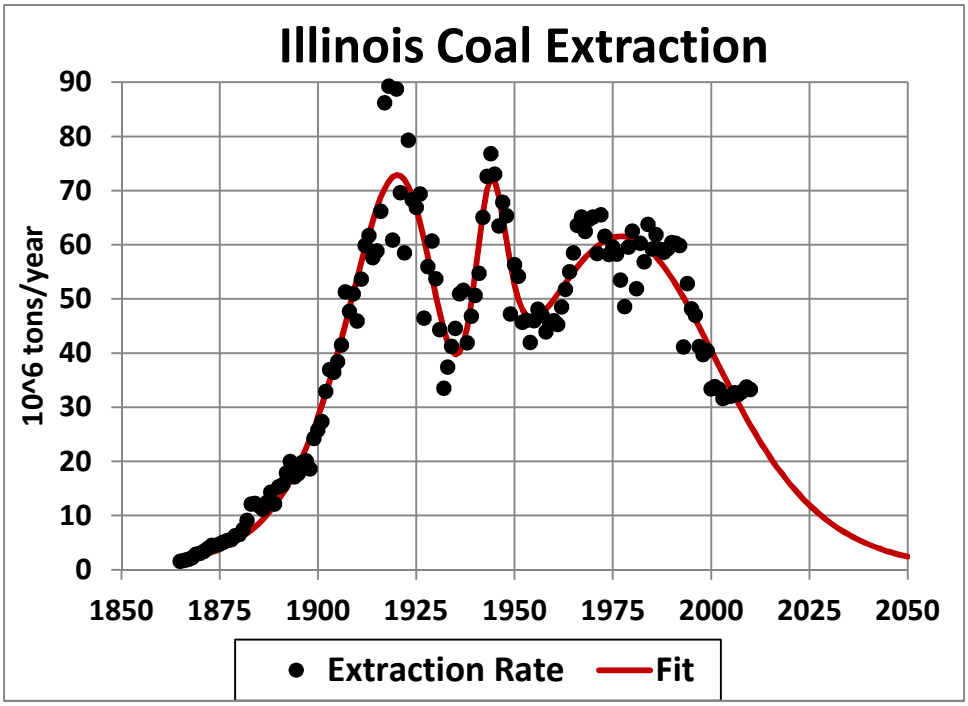
The area under the red best-fit curve is the amount to be extracted; it is 10,035x10^6 tons. The reserve-base number is estimated at 29,300 x10^6 tons; much higher. There could be another peak in the future.

Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



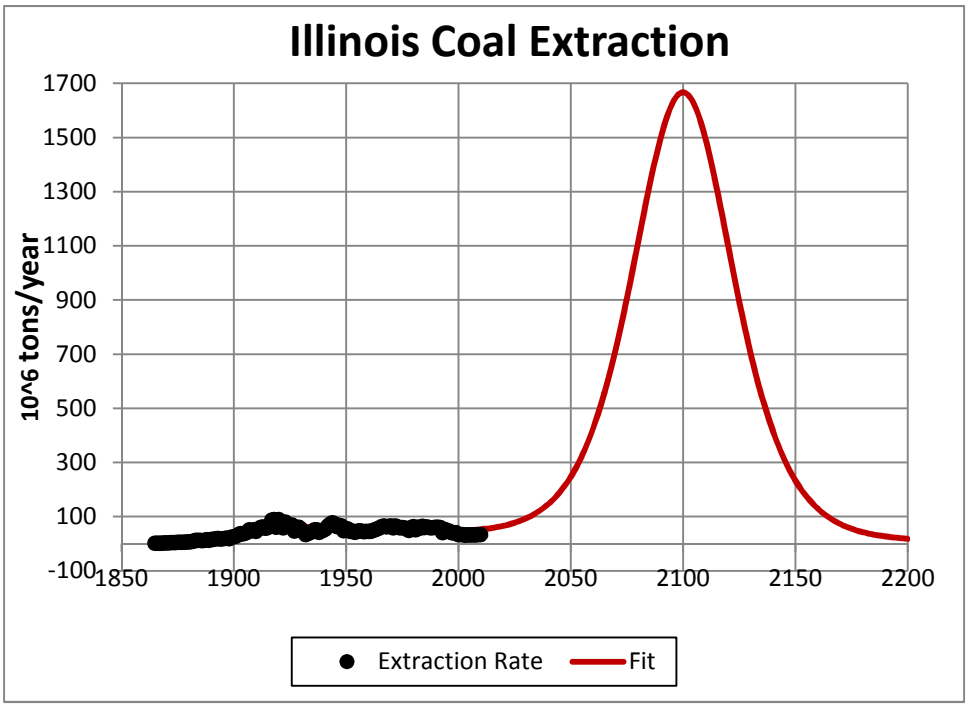
The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental.

