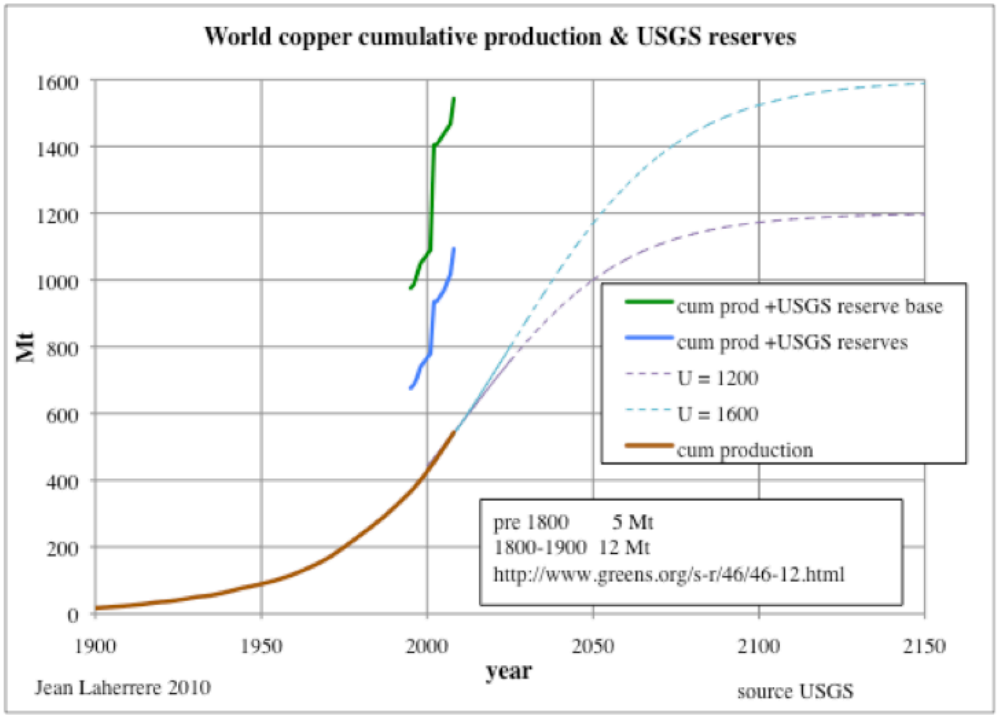
Jean Laherrere 5 March 2010

Copper peak

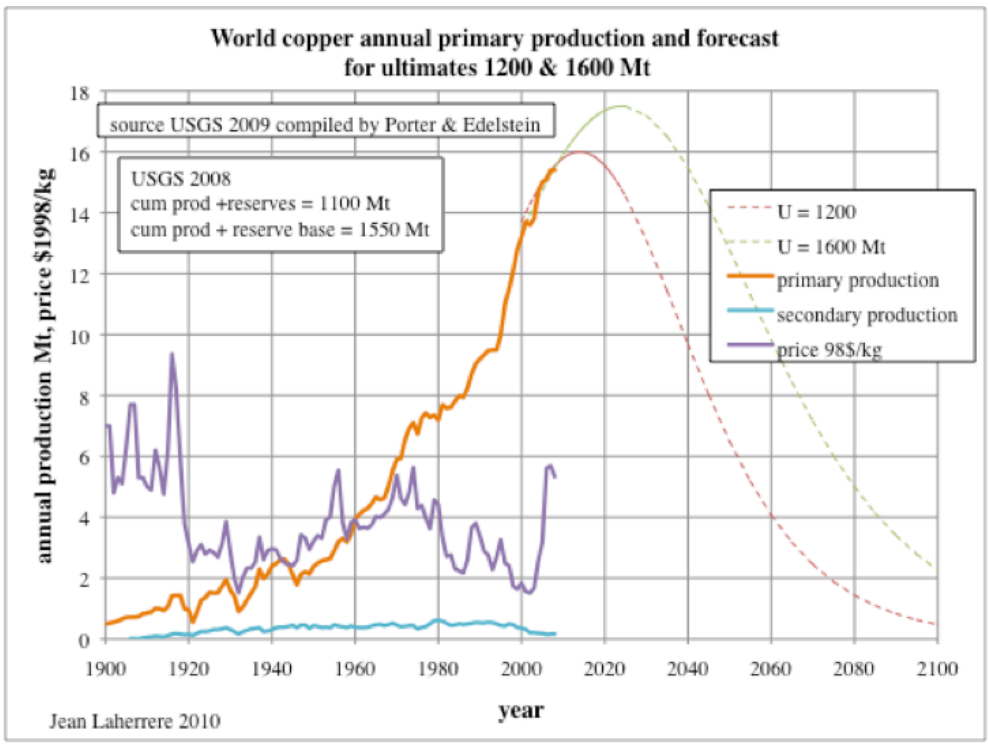
I found fairly easy to model the gold production of the world and of the main producers in Laherrère J.H. 2009 «The gold peak, easier to model than the oil peak» in two parts
http://aspofrance.viabloga.com/files/JL_Goldpeak1_2009.pdf
http://aspofrance.viabloga.com/files/JL_Goldpeak2_2009.pdf
and I have tried to do the same for copper production.
The best source is USGS data, which is complete since 1900 for US and the world. For other countries unfortunately, I had to turn to individual annual reports (from 1932) where the scanned data is hard to read for old reports. USGS should compile the country copper production from the annual reports in one document like Porter and Edelstein did for the world and for the US: U.S. Geological Survey, in Kelly, T.D., and Matos, G.R. «Historical statistics for mineral and material commodities in the United States»: U.S. Geological Survey Data Series 140, available online at http://pubs.usgs.gov/ds/2005/140/.
Since 1995, the USGS reports its annual remaining reserve estimate, as USGS reserves and USGS reserve base. The cumulative production from 6000 years ago to 1900 is estimated at 17 Mt (http://www.greens.org/s-r/46/46-12.html).
The world copper cumulative production can be easily modelled with a logistic curve for ultimates of 1200 & 1600 Mt to fit to the USGS estimates.

