

Fossil Fuels Extraction for the World and the United States

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Introduction

Available energy makes possible plant and animal life. It allows humans to organize into civilizations. Many books and web pages have been written about the uses of energy by humans, so I will not belabor that here.

The main source of available energy for human use since humans evolved was solar energy, which is manifested in many ways; for example, direct radiation, wind and water. The amount of energy available for use by humans greatly increased when ways to efficiently mine coal were developed in the nineteenth century. Then the amount increased even more when ways to efficiently extract petroleum and natural gas from the Earth were developed in the twentieth century.

However, those fossil fuels provide much smaller available energy over time than do solar energies. In fact, humans have extracted the fossil fuels so fast, that the extraction peaks occur within about a century after the extraction started at high volume. After fossil fuels are depleted, only solar energies are available for human use. (Nuclear energy is also subject to depletion, but appears to be less available for human use than fossil fuels, so I do not consider it here. See <http://www.roperId.com/science/uranium.htm> and <http://www.roperId.com/science/NuclearPowerDecline.htm> .)

Herein are shown the time dependences of fossil fuels extraction for crude oil, natural gas and coal for the world and for the United States. It is shown that humans do not have much time left to use the remaining fossil fuels to develop the infrastructure for efficient use of solar energies.

To be realistic one must consider depletion functions to determine the amount of fossil fuels left for human use. It is meaningless to consider the time remaining at current usage rates, as many do, since usage rates vary with time.

Some mathematics is required to understand the time dependence of fossil-fuels extraction. A depletion function that allows asymmetry with time is needed; a good choice is the Verhulst function (<http://www.roperId.com/science/minerals/VerhulstFunction.htm>):

$$P(t) = \frac{Q_{\infty}}{n\tau} \frac{(2^n - 1) \exp\left(\frac{t-t_1}{\tau}\right)}{\left[1 + (2^n - 1) \exp\left(\frac{t-t_1}{\tau}\right)\right]^{\frac{n+1}{n}}}$$

The Q_{∞} parameter is the total amount eventually to be extracted. The n parameter is a measure of the asymmetry: symmetric is $n=1$, skewed to early times is $n<1$ and skewed to later times is $n>1$. The peak of

the curve occurs at date $t_p = t_{1/2} + \tau \ln\left(\frac{n}{2^n - 1}\right)$; thus, when $n=1$ for a symmetric curve, $t_p = t_{1/2}$. As

can be seen in many graphs below, this equation yields a peaked curve; the area under the curve up to a specific date is the total amount extracted up to that data and the total area under the curve is the total amount that eventually will be extracted, Q_∞ . More than one peaked function may be required for some extractions of materials from the Earth.

For more information about minerals depletion see

<http://www.roperld.com/science/minerals/DepletTh.htm> . For more information about the Verhulst function see <http://www.roperld.com/science/minerals/VerhulstFunction.htm> .

The goal of this article is to make clear the contributions of different kinds of fossil-fuels extraction to the energy situation as a function of time for the United States and the world.

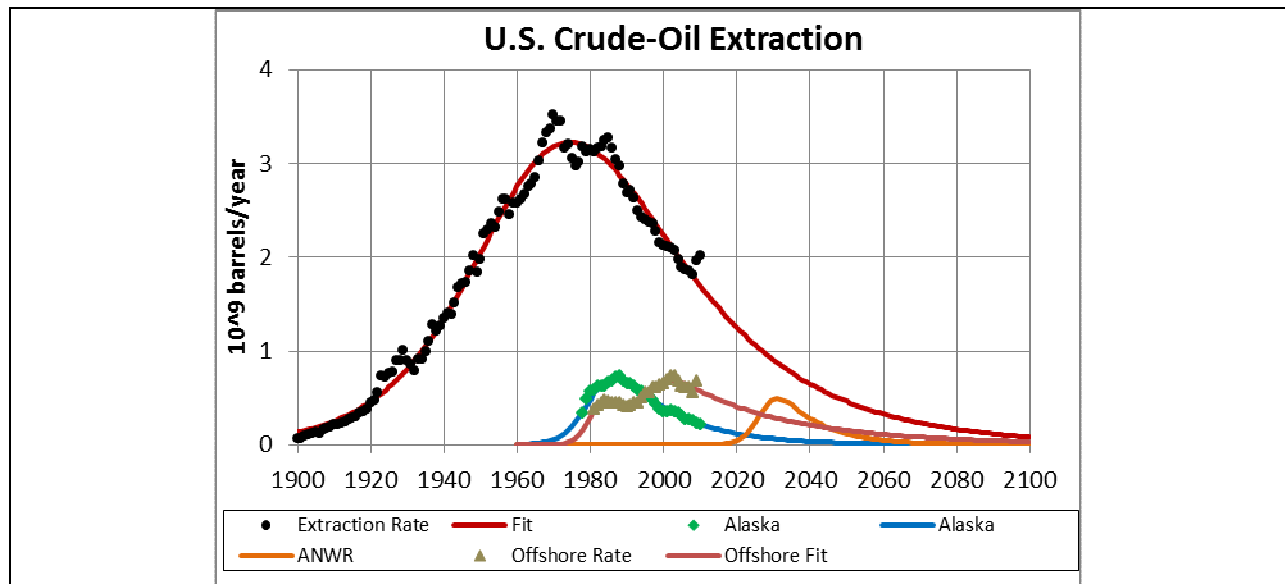
Crude Oil

Good data are available for crude-oil extraction rates for the United States and the world:

<http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=57&aid=1&cid=regions&syid=2006&eyid=2010&unit=TBD>

United States Crude-Oil Extraction

Figure 1 shows a fit of the Verhulst function to the crude-oil extraction data for the United States.