Illinois Coal Extraction



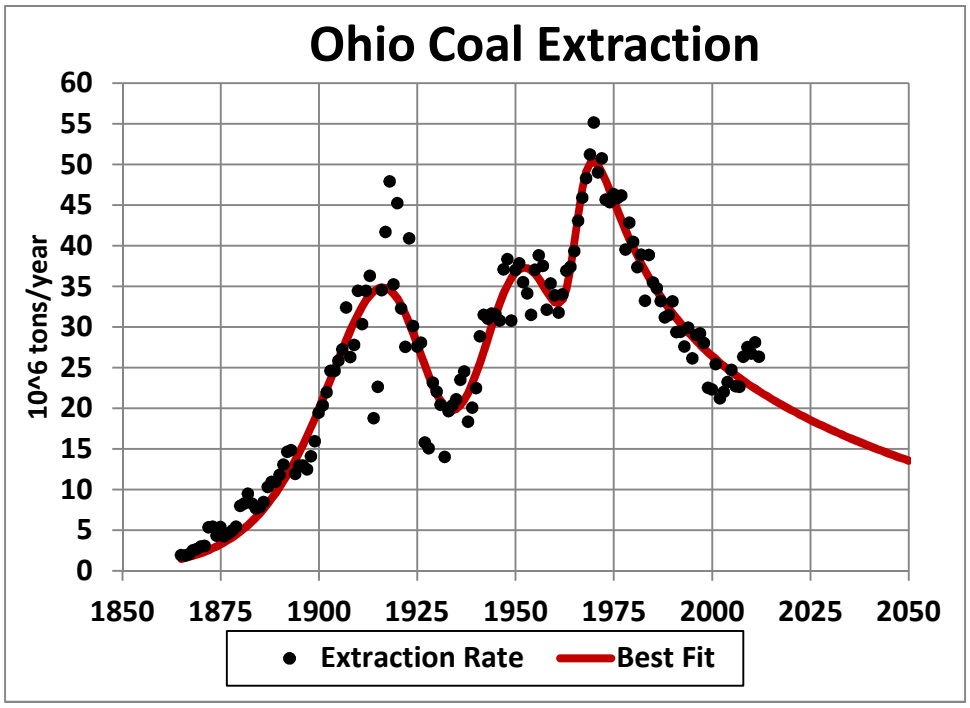
The area under the red best-fit curve is the amount to be extracted; it is 6,646x10^6 tons. There could be another peak in the future.

Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



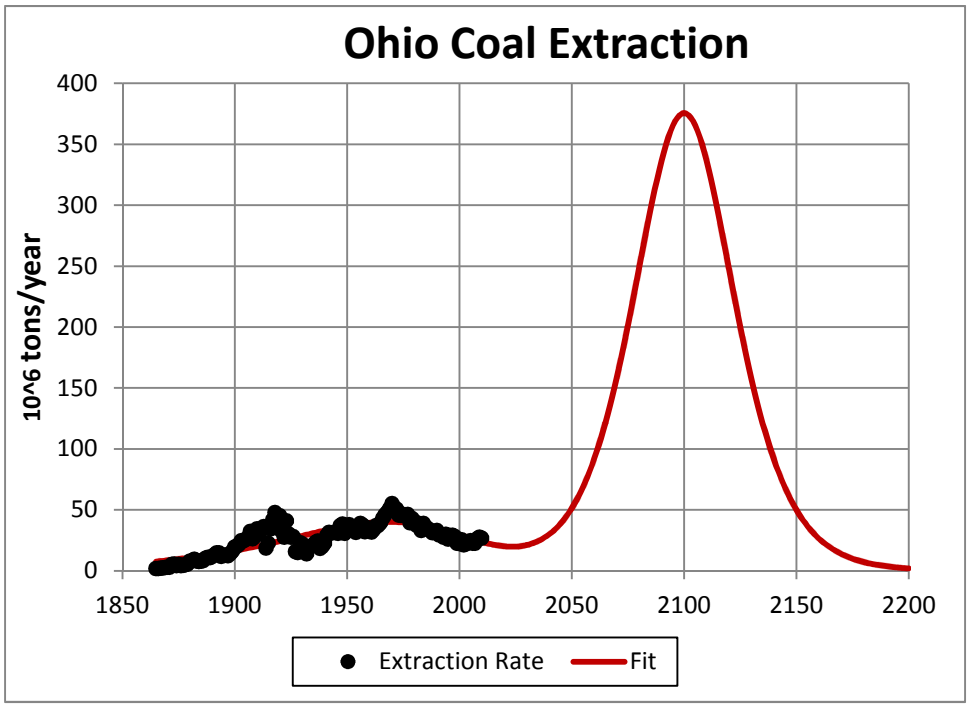
The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental.

Ohio Coal Extraction



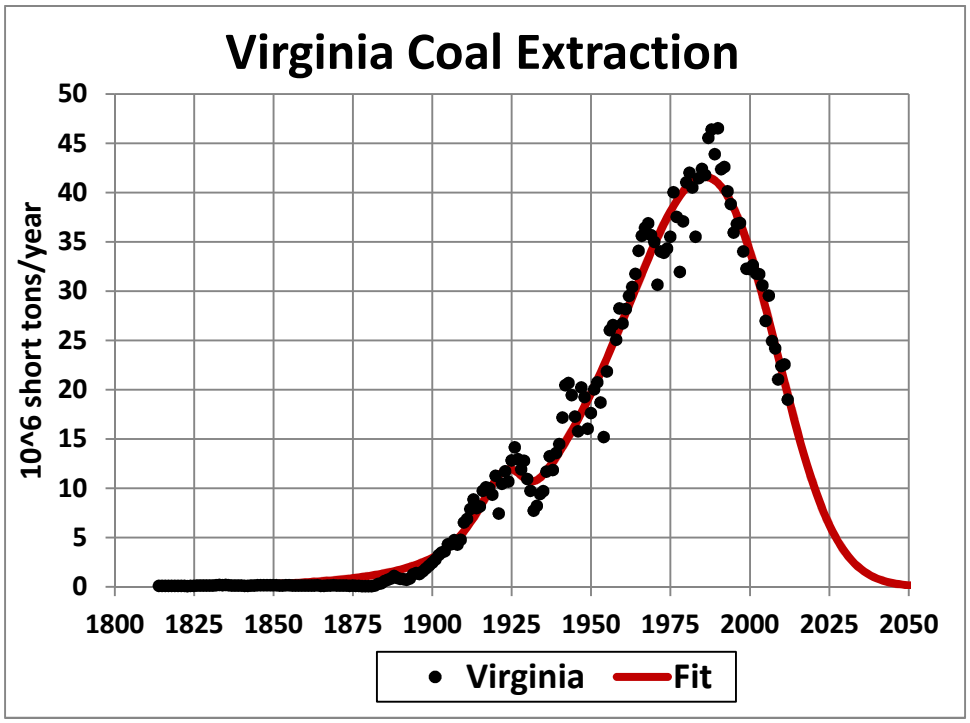
The area under the red best-fit curve is the amount to be extracted; it is 5,597x10^6 tons. There could be another peak in the future.

Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



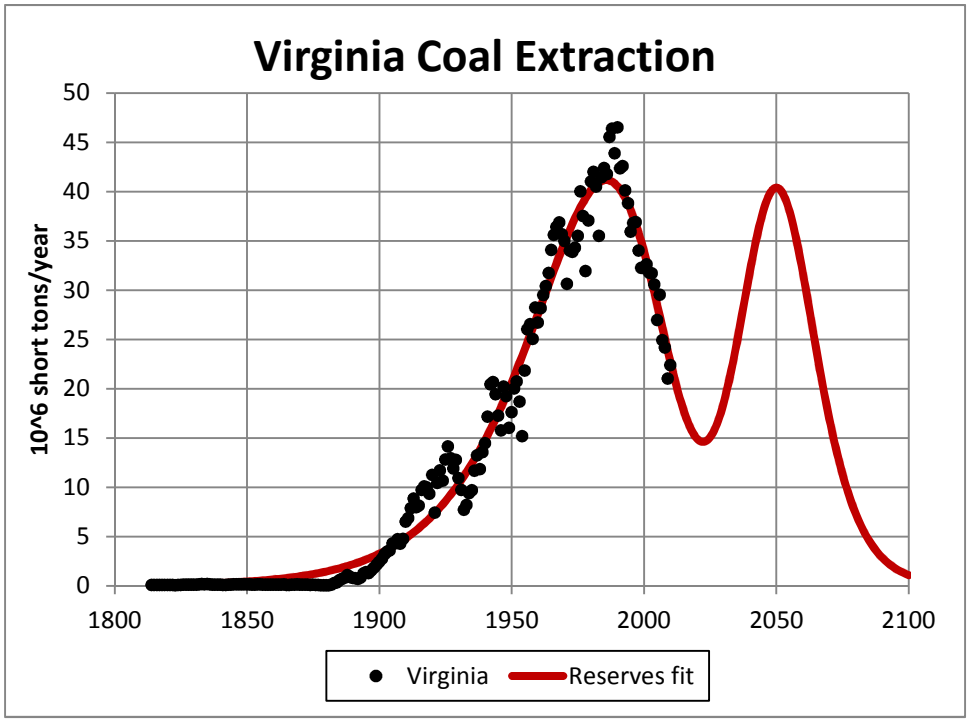
The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental.

Virginia Coal Extraction



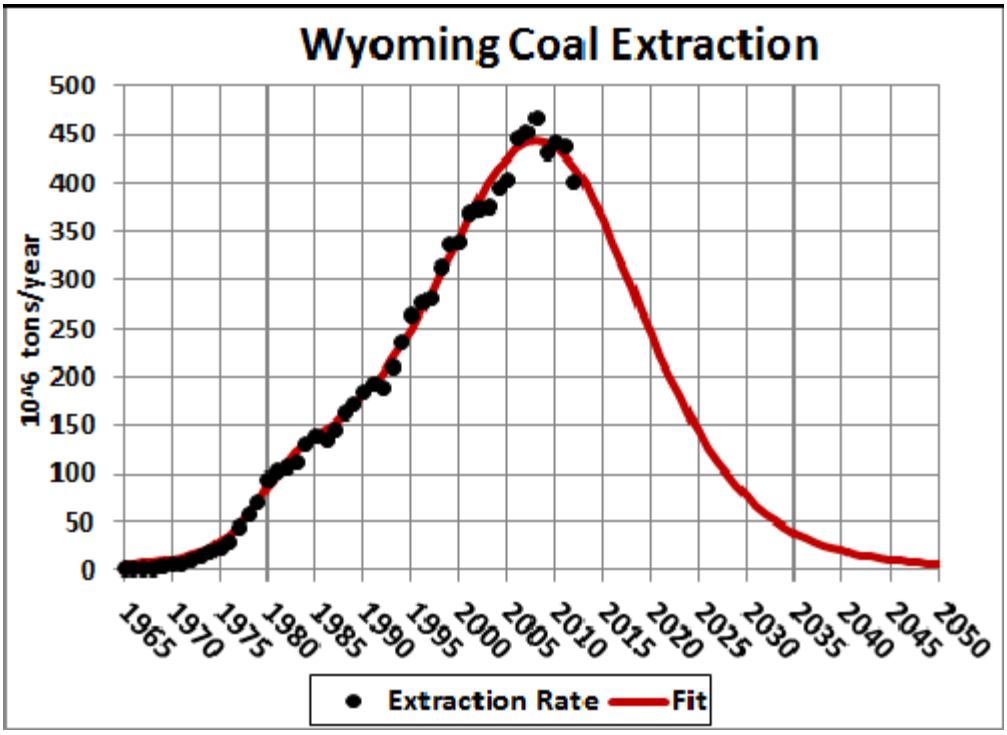
The area under the red best-fit curve is the amount to be extracted eventually (2,824x10^6 tons). There could be another peak in the future.

Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



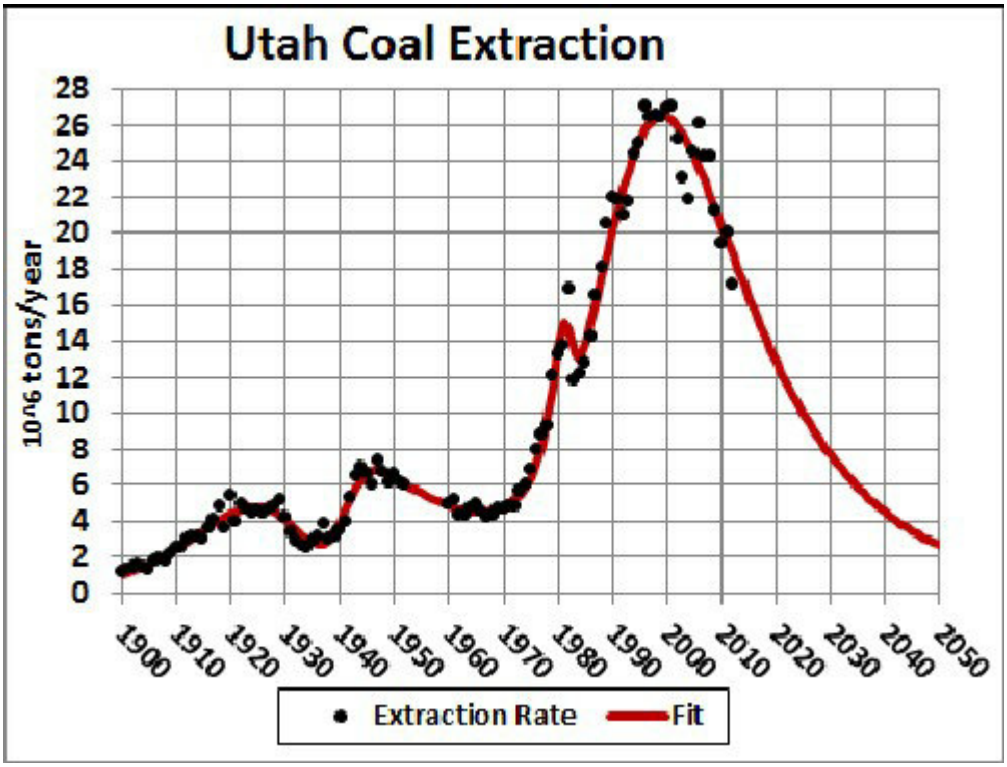
The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental

Wyoming Coal Extraction



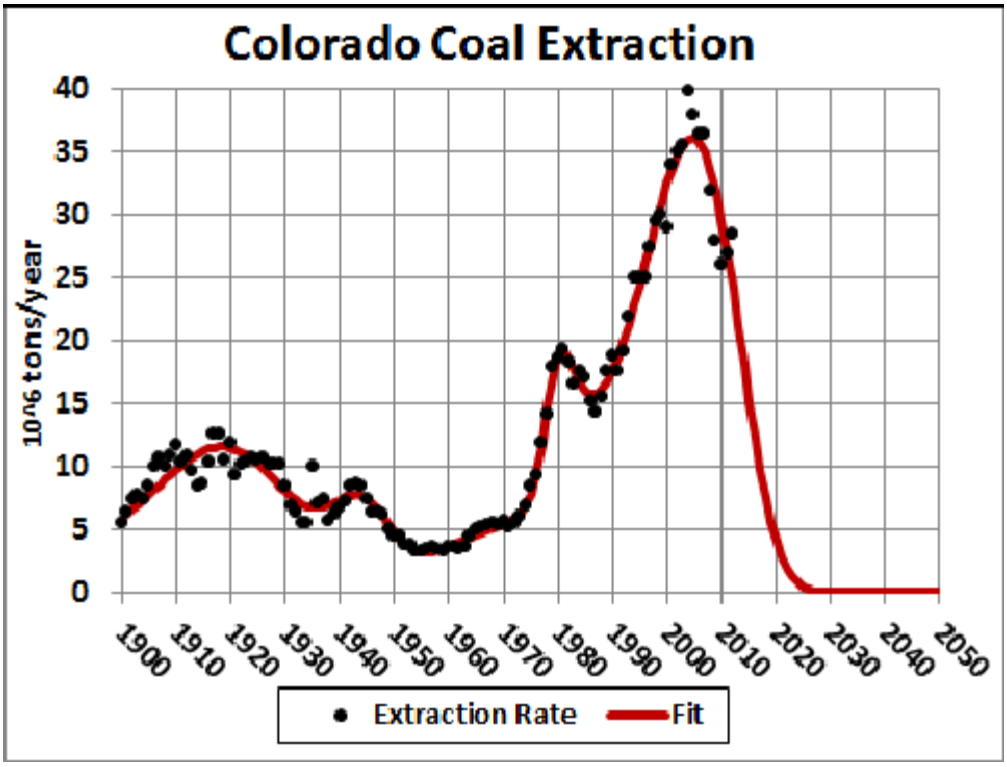
The area under the red best-fit curve is (12,181x10^6 tons).

Utah Coal Extraction



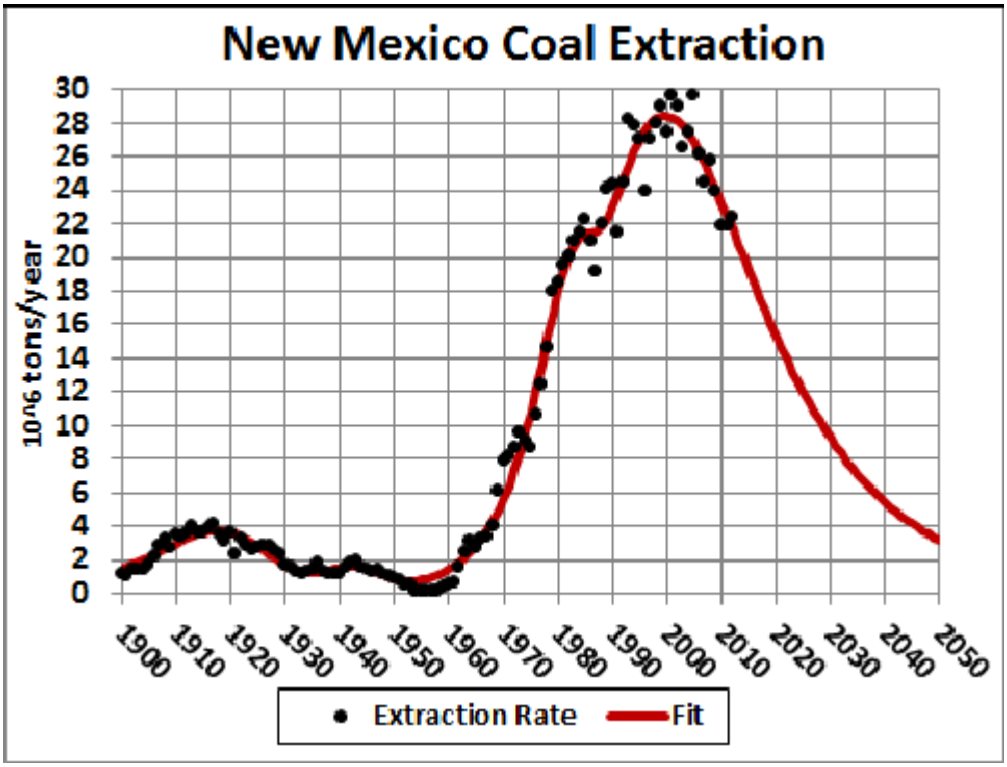
The area under the red best-fit curve is (1,429x10^6 tons).