Figure 1: world copper cumulative production, USGS reserves & forecast for ultimates 1200 & 1600 Mt

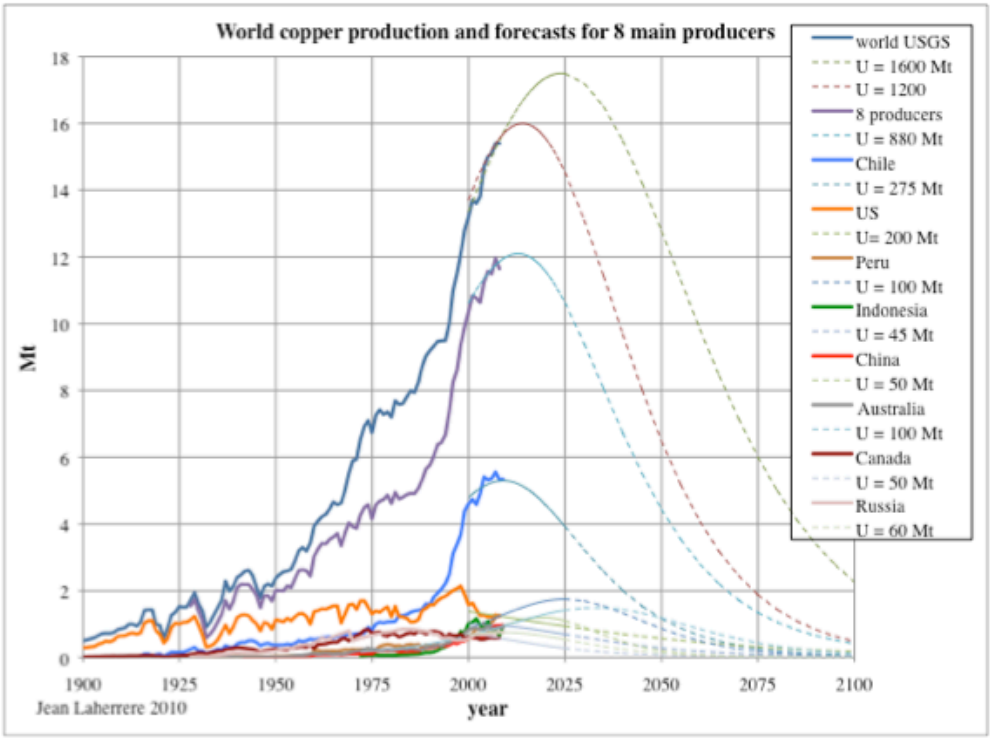


For these two ultimates the annual production can also be easily modelled and the peak seems to start to occur soon despite (or because) the high price increase since 2000, yet copper price today is cheaper than in 1900 when reported in $1998/kg (USGS data). The secondary production is small and decreasing to almost nothing!

Figure 2: world copper annual production & forecasts for ultimates 1200 & 1600 Mt & price



8 main copper producers (Chile, US, Peru, Indonesia, China, Australia, Canada and Russia) have been studied and the synthesis is plotted on a single graph.
These 8 producers have an ultimate of 820 Mt that is about 60% of the world ultimate.
Figure 3: world copper annual production & forecasts for 8 main producers 1900-2100



Gavin Mudd 2009 « Historical trends in base metal mining: back casting to understand the sustainability of mining » http://civil.eng.monash.edu.au/about/staff/.../2009-CMS-03-Base-Metals.pdf shows a copper annual production starting in 1840
Figure 4: world copper annual production from G.Mudd 1840-2008

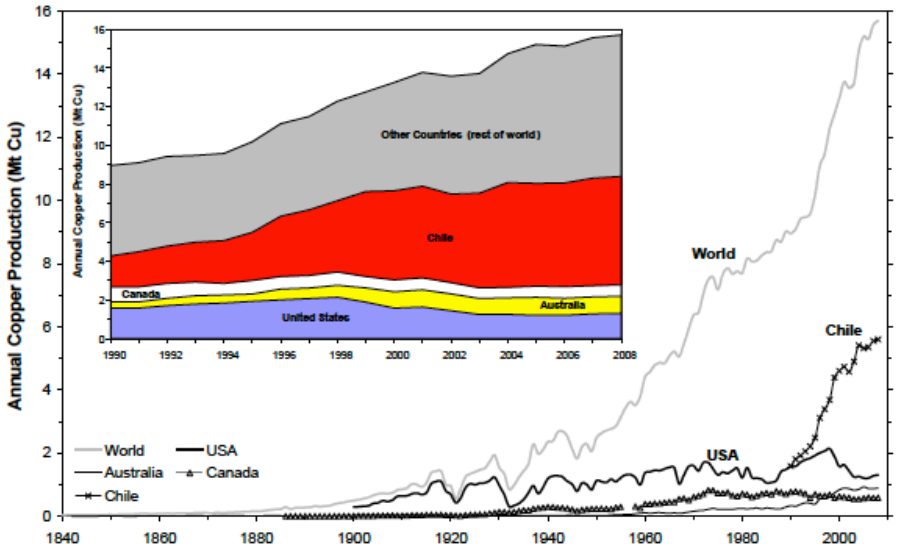


Figure 1 – Mined copper production over time by country (data sourced from [2-10])

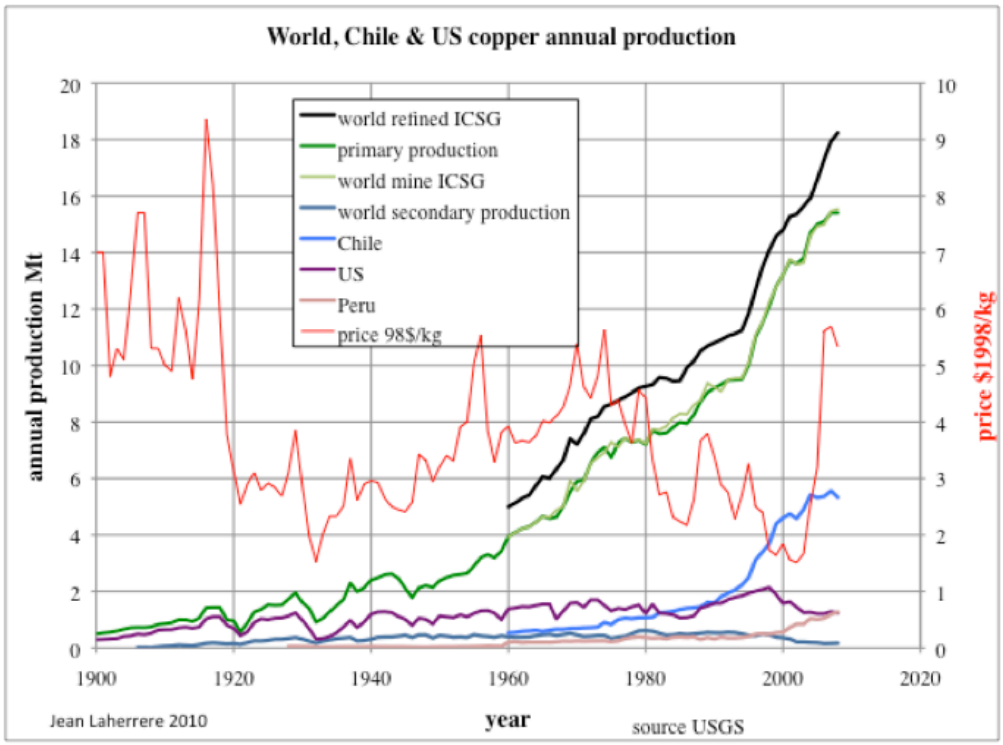
The details for the 8 main copper producers are presented below

