# Copper Depletion Including Recycling

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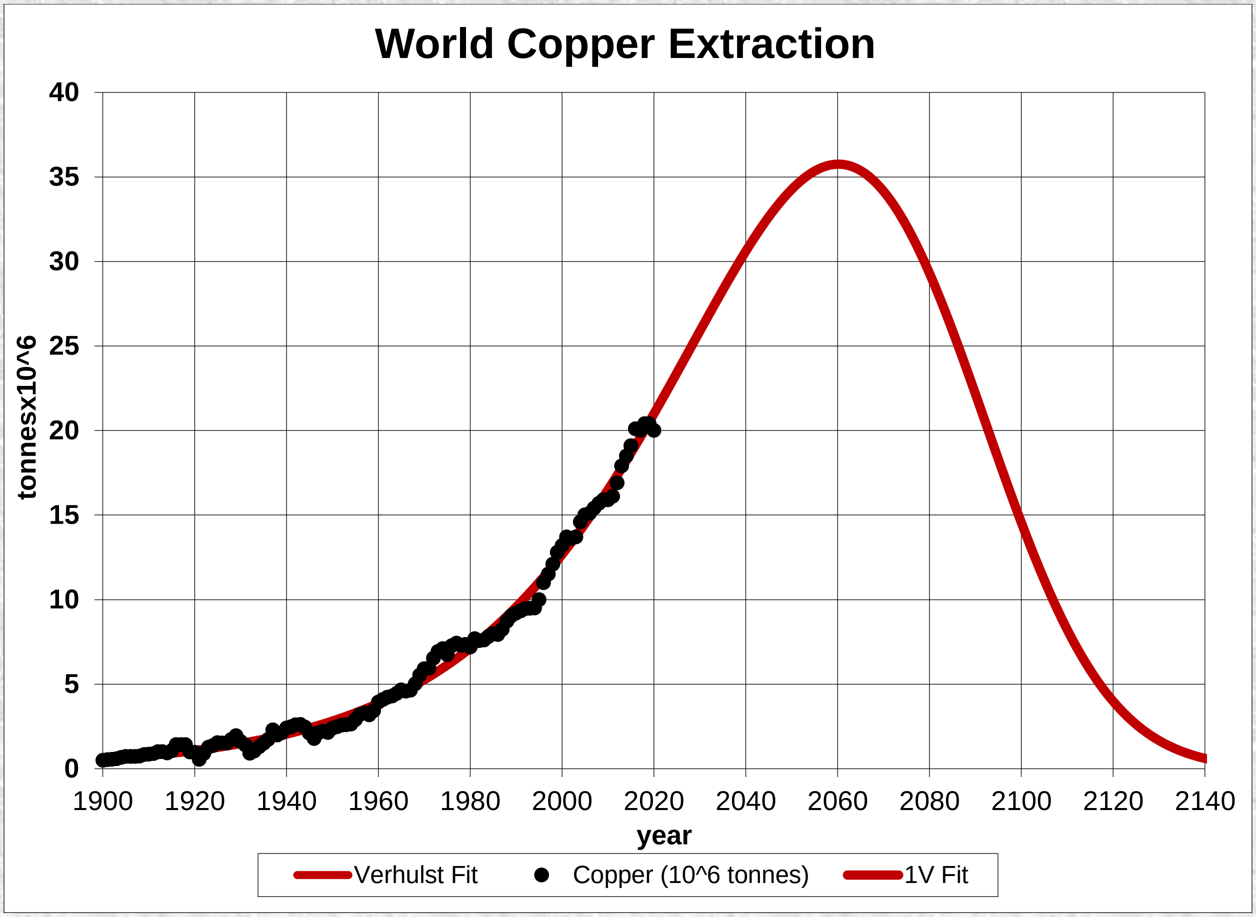
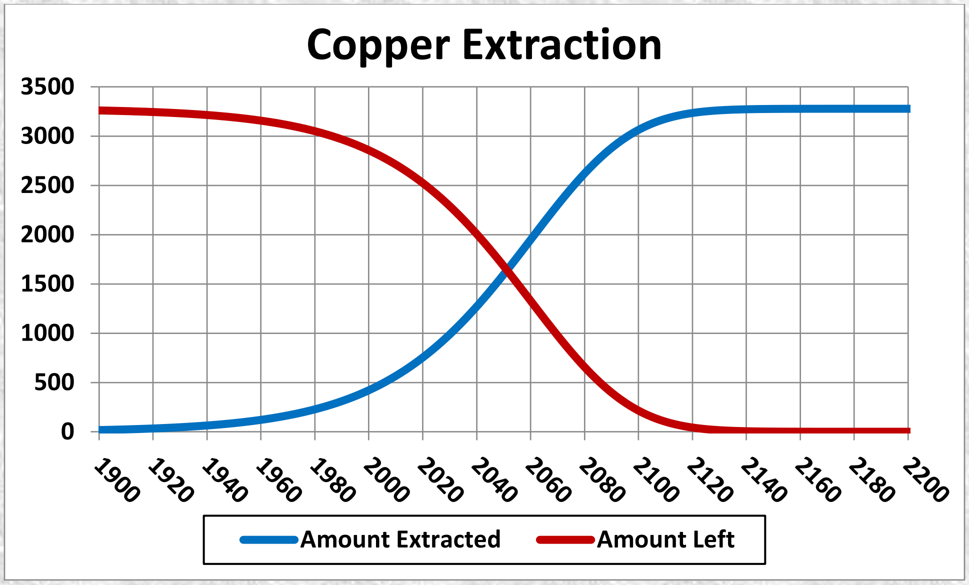
Copper is an important metal of especially great use in electrical conductors. The graph below shows the copper extraction data for the world and a Verhulst function fit to the data.




