Crude-Oil Extraction in the United States

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Introduction

The amount of crude-oil that can be extracted inside the United States is a crucial number for the future of the country. This article does the math to arrive at a reliable estimate at that number. The components of the number from some of the different sources are delineated.

Crude-Oil Extraction and Reserves 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/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm . EIA also has reserves data: http://www.eia.gov/dnav/pet/pet_crd_pres_dcu_NUS_a.htm . ("Proved reserves of crude oil as of December 31 of the report year are the estimated quantities of all liquids defined as crude oil, which geological and engineering data demonstrate with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating conditions. Reserves of crude oil which can be produced economically through application of improved recovery techniques (such as fluid injection) are included in the "proved" classification when successful testing by a pilot project, or the operation of an installed program in the reservoir, provides support for the engineering analysis on which the project or program was based.")

Depletion Function to Fit to Data

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

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

Q_∞ is the amount to be eventually extracted, τ is the rising exponential time constant, n τ is the declining exponential time constant and $t_{1/2}$ is the time at which the resource is one-half depleted. The maximum of P(t) occurs at $t_{max} = t_{\frac{1}{2}} + \tau \ln\left(\frac{n}{2^n - 1}\right)$, which yields $P_{max}\left(t_{max}\right) = \frac{Q_\infty}{\tau}\frac{1}{\left(n+1\right)^{\frac{n+1}{n}}}$.

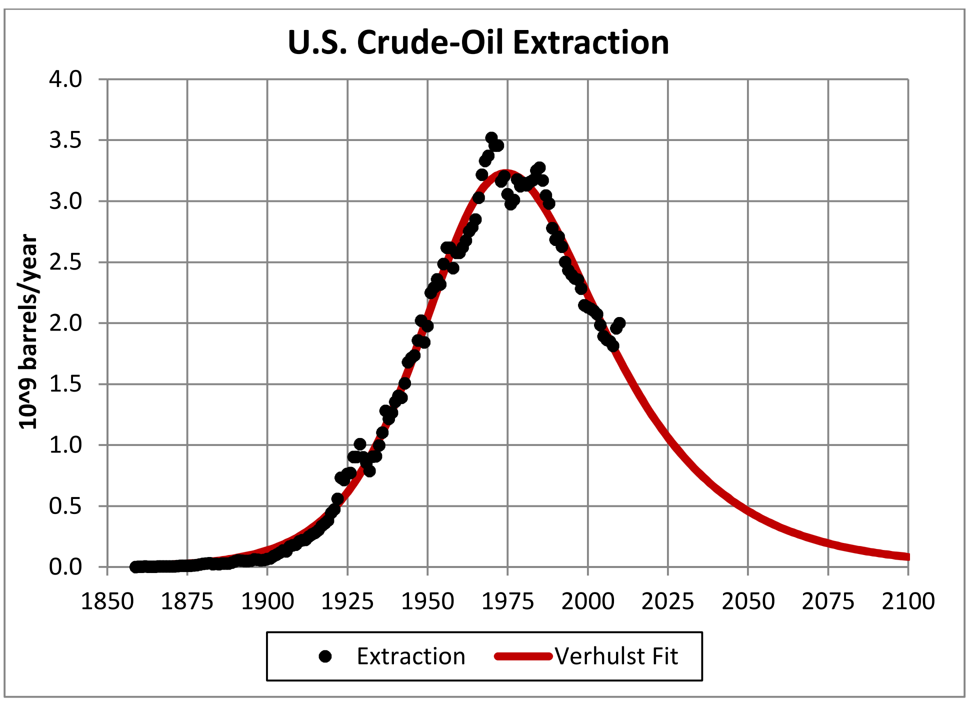
It is useful to define a "duration" for the extraction by the difference in the times when (f-1)/f has been extracted and when 1/f has been extracted:

$$D = \tau\left[\ln\left(\frac{f^n - 1}{2^n - 1}\right) - \ln\left(\frac{\left(\frac{f}{f-1}\right)^n - 1}{2^n - 1}\right)\right].$$

From that duration function one can calculate, setting f=10, the time interval between when one-tenth of the extraction occurs and when nine-tenths of it occurs (i.e., the middle 80% of the extraction amount); it is 90.5 years for crude-oil extraction for the United States. Call this the "**duration**" of crude-oil extraction for the United States. So, one could say, with this definition, that crude oil "will last" ~90 years in the United States.