-Details

-World

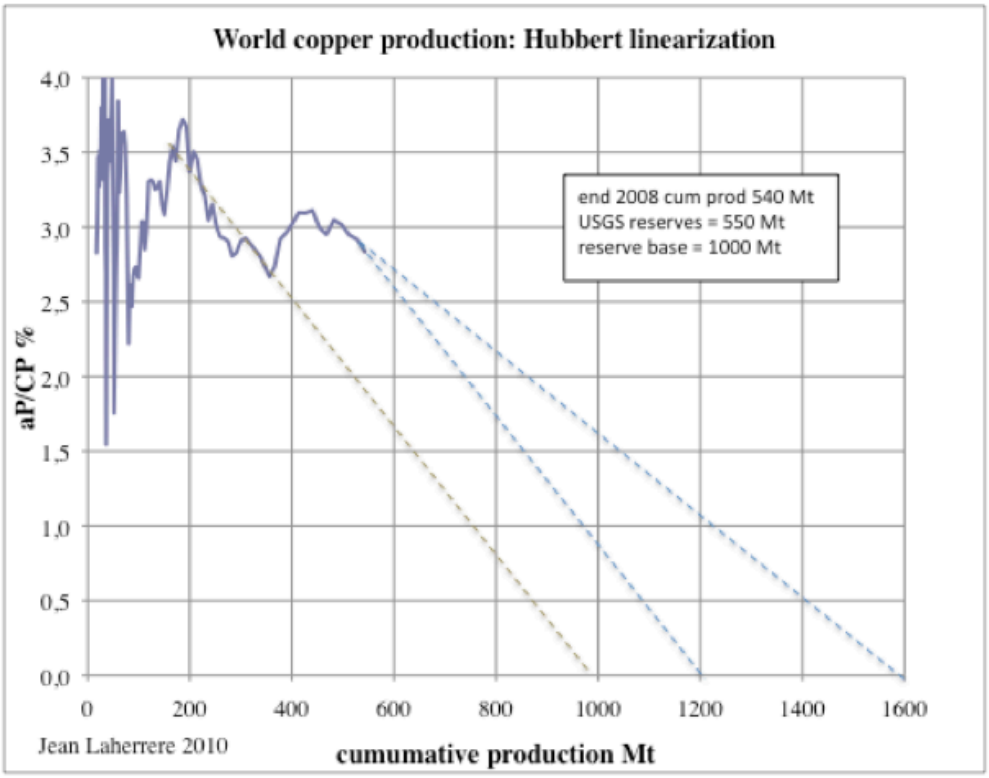
The world primary production is less than the secondary production and both added less than the refined reported by ICSG

Figure 5: world, Chile, Peru & US copper annual production as copper price



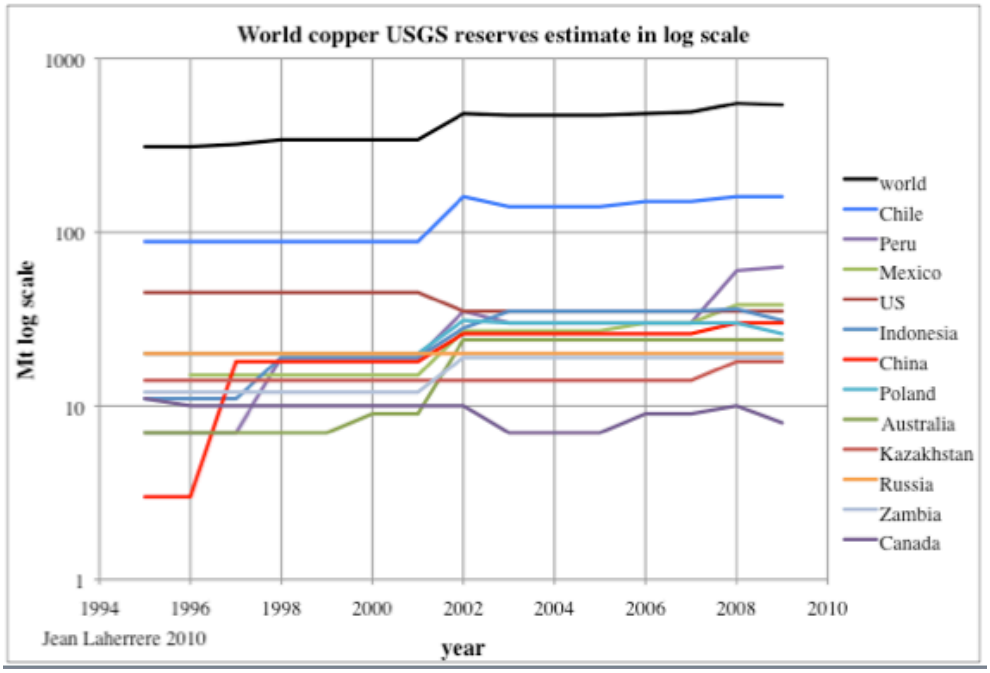
The Hubbert linearization of production data being the growth of production (or annual/cumulative in %) versus cumulative production is extrapolated with a linear trend hoping to obtain the ultimate, but it works only if the cumulative production fits a logistic curve, when in reality there are often several cycles.

The present plot for the world shows only a recent trend from 2000 which can be extrapolated towards 1600 Mt (present cumulative production +USGS reserve base) but the previous declining trend (1975-1995) was trending towards 1000 Mt.
Figure 6: world copper production: Hubbert linearization



Hubbert linearization is a poor way to estimate the ultimate!