Copper extraction rate for the world and several Verhulst functions fit to the data.
There may be another future peak.

It appears that the recent rapid rise in extraction rate is unsustainable for more than two decades from now.

Taking the extraction curve of the Verhulst fit, the crossover point at year ~2050 when the amount extracted is equal to the amount left to be extracted is shown here:

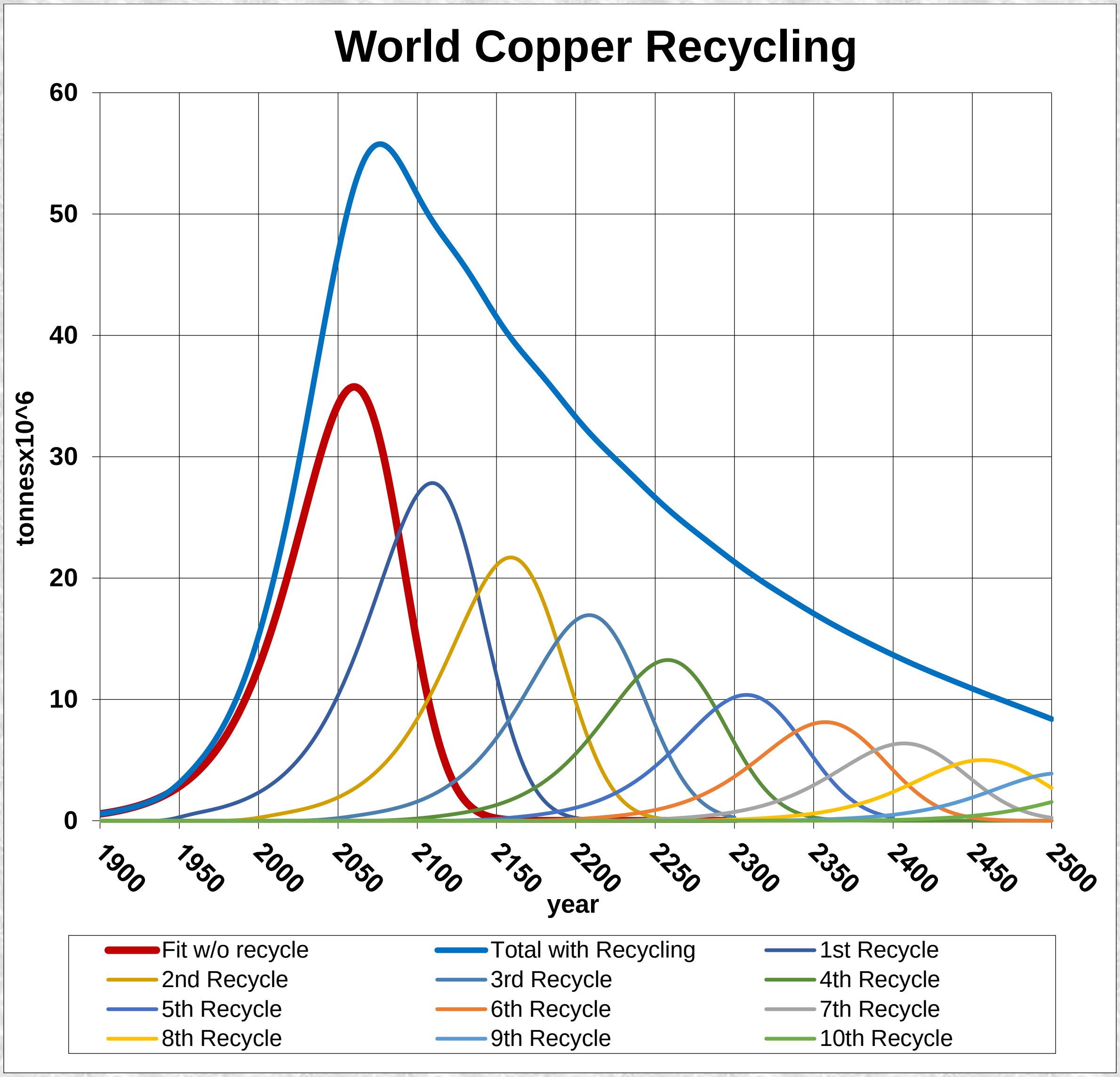


# Recycling

Copper is the third most recycled of all minerals after iron and aluminum. Assume that:

- The copper extraction curve is the average of the two curves given above.
- Recycling of copper follows a hyperbolic tangent curve from 40% to 81% recycling with a break point of year 1940 and width 5 years.
- The recycling is delayed by a Gaussian curve peaking at a delay of 50 years and a width of 8 years.

The effective copper available for making items after the first ten recycling cycles is shown in the following graph, along with the effective copper available for each cycle:




The equation for the amount available for a recycling cycle N is

$$R_N = \frac{1}{2}\left[0.8+0.4+(0.8-0.4)\tanh\left(\frac{t-1940}{8}\right)\right]\sum_{i=1}^{N}\left\{E(t_i)\exp\left[-\left(\frac{t-t_i-50}{8}\right)^2/2\right]\right\}/\left(8\sqrt{2\pi}\right),$$

where $E(t_i)$ is the amount available from the previous cycle at year $t_i$. Here is an example of the Excel coding:

{=(($J$2+$I$2)/2+(($J$2-$I$2)/2)*TANH((A27-$K$2)/$L$2))*SUM($I$27:I27*(EXP(-1*((A27-$A$27:A27-$N$2)/$O$2)^2/2))/$O$2/SQRT(2*PI()))} (The curly bracket surrounding the term makes it into an array; it must be entered by holding down the SHIFT & CTRL keys while pressing the ENTER key.)