Colorado Coal Extraction



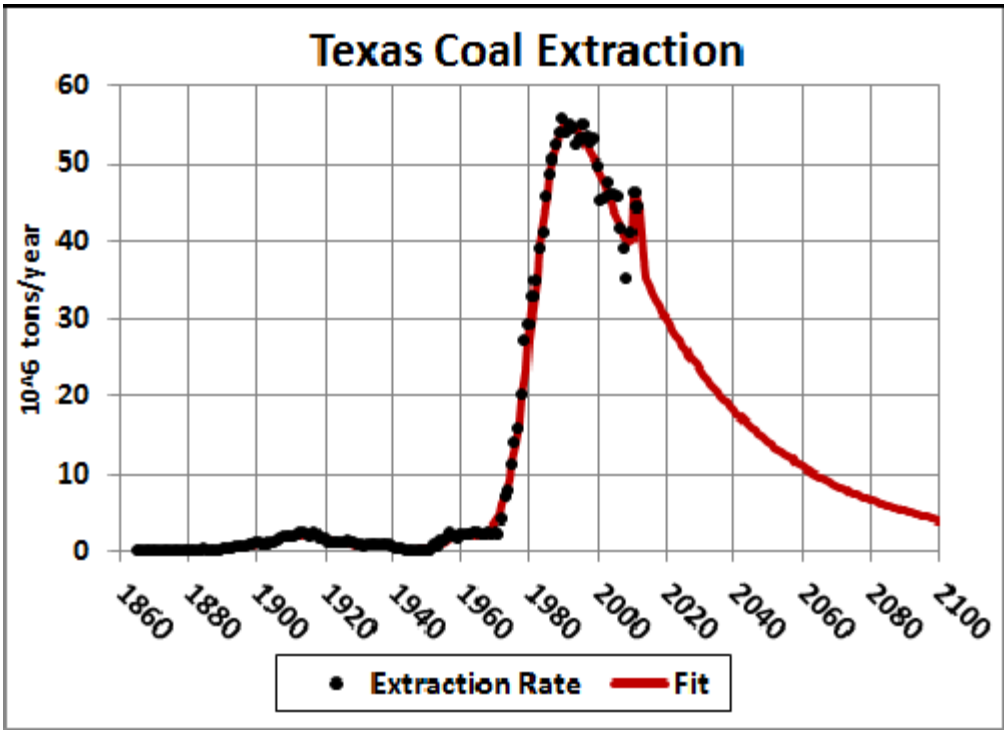
The area under the red best-fit curve is (1,619x10^6 tons).

New Mexico Coal Extraction

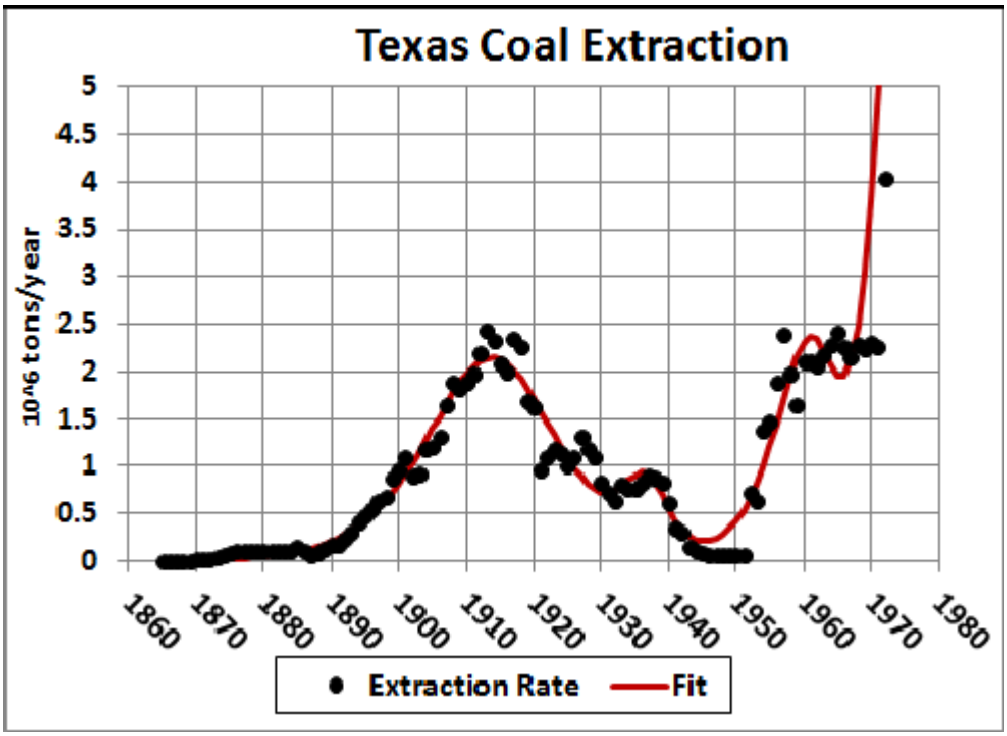


The area under the red best-fit curve is (1,505x10^6 tons).