The best approach is to rely on the geological inventory of the world potential estimated by the USGS, and based on the study of known discoveries and possible yet to find.
The USGS does not give a good and precise definition of its estimates reported as reserves and reserve base!
Contrary to the obsolete SEC rules for oil, forbidding reporting probable reserves (now changed in 2010) the SEC rules for mineral (industry guide 7) allow to report proved and probable.
USGS data on copper reserves changes only its values from time to time when it shows the remaining discovered reserves and should be decreased when production and no new discovery.
Only US and Canada reserves have decreased!
The reserves reported by the USGS since 1995 shows a poor evolution when plotted in a log scale
Figure 7: world & main producers copper reserves USGS estimate in log scale

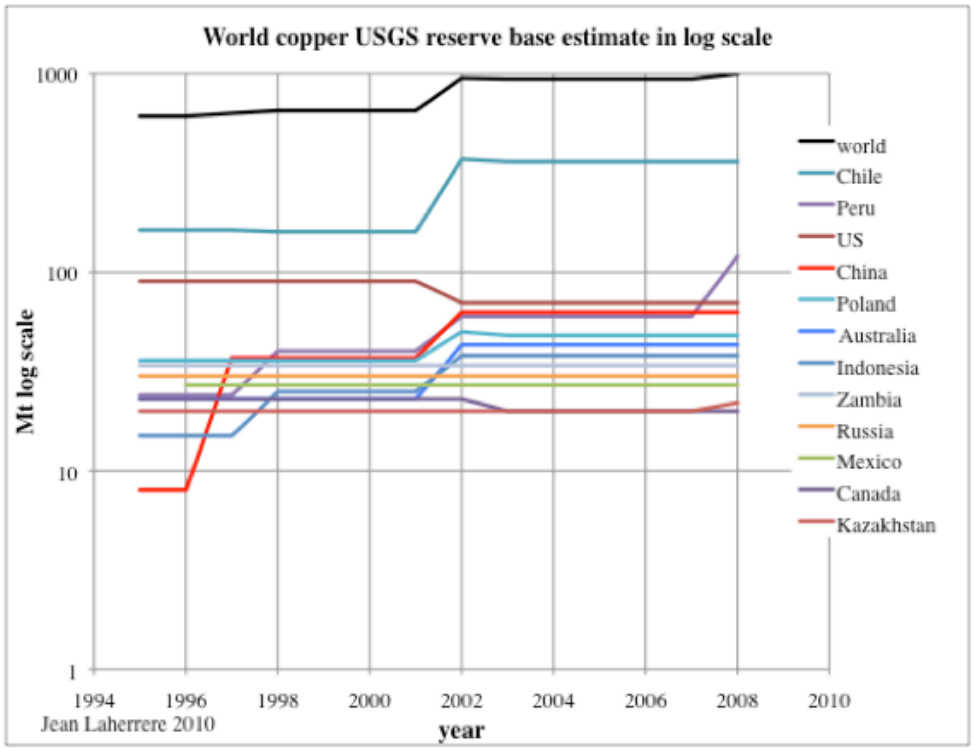


This poor evolution, such as for Russia with no change during 15 years, means that their estimate lacks good data!

Geoscience Australia in their 2009 report (http://www.ga.gov.au/image_cache/GA16013.pdf) use a more precise definition of resources and report Economic Demonstrated Resources (EDR) for Australia and the world at end 2008 being 78 Mt and 603 Mt, whereas the USGS reserves stand at 24 Mt and 540 Mt and the USGS reserve base amounts to 43 Mt and 1000 Mt. USGS reserves look pessimistic compared to Geoscience Australia EDR.

The reserve base looks similar, but should be an upper limit.

Figure 8: world & main producers copper reserve base USGS estimate in log scale



In mining, economics depends mainly on the grade of the ore and it is important to plot the evolution with time. But my data is not good enough.

Gavin Mudd 2009 has a graph showing the decline of the ore grades for the world, US, Australia and Canada, all declining below 1% in 2008. The economic threshold is difficult to be estimated.

Figure 9: world, USA, Canada and Australia ore grade 1900-2008

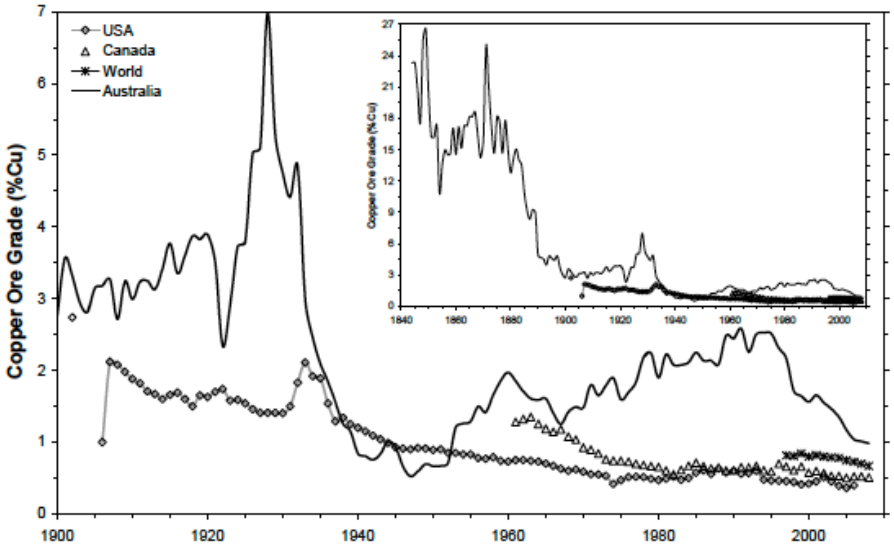


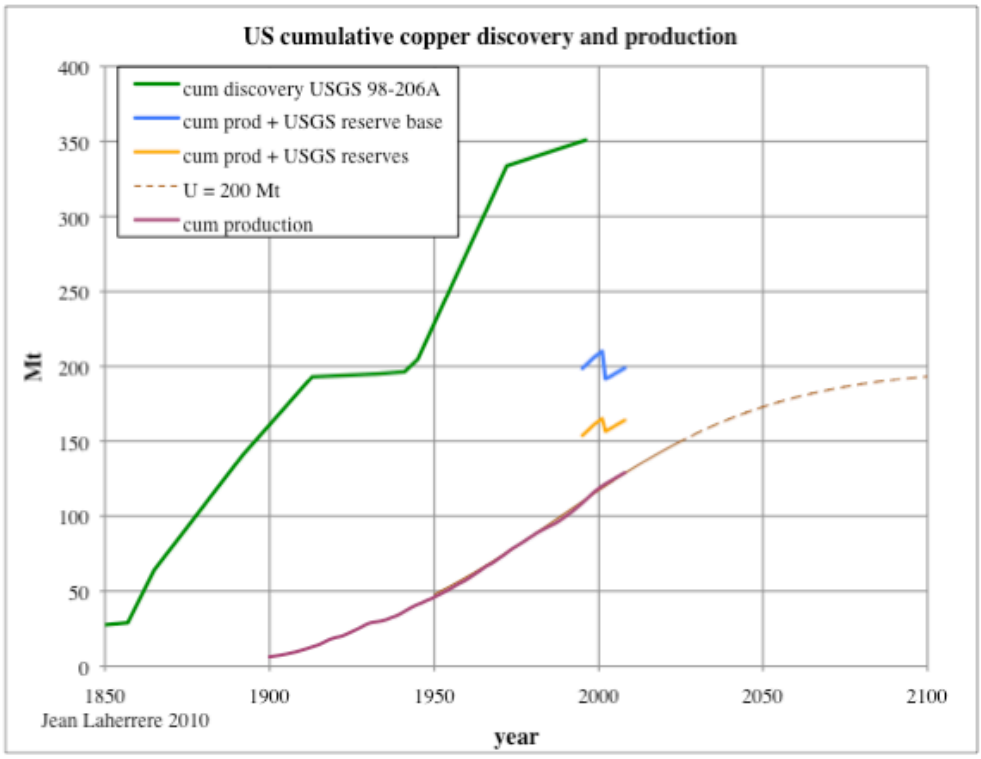
Figure 2 – Copper ore grades over time by country and approximate world average