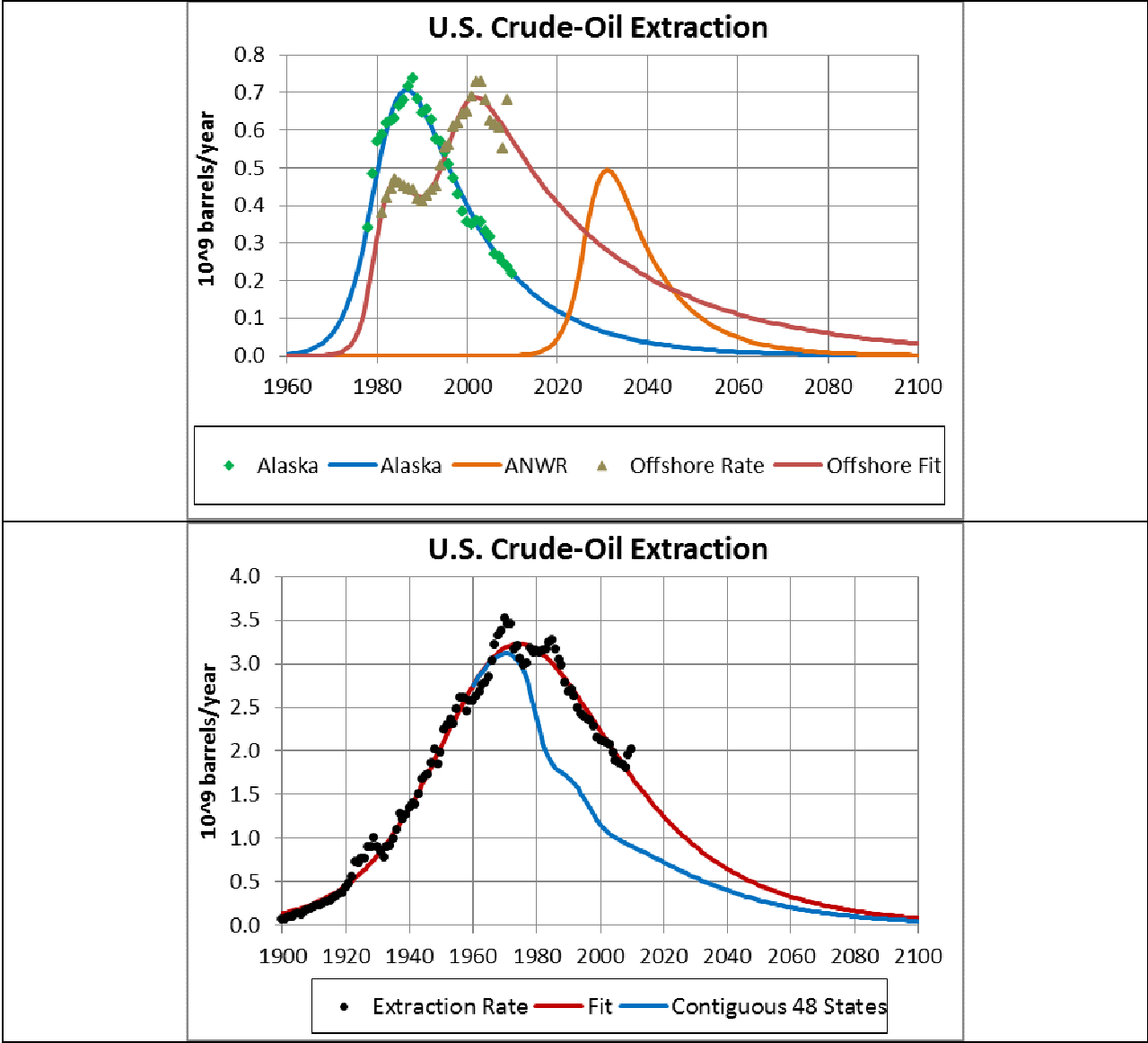


Figure 1. U.S. Crude-Oil Extraction

Note the fit to the Alaskan extraction (green data points and blue curve), which caused a blip in the overall U.S. extraction curve and similarly for offshore extraction (other-colors data points and curves). The orange curve shows a guess at the extraction curve for the proposed extraction of crude oil in the Alaskan National Wildlife Refuge (ANWR; <http://en.wikipedia.org/wiki/ANWR>) assuming total extraction of 10 billion barrels (<http://www.warriorsfortruth.com/alaska-oil-anwar.html>) ; doubling the amount to be extracted in ANWR would not change the peak position by more than a few years. As for the Prudhoe Bay, Alaska extraction and offshore extraction, ANWR extraction would only be a blip in the overall U.S. extraction curve.

World Crude-Oil Extraction

Figure 2 shows a fit of two Verhulst functions to the crude-oil extraction data for the world.