Depletion Fit to Total United States Crude-Oil Extraction Data

The best fit of the Verhulst depletion function to the U.S. extraction data is:



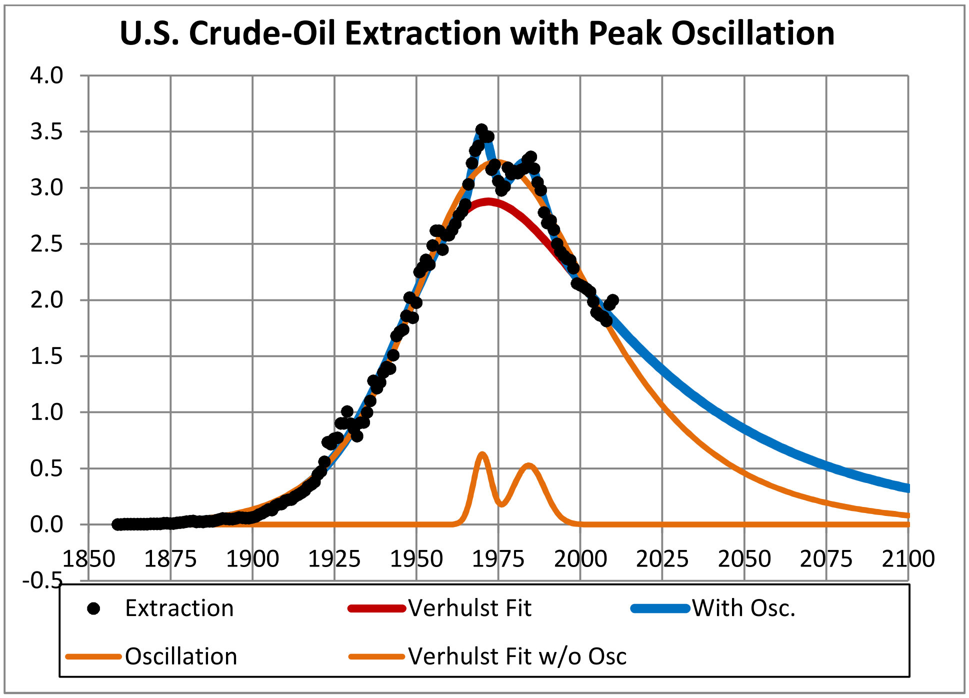
The parameters of the fit are:

Q_∞ (10^9 barrels)	$t_{1/2}$ (year)	τ (years)	n
253.8	1979.8	15.68	1.843

Interesting calculated values are:

Peak Year	Duration (80% in middle)
1974.5	90.5 years

One can improve the fit by adding two Gaussian functions, a·exp[-b(t-c)], to represent the two small blips around the overall extraction peak:

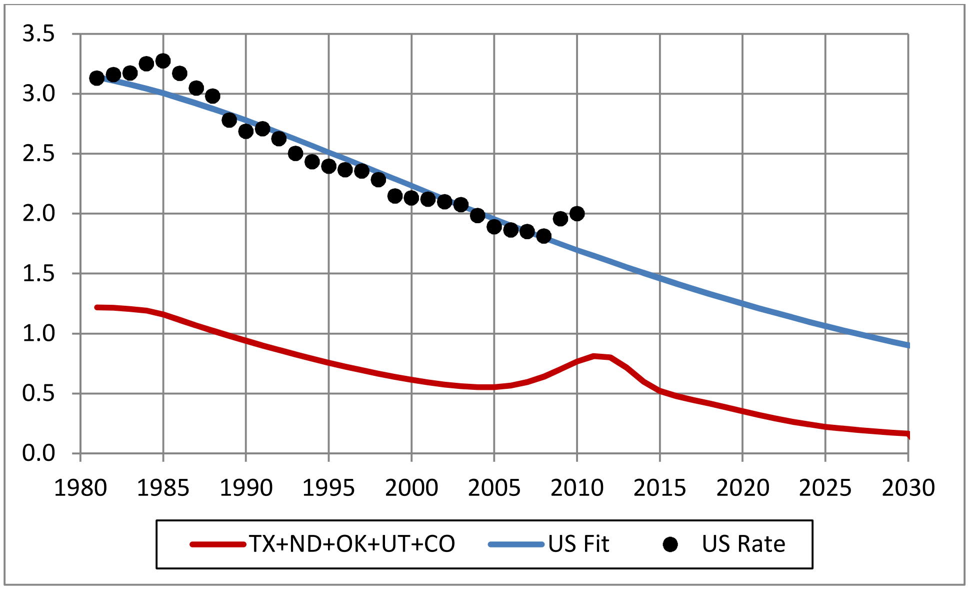


The parameters of this fit are:

Q_∞ (10^9 barrels)	$t_{1/2}$ (year)	τ (years)	n
285.9	1988.1	13.95	3.685

Gaussian #	a	b	c
1	0.6209	1970.1	0.07056
2	0.5277	1984.2	0.02114

It appears that another blip may be occurring. A detailed discussion of that possibility is given in http://www.roperld.com/science/minerals/crudeoilusresurgenceno.pdf . The result is

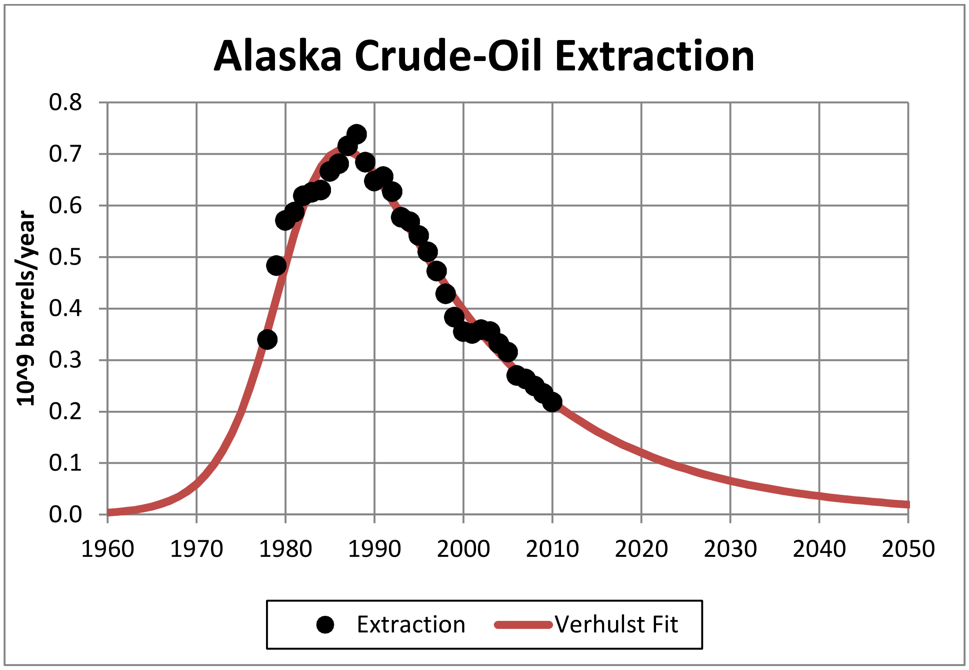


The predicted blip is slightly smaller the two previous blips surrounding the peak.