-US

The cumulative US copper discovery (starting in 1545) from USGS 98-206A is 350 Mt at end 1998 and seems very optimistic compared to the USGS reserve base (around 200 Mt with cumulative production).

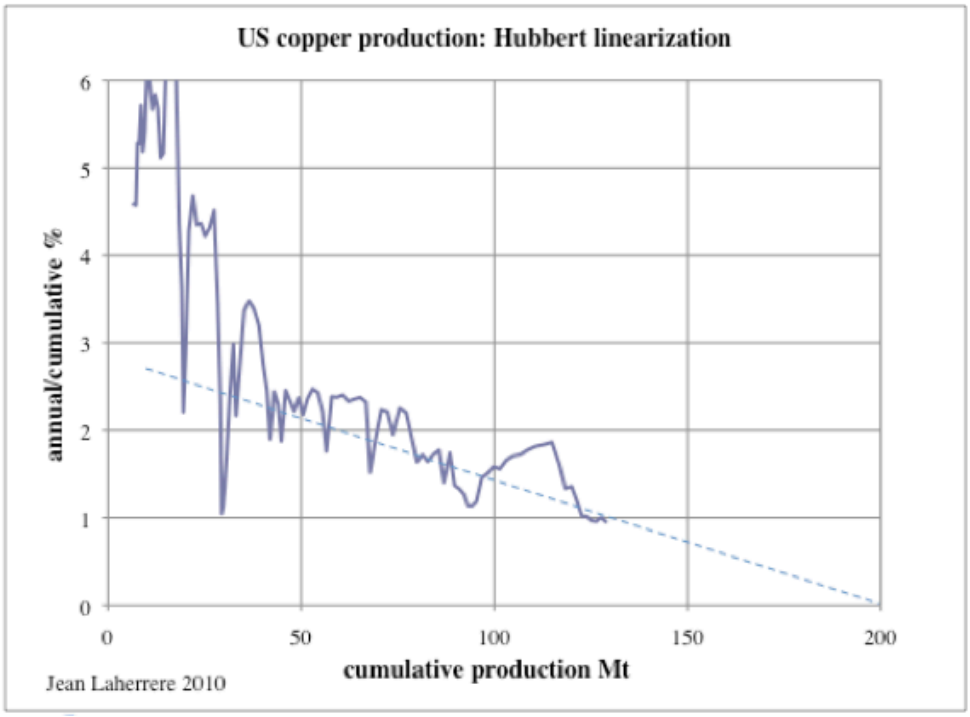
The cumulative production in 1900 is assumed to be around 6 Mt and it is at 129 Mt at end 2008. We have taken 200 Mt as the ultimate production.

Figure 10: US copper cumulative discovery and production & USGS reserves & forecast for an ultimate of 200 Mt



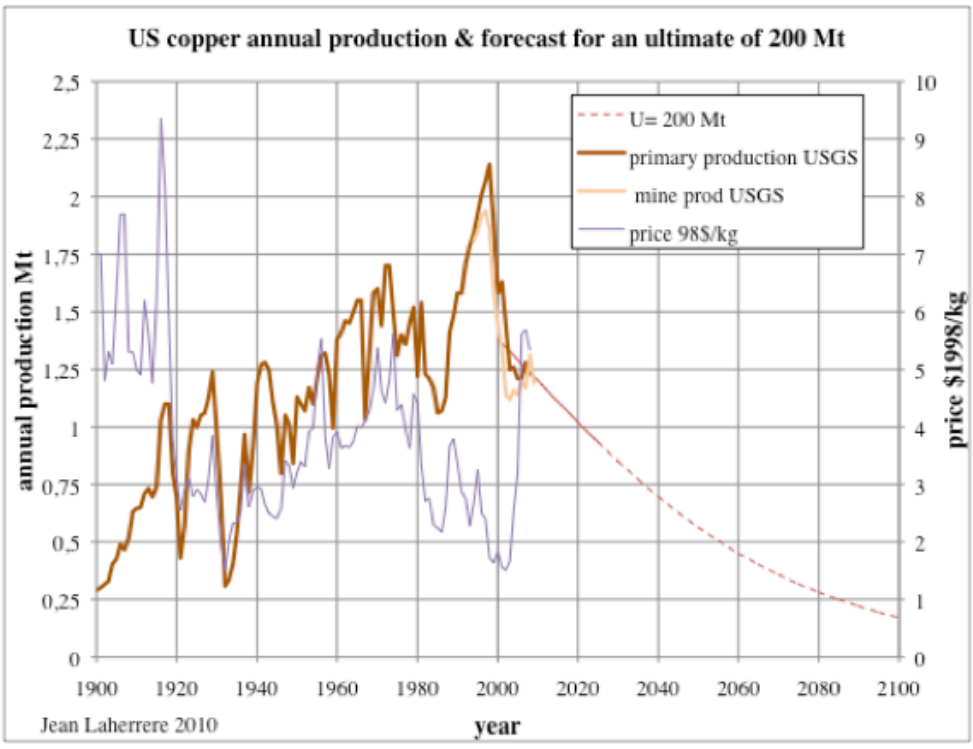
The Hubbert linearization of production is more reliable, having passed peak, trending towards 200 Mt.

Figure 11: US copper production: Hubbert linearization



The US copper annual production is increasing chaotically from 1900 to a peak in 1998 at 2.1 Mt, and drops drastically to 1.2 Mt in 2005, despite a sharp increase in price!