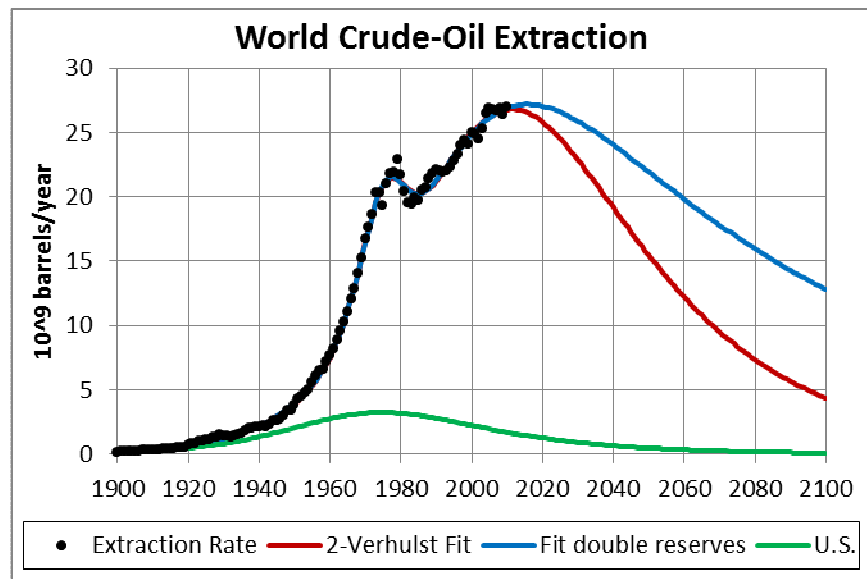
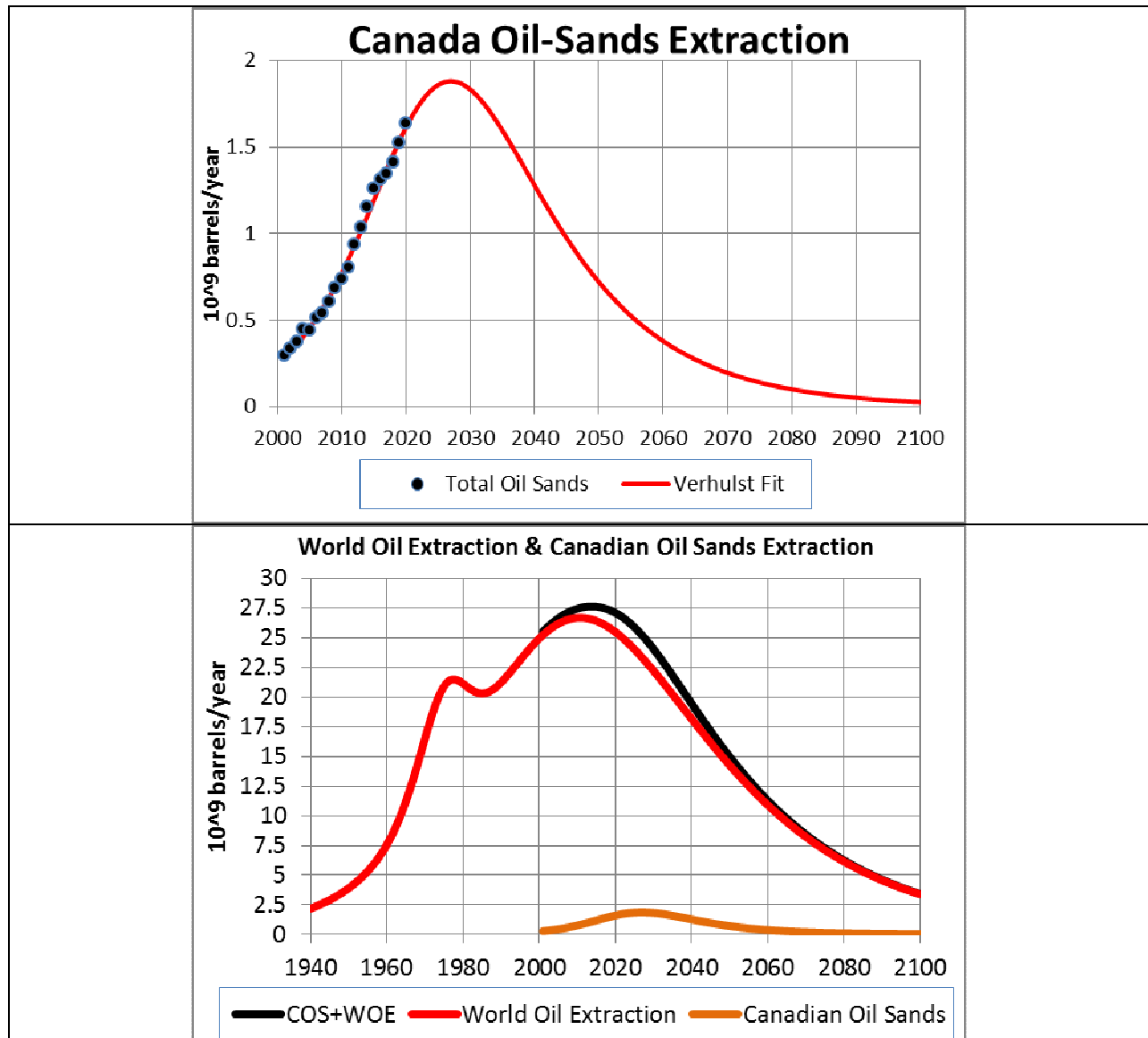


Figure 2. World Crude-Oil Extraction

The red curve assumes an optimistic (<http://www.eia.gov/international/reserves.html>) world crude-oil reserves of 1500 billion barrels and the blue curve assumes unrealistically high double reserves of 3000 billion barrels. The peaks differ by only ~ 4.5 years.