Contributions to U.S. Crude-Oil Extraction

Alaska Extraction

The extraction of crude oil in Alaska was an important factor that kept the decline from being so fast after the peak of U.S. extraction. The best fit of the Verhulst depletion function to the Alaska extraction data is:



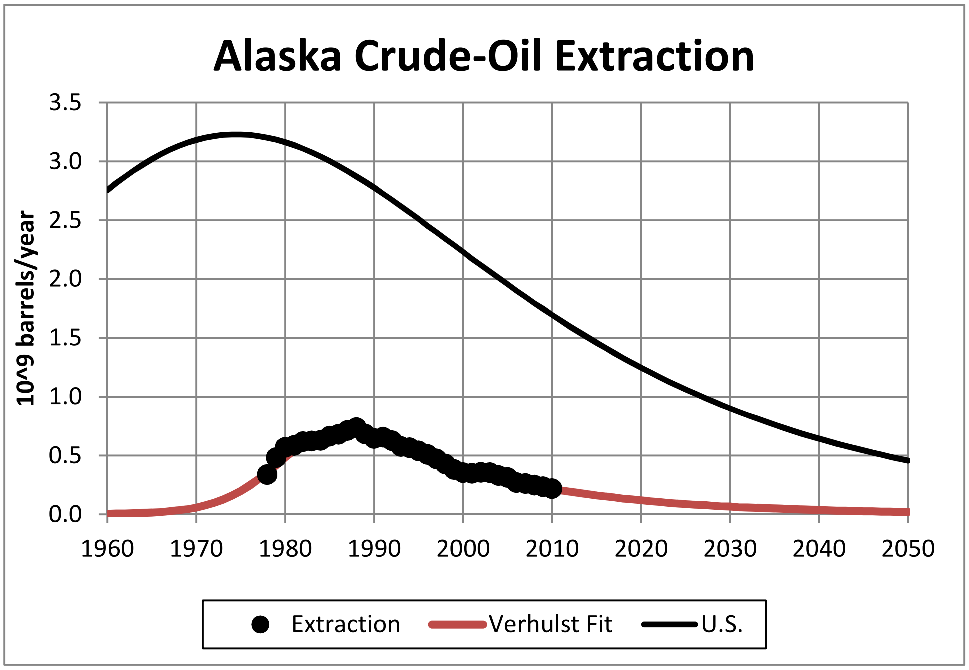
The parameters of the fit are:

Q_∞ (10^9 barrels)	$t_{1/2}$ (year)	τ (years)	n
20.91	1992.3	3.649	4.554

Interesting calculated values are:

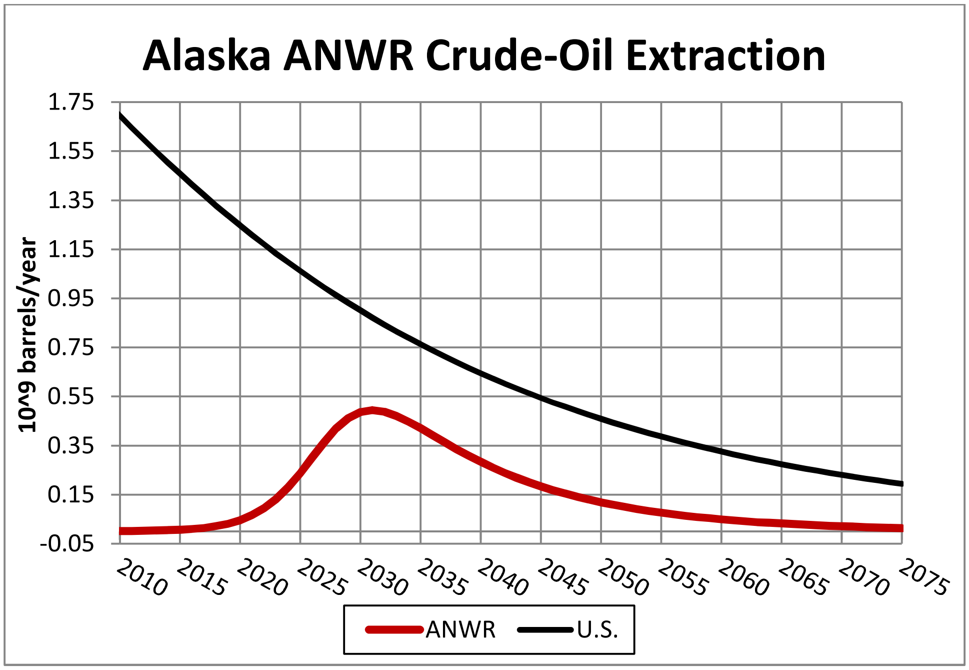
Peak Year	Duration (80% in middle)
1986.5	40.0 years