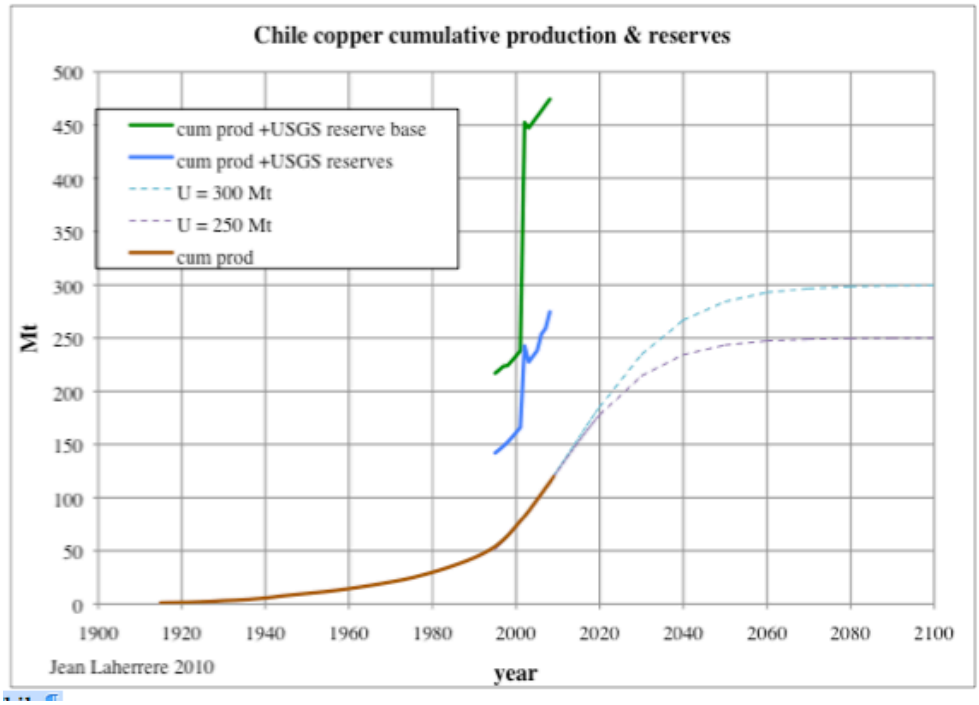
Figure 12: US copper annual production for an ultimate of 200 Mt



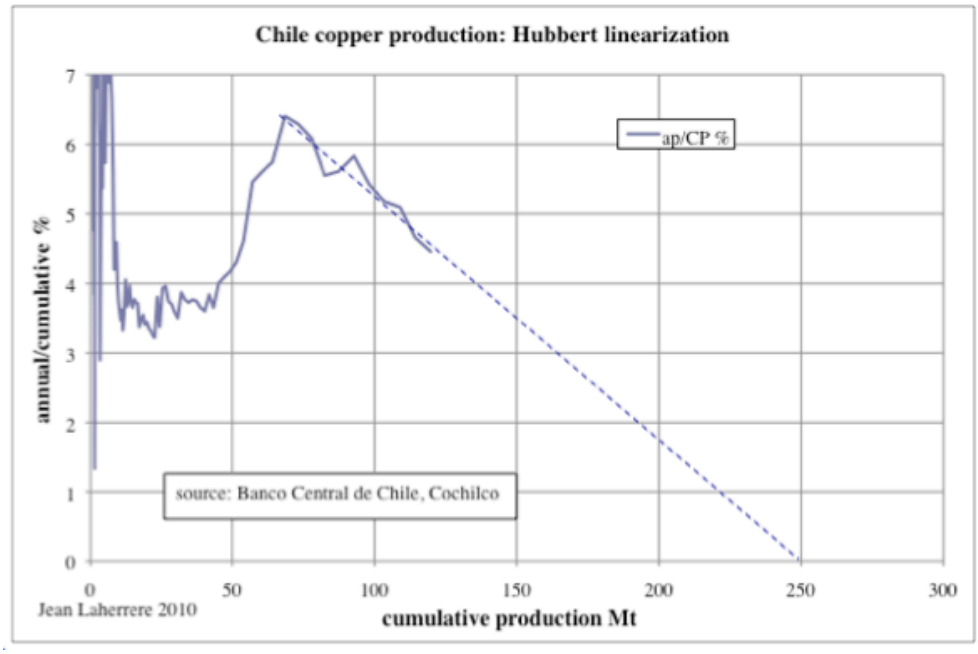
-Chile

The USGS has almost doubled the Chile copper reserves from 1995 to 2009

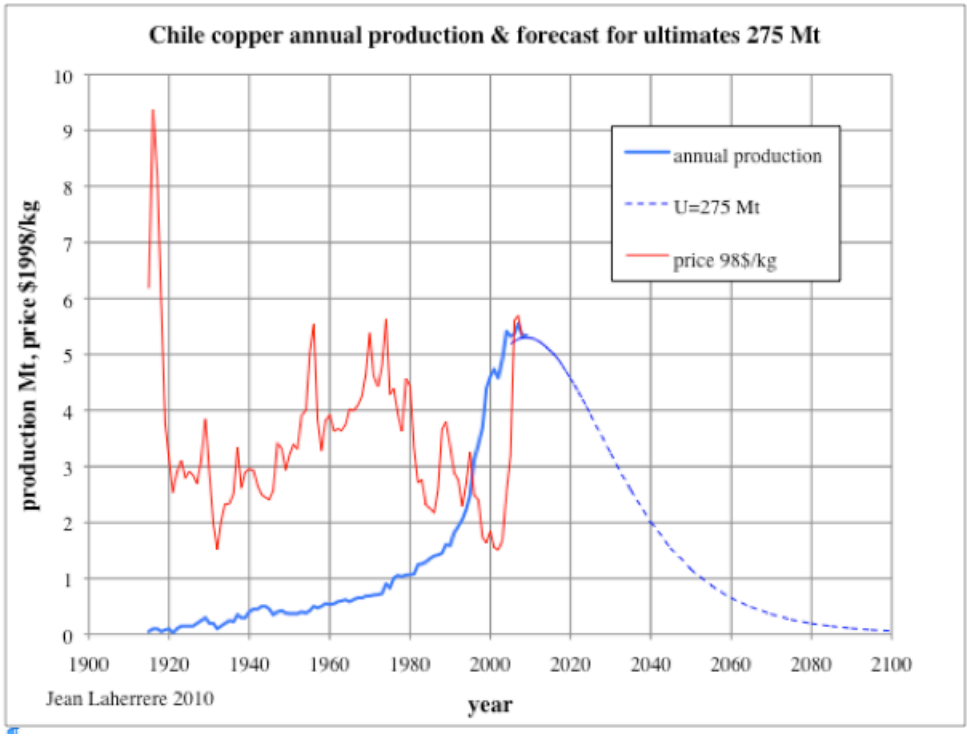
Figure 13: Chile copper cumulative production and USGS reserves & forecast for ultimates 250 & 300 Mt