Canadian Oil Sands Extraction of Crude Oil

Some are touting Canadian oil sands as a future large contributor to crude-oil supplies for the United States. Using data from <http://www.capp.ca/aboutUs/mediaCentre/Pages/2008CanadianCrudeOilForecast.aspx#L2WklAD74HHm>, which forecasts crude-oil extraction from Canadian oil sands to the year 2020, a Verhulst-function fit yields the curve in Figure 3.



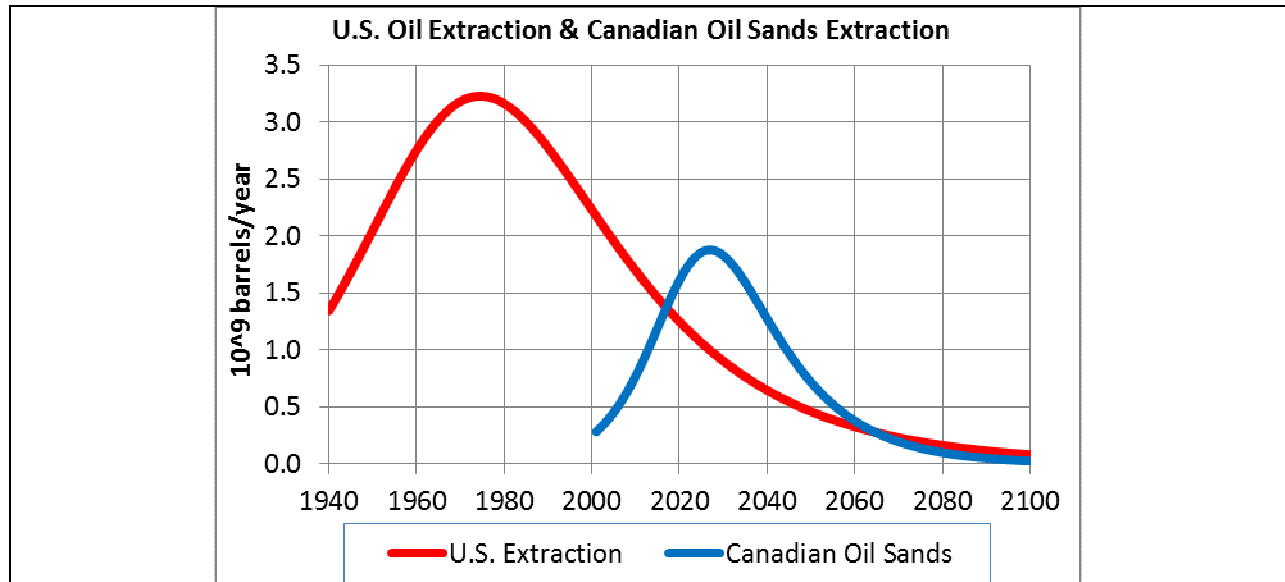


Figure 3. Crude-Oil Extraction from Canadian Oil-Sands

The curve is the best fit of a Verhulst function to the forecasted Canadian oil-sands extraction “data”; it has a Q value of 73.4 billion barrels, which is much more than would be expected from the reserves given (<http://www.capp.ca/library/statistics/basic/Pages/default.aspx?qOSe3lL0upC6> lists 2006 reserves of ~12 billion barrels). That is, by 2010 about 7 billion barrels had been extracted; add that to 12 billion and Q would be 19 billion, much less than 73 billion. The second graph shows the small blip of crude oil from Canadian oil sand on the total world extraction curve. The third graph compares Canadian oil-sand extraction to United States crude-oil extraction.

From the world viewpoint, Canadian oil sands would be a small blip on the extraction curve (~2 billion barrels/year compared to ~25 billion barrels/year).

It appears that, in an unlikely case where the United States would get most of the crude oil from Canadian oil sands, the result would be a peak before year 2030 of slightly more than one-half of the extraction peak for United States crude oil that occurred ~1975.

Conclusion about the Availability of Crude Oil

Humans do not have much time left to use the remaining fossil fuels to develop the infrastructure for efficient use of solar energies. Future generations will ask why their ancestors burned fossil fuels so extravagantly instead of using it to make materials and for creating future-energy infrastructure.

For depletion-function fits to crude-oil extraction data for other countries, see <http://www.roperId.com/science/minerals/FossilFuels.htm> .

Natural Gas

Good data are available for natural-gas extraction rates for the United States and the world:

<http://www.eia.gov/emeu/aer/txt/ptb0602.html> .

The proven reserves/resources values have been rising over the last few years

(http://www.rigzone.com/news/article.asp?a_id=101780 and <http://geology.com/energy/world-shale-gas/>) due to the ease of fracking for shale gas with few environmental controls.

United States Natural-Gas Extraction

Figure 4 shows a fit of the Verhulst function to the shale-gas extraction data for the United States using a Q value of 1000 trillion cubic feet, which is more than the estimated recoverable reserves of 862 Tcf

(<http://geology.com/energy/world-shale-gas/>).