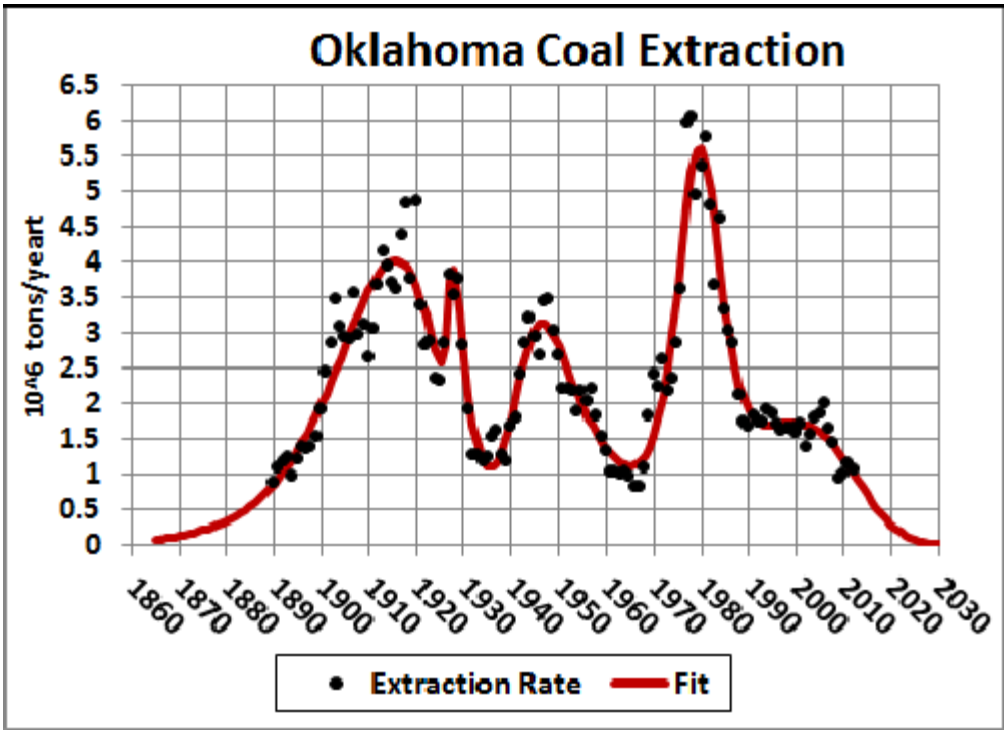
Texas Coal Extraction



The area under the fit curve is the total amount to be extracted eventually; it is 3,191x10^6 tons.