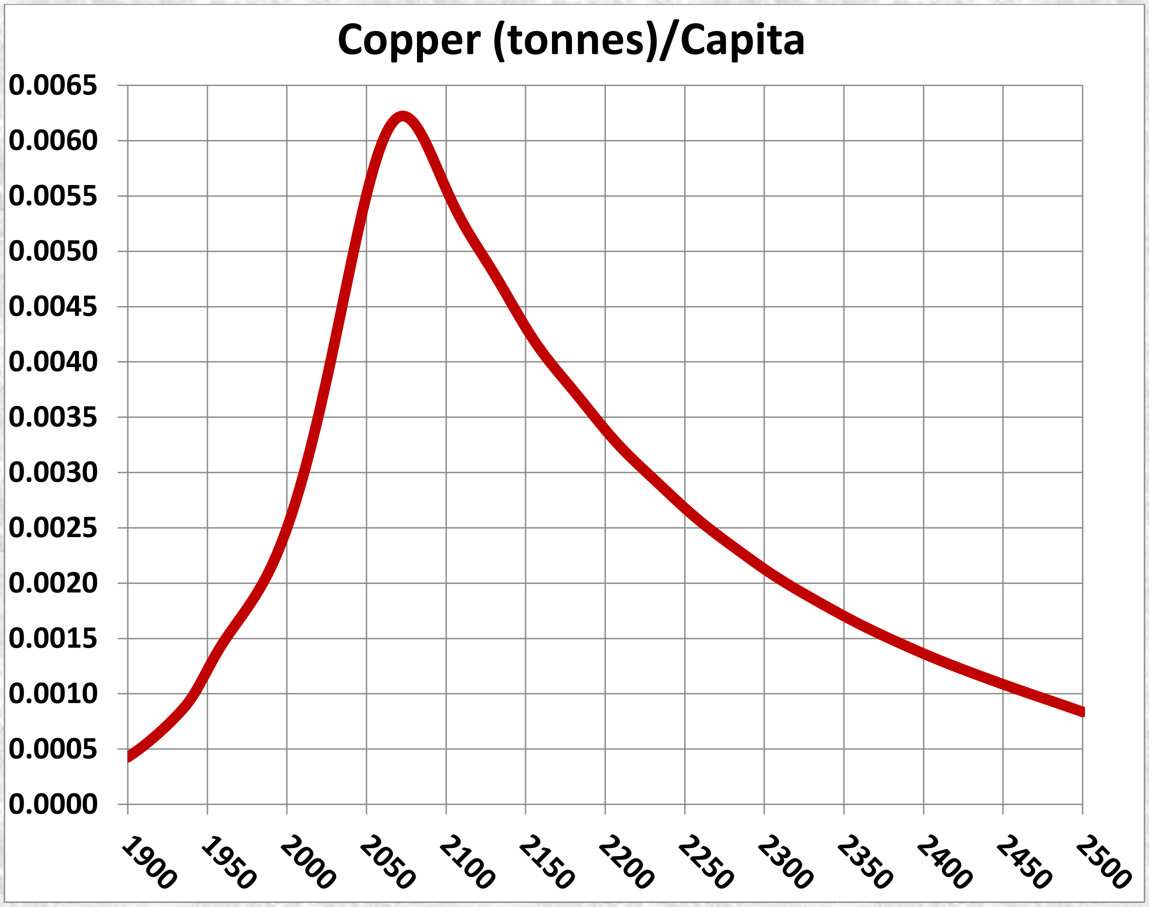
Of course, the recycling could be extended to more cycles, skewing the curve further into the future. However, the peak and fall off after it will not change because further cycles are essentially zero in that time region.

Thus, under the assumptions given above, the effective amount of copper available for making items peaks at about year 2045 and falls off rapidly after that. Humans will have taken concentrated copper deposits and scattered them across the surface of the earth.

The Excel spreadsheet is set up to make it easy to calculate with different recycling assumptions.

## Copper Per Capita

Dividing the copper recycling curve above by the projected world population (asymptote ~$10^{10}$), one gets:



## References


- http://www.resilience.org/stories/2010-03-31/copper-peak
- *Boom, Bust, Boom: A STory about Copper, the Metal that Runs the World* by Bill Carter, Scribner, 2012


Minerals Depletion