A comparison of the Alaska extraction to the total U.S. extraction is informative:



Alaska extraction kept the U.S. extraction from falling very rapidly after the peak.

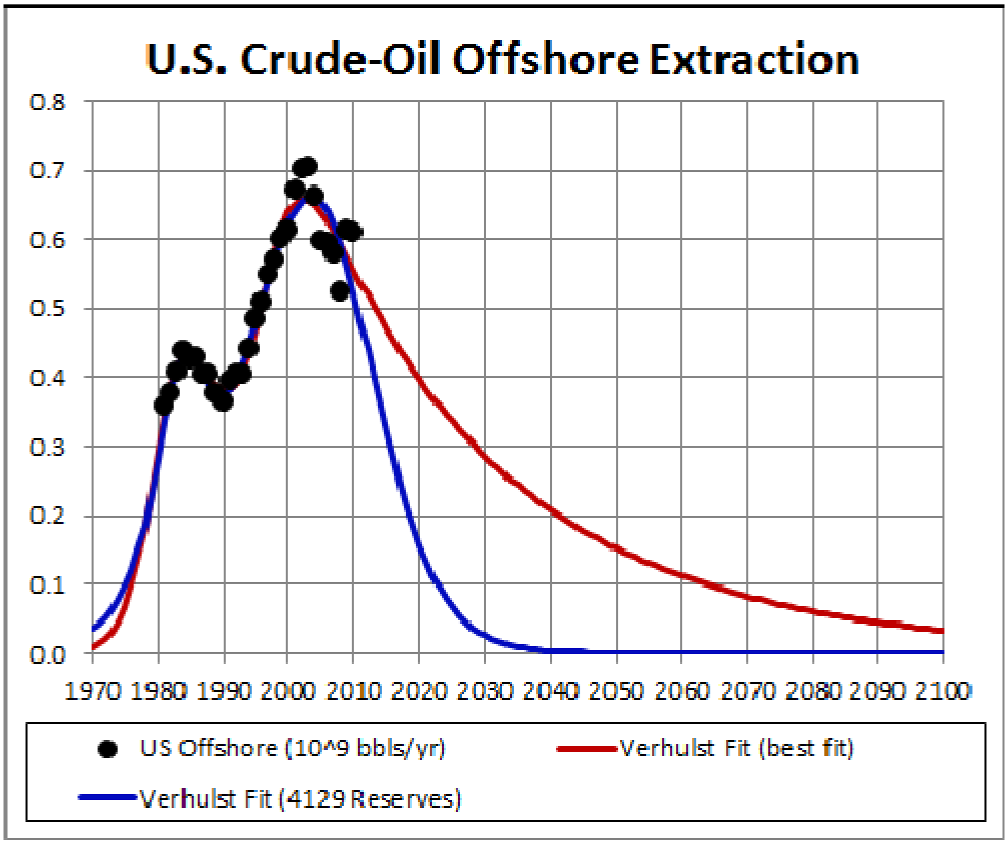
Much discussion has been made about further Alaskan crude-oil extraction from the Arctic National Wildlife Refuge (ANWR) (http://en.wikipedia.org/wiki/Arctic_National_Wildlife_Refuge). In the depletion fit shown below I make a high-value assumption that the eventual total extraction will be 10^{10}barrels (http://pubs.usgs.gov/fs/fs-0028-01/fs-0028-01.htm). Further assumptions made are that the initial speed of extraction will be ~30% less than the Prudhoe-Bay speed and that the asymmetry will be the same as for Prudhoe-Bay extraction:



If the assumptions are correct, ANWR extraction would peak at ~2030 slightly smaller than previous Alaska extraction and would have a duration of ~27 years.