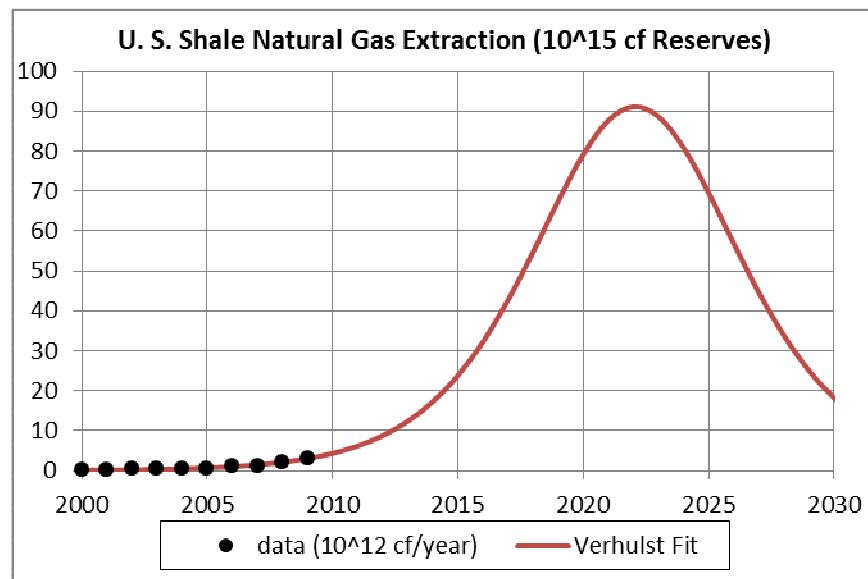


Figure 4. U.S. Shale-Gas Extraction

An assumption was made that the curve is symmetric, although it probably will be asymmetric, perhaps falling off faster than rising if environmental degradation increases due to the extraction or perhaps falling slower than rising. The rise in shale-oil extraction is increasing so fast that it will peak in slightly over a decade and then fall rapidly, similar to what happened for Alaskan oil (see Figure 1 above).

Figure 5 shows a fit of a three Verhulst functions to all natural-gas extraction data for the United States, using the shale-gas fit of Figure 4.

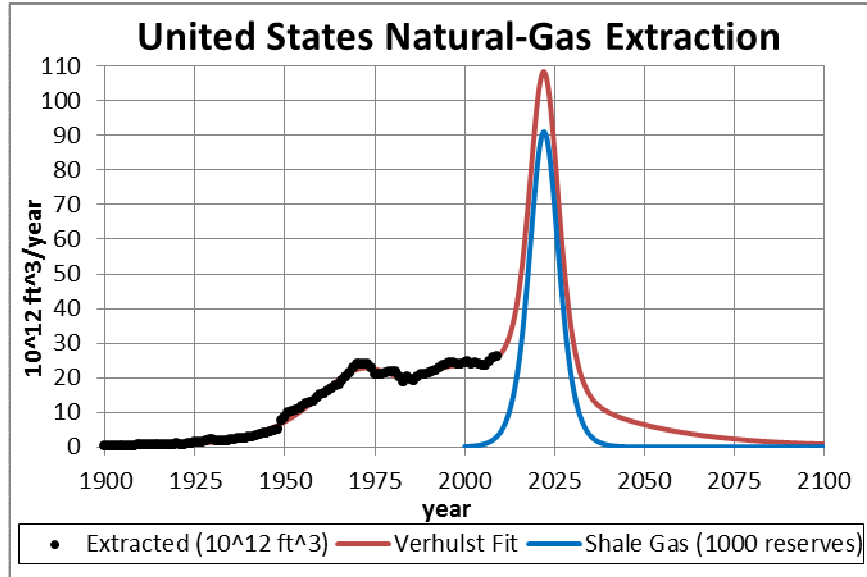
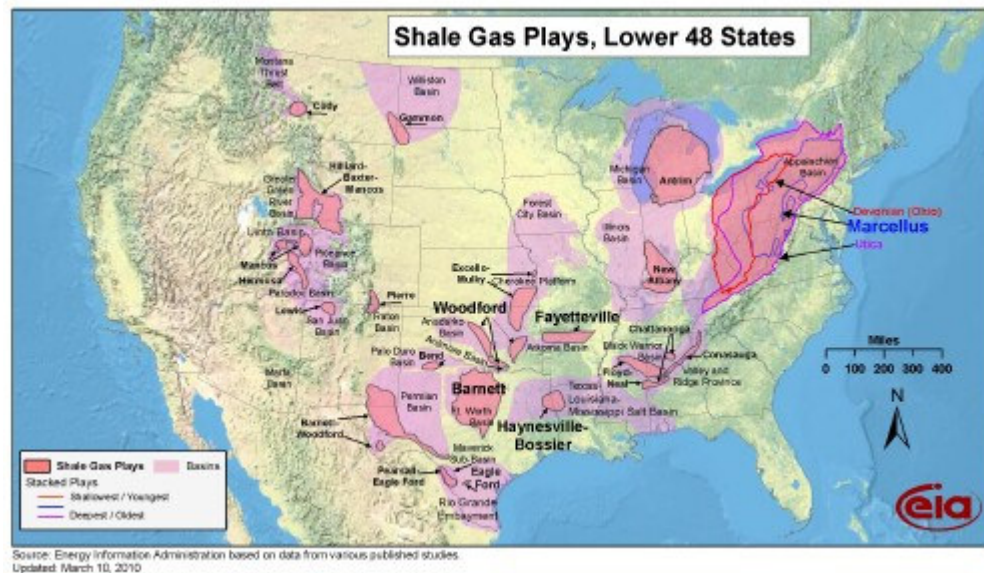


Figure 5. U.S. Natural-Gas Extraction

The natural-gas industry has been showing television commercials stating that shale gas will supply energy for the United States for one-hundred years. If the extraction continues at the current fast pace, as is assumed here, that statement is about a ten-fold exaggeration. We could decide to slow down the extraction, but that seems unlikely; humans tend to use up resources as fast as possible. Replacement of coal by natural gas in electricity production and replacement of gasoline and diesel by natural gas for transportation will gravitate toward extracting shale gas as fast as possible.