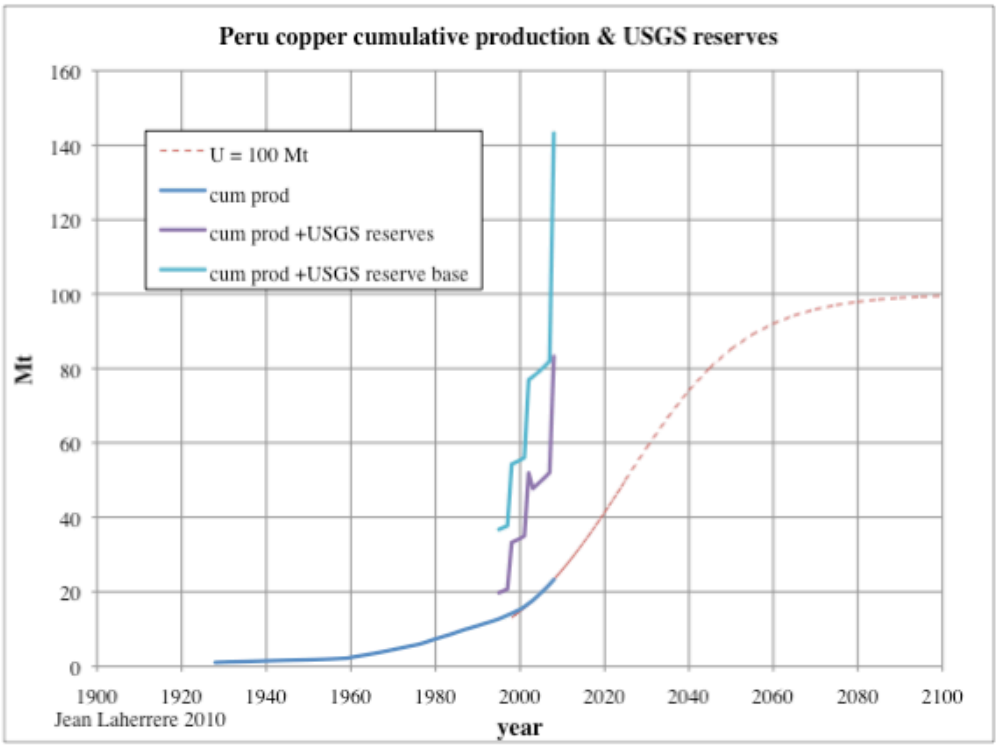
We have modelled for an ultimate of 250 Mt because the Hubbert linearization since 1999 trends towards such value, but also 300 Mt, guessing that 275 Mt is not a bad value.
Figure14: Chile copper production: Hubbert linearization



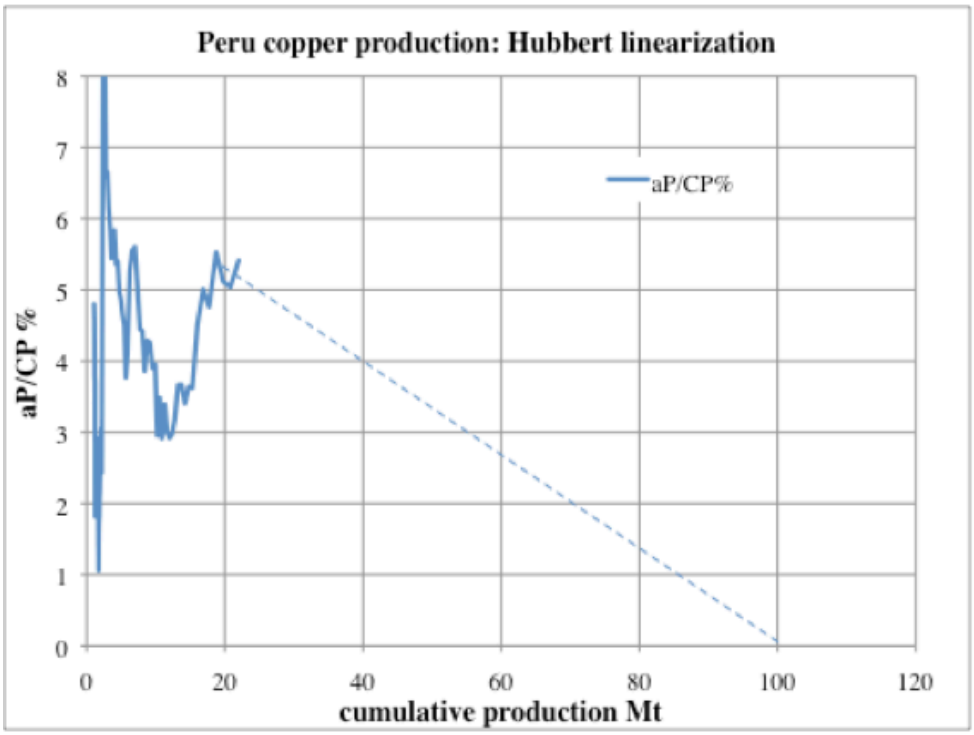
Chile copper production has peaked in 2007
Figure 15: Chile copper annual production & forecast for an ultimate of 275 Mt