Offshore Extraction

Offshore crude-oil extraction peaked in ~2003. The best Verhulst-function fit to the data is the red curve:



The best fit is considerably higher than the result when the EIA 2009 estimate of offshore reserves (4.129×10^9 barrels, http://www.eia.gov/dnav/pet/pet_crd_pres_dcu_RUSF_a.htm) is used to constrain the fit, shown by the blue curve.

The parameters of the fits are:

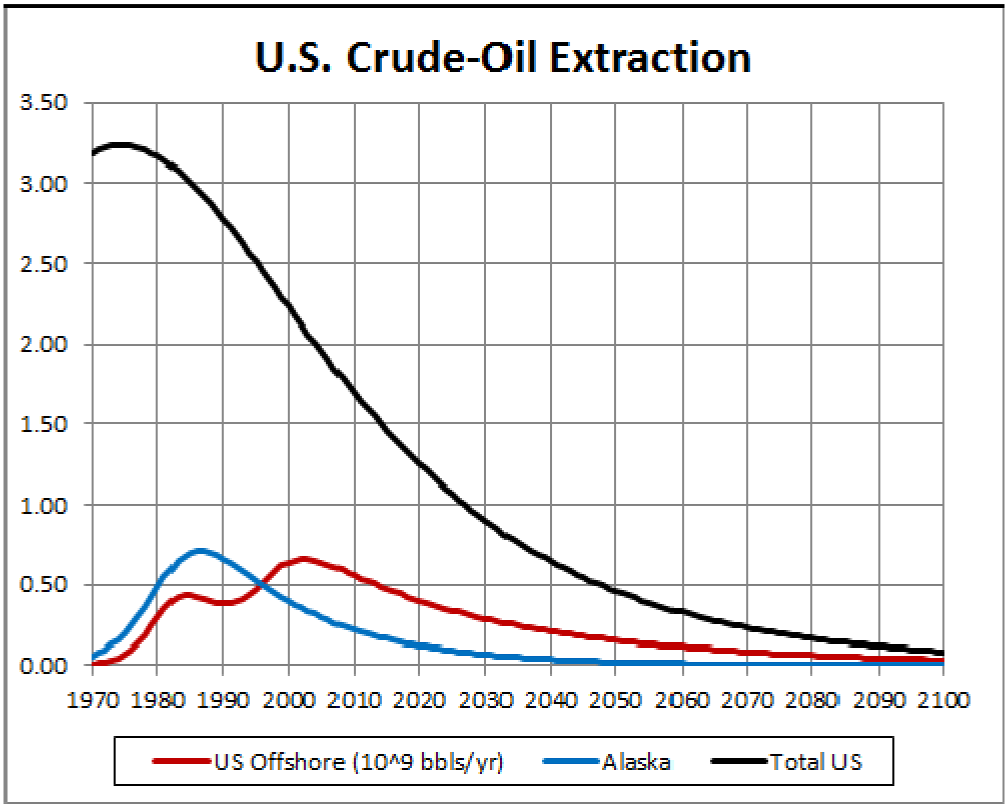
Fit	Q_∞ (10^9 barrels)	$t_{1/2}$ (year)	τ (years)	n
Best Fit:	33.5	2019.6	2.953	11.22
4.129×10^9-reserves Fit:	20.1	2001.9	7.863	0.4482

Interesting calculated values are:

Fit	Peak Year	Duration (80% in middle)
Best Fit:	2003.8	73.9 years
4.129×10^9-reserves Fit:	2003.5	28.5 years

The duration value is for the large peak.

It is informative to compare offshore-crude-oil extraction and Alaska-crude-oil extraction to the total U.S. extraction:



Offshore-crude-oil extraction and Alaska-crude-oil extraction have worked together to smoothly keep the U.S. decline from being more precipitous.

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