The locations for shale natural gas in the United States are shown here:



World Natural-Gas Extraction

Extraction of natural gas from shale for the world not yet into a fast rise, so it is impossible to project with much accuracy into the future.

Figure 6 shows a fit of the Verhulst function to the shale-gas extraction data for the world using a Q_{∞} value of 8,000 trillion cubic feet (Tcf), which is more than the estimated recoverable resources of 6,622 Tcf (<http://geology.com/energy/world-shale-gas/>).

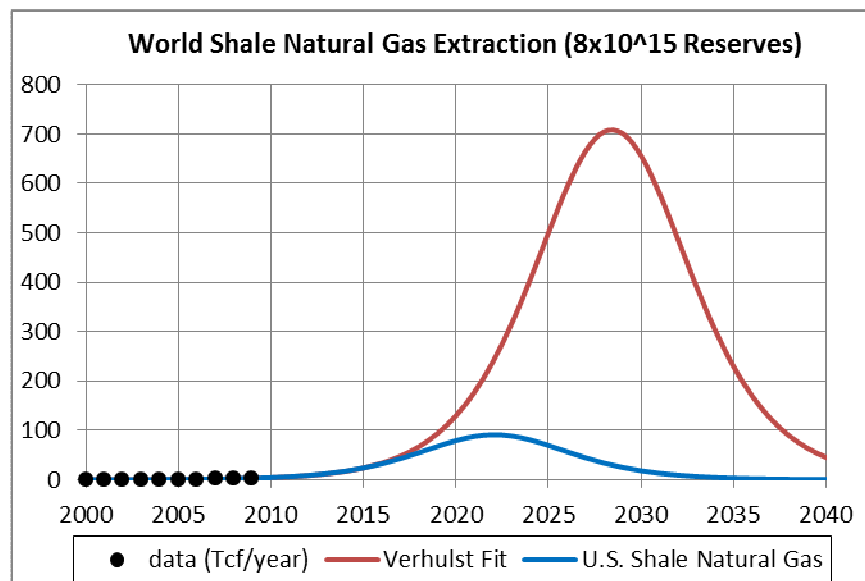


Figure 6. World Shale-Gas Extraction

An assumption was made that the curve is symmetric, although it probably will be asymmetric, perhaps falling off faster than rising if environmental degradation increases due to the extraction or perhaps

falling slower than rising. Also, an assumption is made that the time constant of the rise is about the same as for the United States and the peak is about a decade after the United States' peak.

The rise in shale-oil extraction is increasing so fast that it will peak in slightly over a decade after it starts its fast rise and then fall rapidly, similar to what happened for Alaskan oil (see Figure 1 above).

Figure 7 shows a fit of a two Verhulst functions to all natural-gas extraction data for the world, using the shale-gas fit of Figure 6.

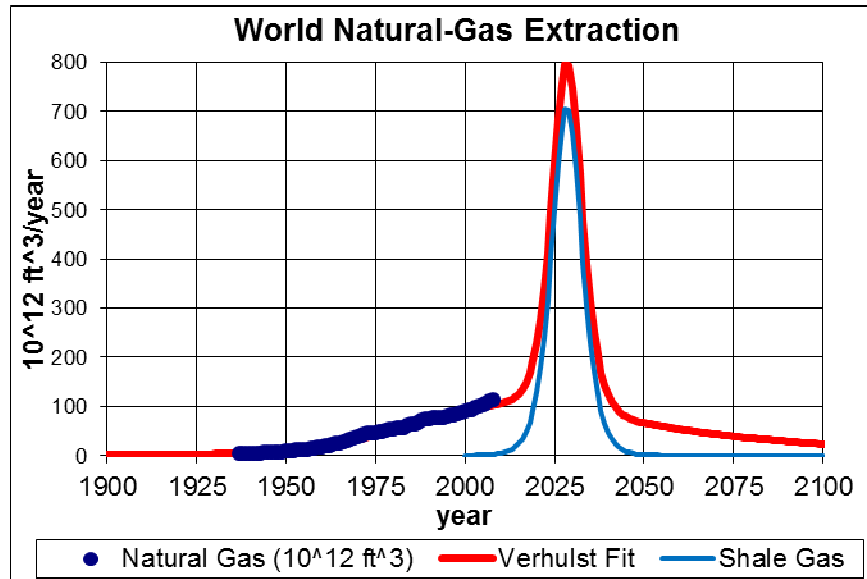
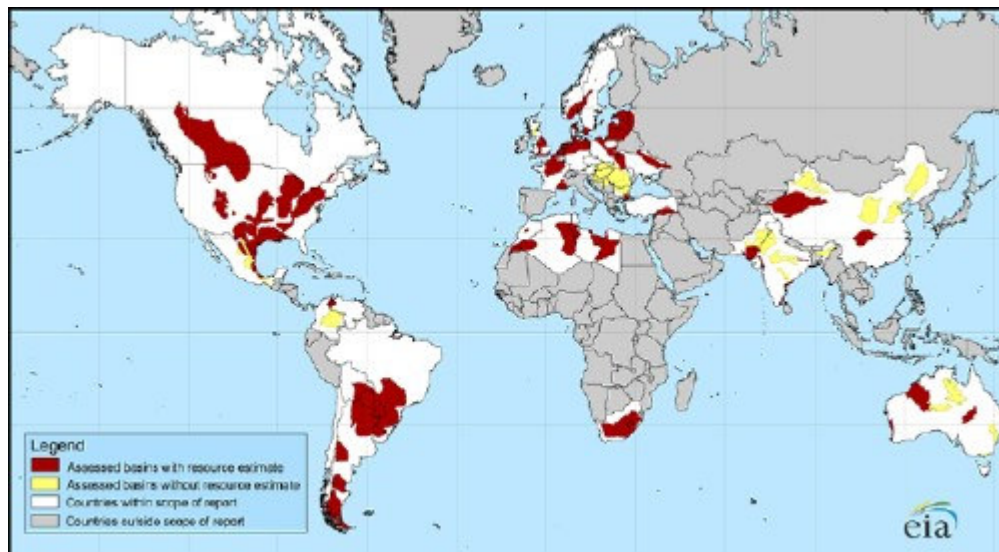