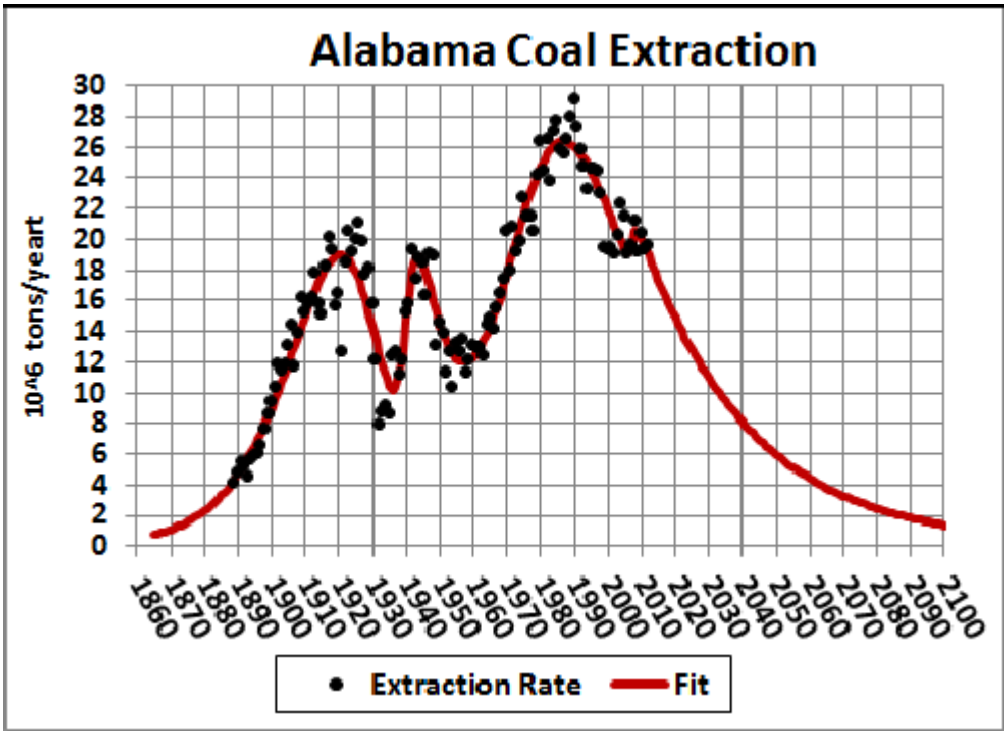


Oklahoma Coal Extraction



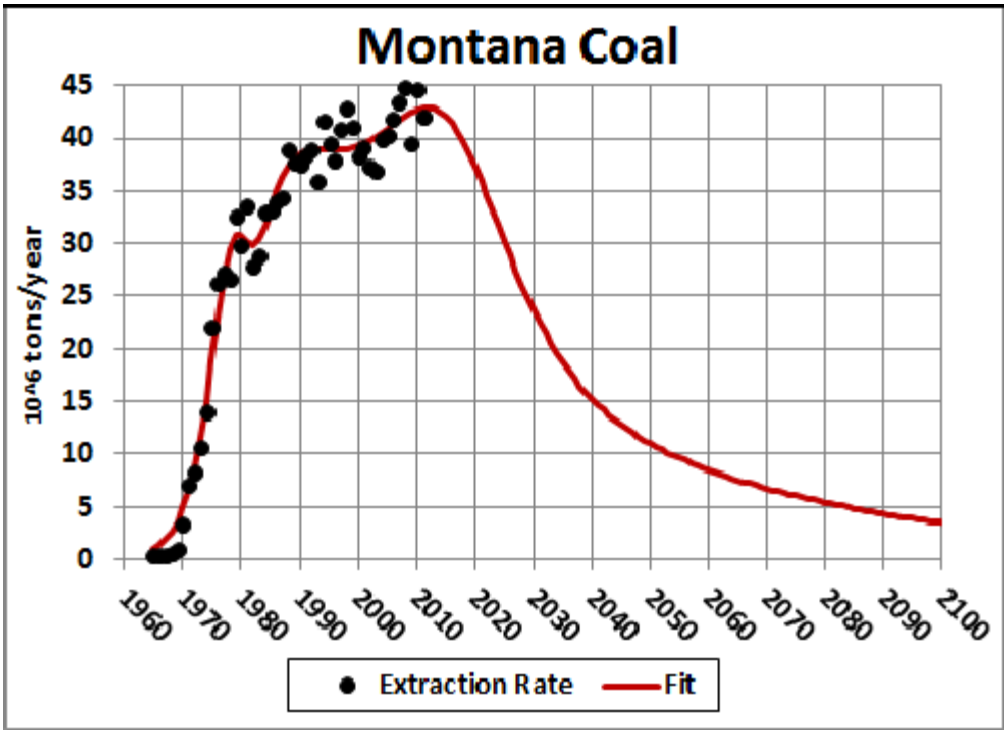
The area under the fit curve is the total amount to be extracted eventually; it is 311×10^6 tons.

Alabama Coal Extraction



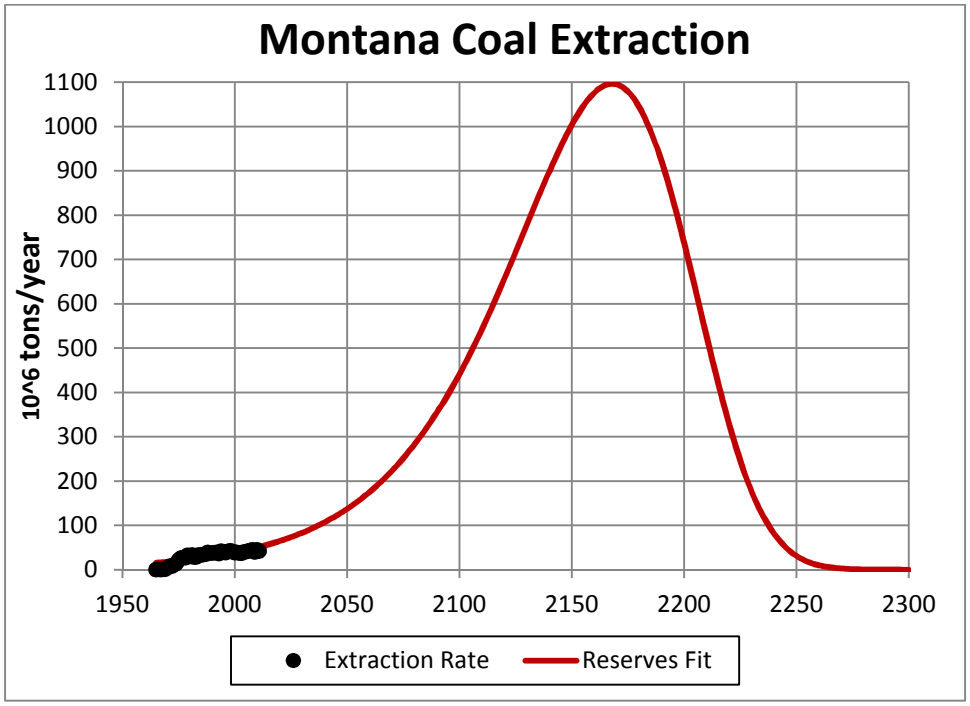
The area under the fit curve is the total amount to be extracted eventually; it is $2{,}759 \times 10^6$ tons.

Montana Coal Extraction



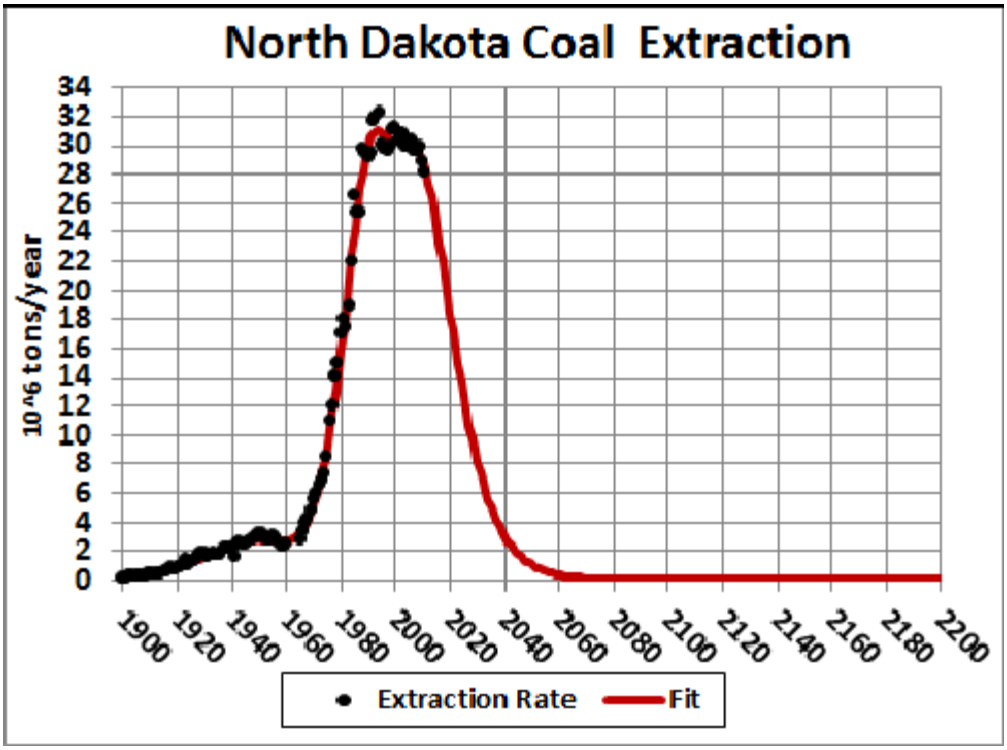
The area under the red best-fit curve is the amount to be extracted eventually (2,855x10^6 tons).