Figure 7. World Natural Gas Extraction

Humans will fare best if the brief decadal bonanza of natural gas from shale is used to develop the infrastructure for renewable energy and energy efficiency instead of fighting wars and frivolous uses.

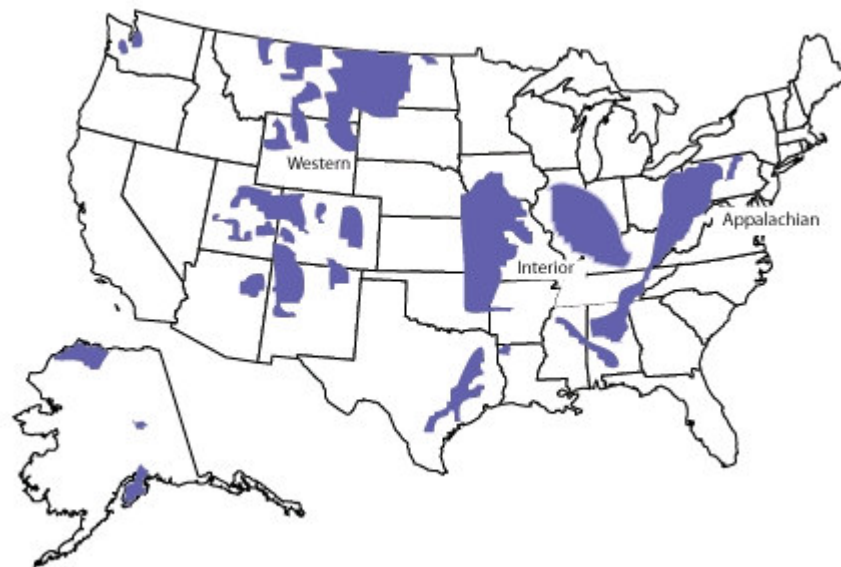
The locations for shale natural gas for the world are shown here:



Coal

United States Coal Extraction

There are a plethora of estimates of recoverable reserves/resources for coal in the United States (e.g., <http://www.eia.gov/cneaf/coal/reserves/reserves.html> and http://www.eia.gov/cneaf/coal/reserves/table14_09.pdf). The locations of coal deposits for the United States are shown here:



Most of the coal being mined is bituminous; most of the available anthracite, the best-energy coal, has been extracted already. Extraction of the least –energy coal, lignite, is ramping up.

Figure 8 shows a fit of three Verhulst functions to coal extraction data for the United States.

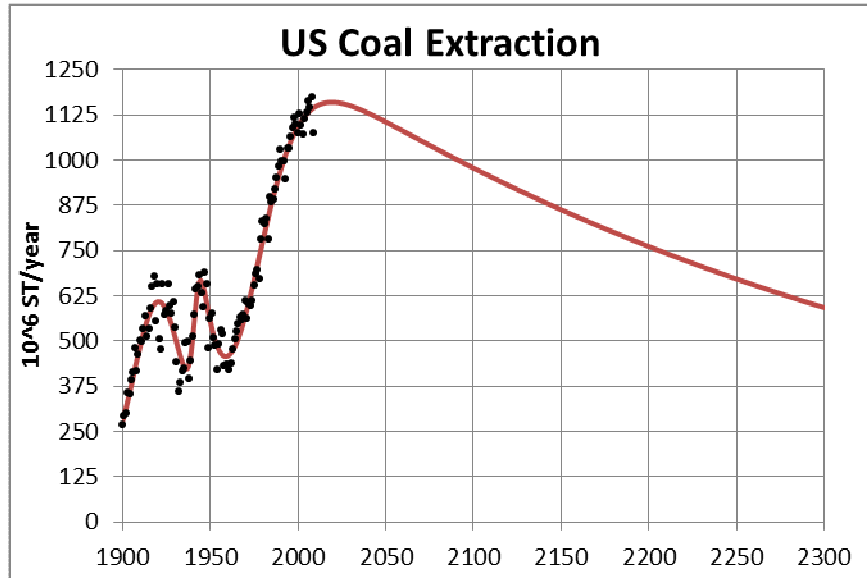


Figure 8. United States Coal Extraction

I used an unrealistic very large value for the total amount to be extracted (565 billion short tons), frankly, for its scare value. Of course, instead of gradually falling off with time there could be multiple peaks with faster depletion. Extracting this amount of coal in the United States would cause great environmental damage, atmospheric pollution and disastrous global warming (<http://www.roperld.com/science/GlobalWarmingRoper.htm>).