Suppose an amount equal to the sum of the reserve base and the amount already extracted could be extracted eventually. The depletion curve might then be:



The second peak might be smaller and more spread out, which means that it would peak at a later time. It is unlikely that a second peak will occur, given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental.

North Dakota Coal Extraction



The area under the fit curve is the total amount to be extracted eventually; it is 1,527x10^6 tons.

Conclusion

It appears that the reserve-base values for most states are much too high. Given that the environmental, including global warming, and health effects of mining and burning coal are so detrimental, it is unlikely that those amounts of coal will be mined and burned. Perhaps, if humans decide to use the coal for making useful objects instead of burning it and much improvement is made in the mining techniques, a larger part of the reserve base will be mined.

References

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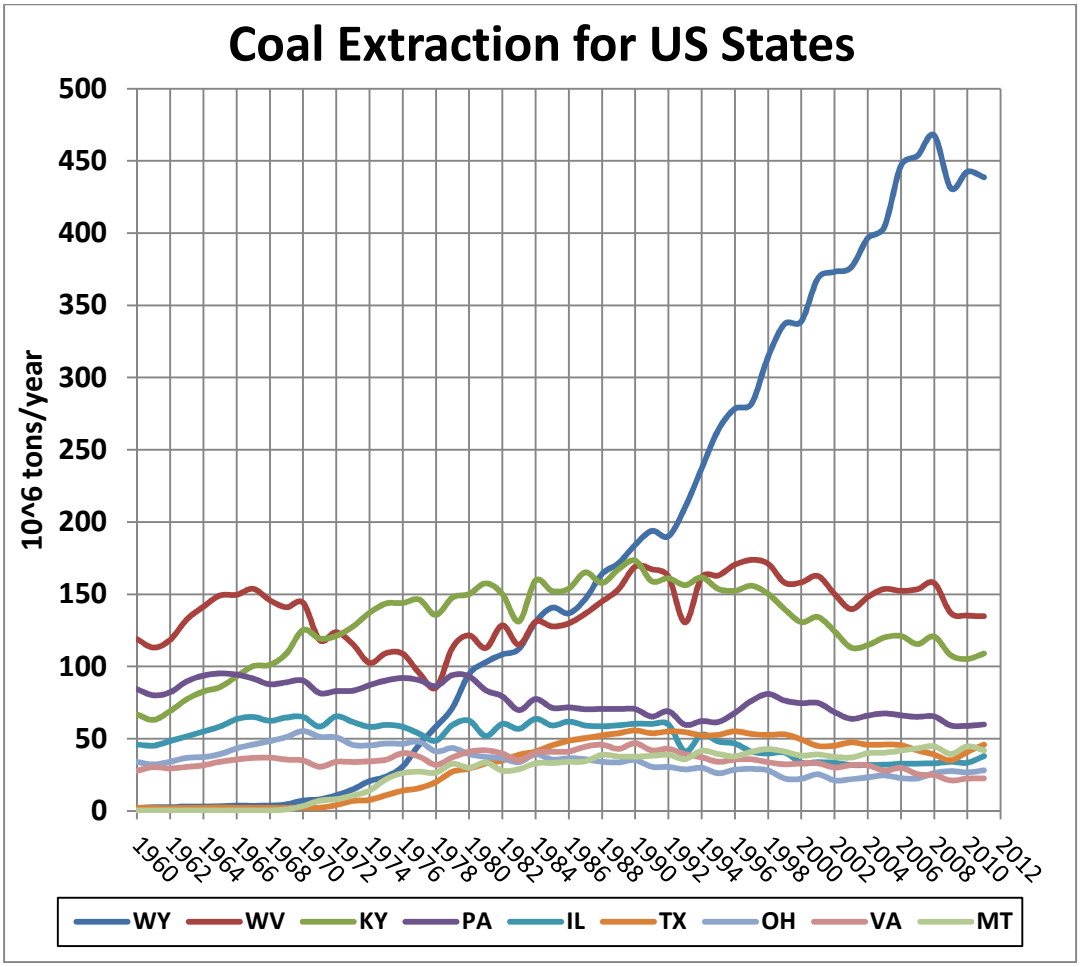
- http://www.eia.gov/state/seds/sep_prod/xls/Prod_dataset.xls
- http://www.eia.gov/coal/annual/pdf/table1.pdf
- http://www.eia.gov/coal/annual/pdf/table14.pdf
- http://www.eia.gov/coal/annual/archive/05842011.pdf
- http://geology.utah.gov/emp/energydata/statistics/coal2.0/pdf/T2.2.pdf



http://www.roperld.com/science/minerals/FossilFuels.htm