World Coal Extraction

Figure 9 shows a fit of the Verhulst function to coal extraction data for the World.

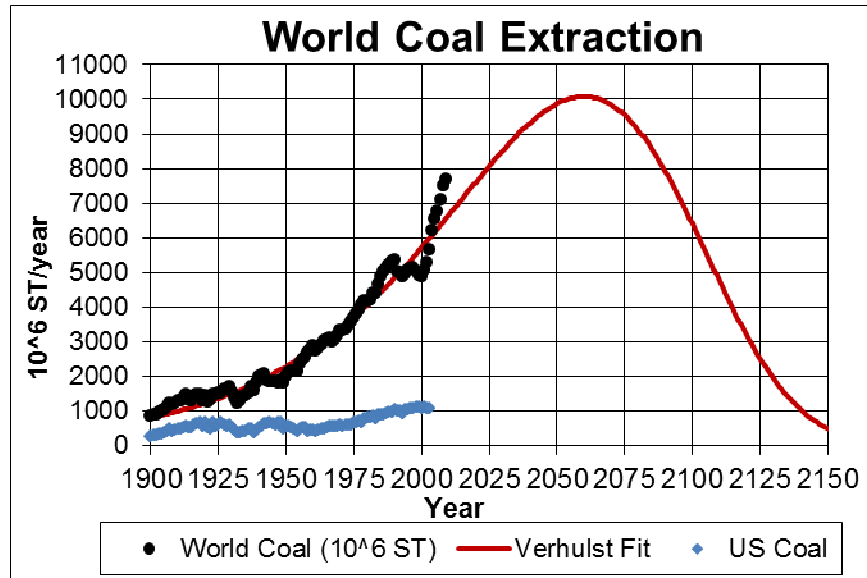


Figure 9. World Coal Extraction

The total amount extracted used is 1.3 trillion short tons. The recent rapid rise is due to extraction in China and India. As more data come in in future years, a double-Verhulst-function fit should be done. It appears that world coal extraction will rise very rapidly and then fall off very quickly.

There are some indications that the estimated world-coal reserves value is too high; if that is so, the peak will occur sooner than 2050

(http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Coal_10-07-2007ms.pdf).

Conclusion

The proper way to project extraction of fossil fuels into the future is through a depletion function that starts from zero, rises to a peak and then falls off to zero at large times, with possible asymmetry. Referring to amount left at current consumption rate, which is often used, has no predictive power.

The Verhulst function has proven to be a good depletion function with properties described above; it is essentially the logistic function generalized to allow asymmetry, which usually occurs for fossil fuels.

The Verhulst function was used in this work to fit extraction data for crude oil, natural gas and coal extractions for the United States and the World.

Crude Oil

Crude-oil extraction for the United States peaked ~1970 and is right at peaking for the world. Alaskan and offshore oil provide only decadal minor additions to the crude-oil supply for the United States. Crude-oil extracted from Canadian oil sands could provide a sizeable addition to the United States oil supply for about a decade at a great cost in environmental destruction and global warming forcing.

Crude oil extraction for the world is peaking about now.

Natural Gas

Natural-gas extraction for the United States is experiencing a rapid rise due to fracking shale deposits. It will probably rise very rapidly for about a decade and then fall rapidly.

Natural-gas extraction for the world will probably start rising rapidly in about a decade and then will fall rapidly.

Coal

There may be enough coal available to cause disastrous global warming (<http://www.roperld.com/science/GlobalWarmingprediction.htm>). Humans have yet to decide that it is better to adjust energy desires to renewable energy, especially in the developing countries.

Future Energy

The focus of this work has been fossil-fuels extraction for the United States and the world. Here are some links about future energy sources as fossil-fuels use decline:

- Future World Energy: <http://www.roperld.com/science/EnergyFuture.htm>
- Global Energy: <http://www.roperld.com/science/EnergyRoper.htm>
- Energy System Need for the United States (and the World): <http://www.roperld.com/Science/EnergySystemUS.htm>
- Fossil-Fuels Energy Return on Energy Invested: <http://www.roperld.com/science/minerals/EROEIFossilFuels.htm>
- Energy Social Cost: <http://www.roperld.com/science/minerals/energysocialcost.htm>
- World Renewable Energy: <http://www.roperld.com/science/worldrenewableenergy.htm>
- The Solar Future: <http://www.roperld.com/science/SolarFuture.htm>
- Currency System Based on Energy Consumed: <http://www.roperld.com/science/CurrencySystems.htm>
- Global Heat Pollution: <http://www.roperld.com/science/earthradiation.pdf>