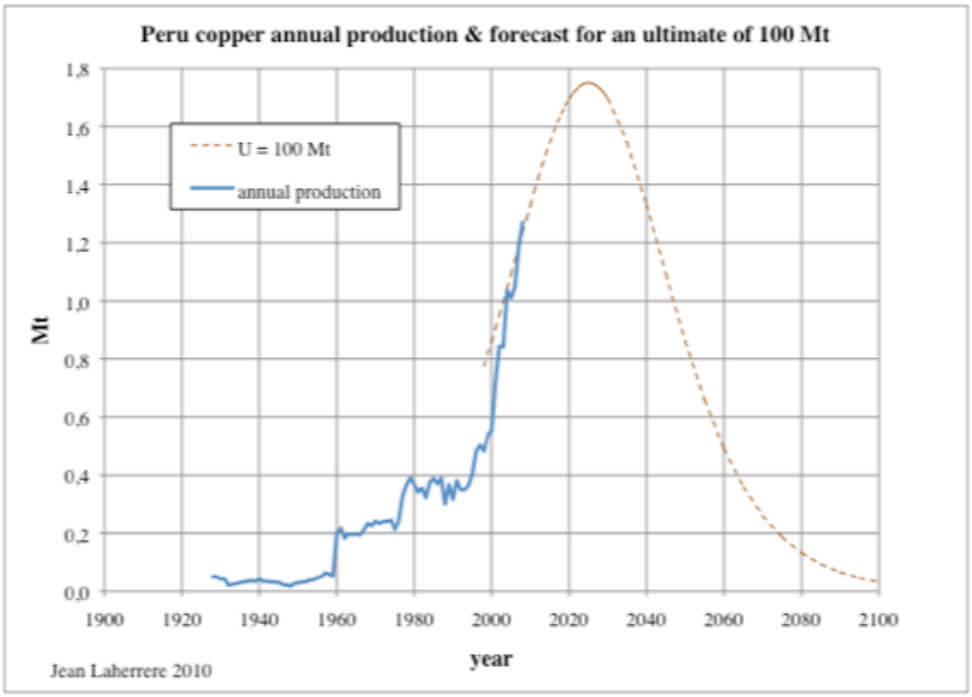
-Peru
Like for Chile, the USGS has doubled its reserves estimate, but in 2008 from 30 to 60 Mt.
We guess that the ultimate is around 100 Mt
Figure 16: Peru copper cumulative production and USGS reserves & forecast for an ultimate of 100 Mt



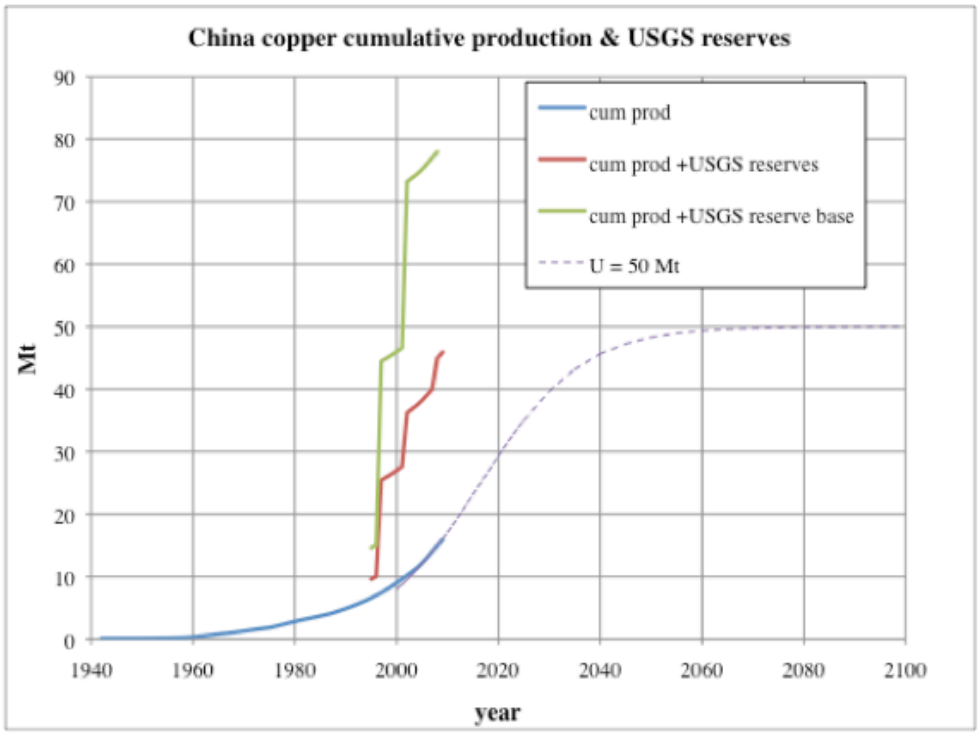
The Hubbert linearization is hopeless, being far from peak.
Figure17: Peru copper production: Hubbert linearization



For an ultimate of 100 Mt, Peru copper production will peak around 2025 at 1.7 Mt.
Figure 18: Peru copper annual production & forecast for an ultimate of 100 Mt

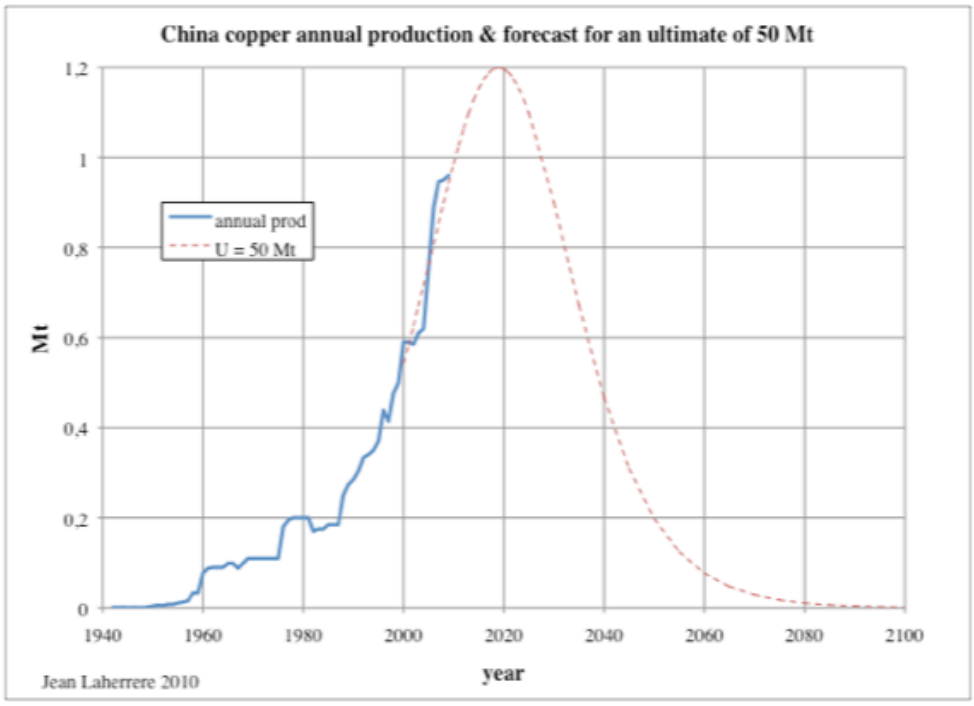


-China
Data for China is hard to check and the USGS has increased its reserves lately. We have taken an ultimate of 50 Mt.
Figure 19: China copper cumulative production and USGS reserves & forecast for an ultimate of 50 Mt

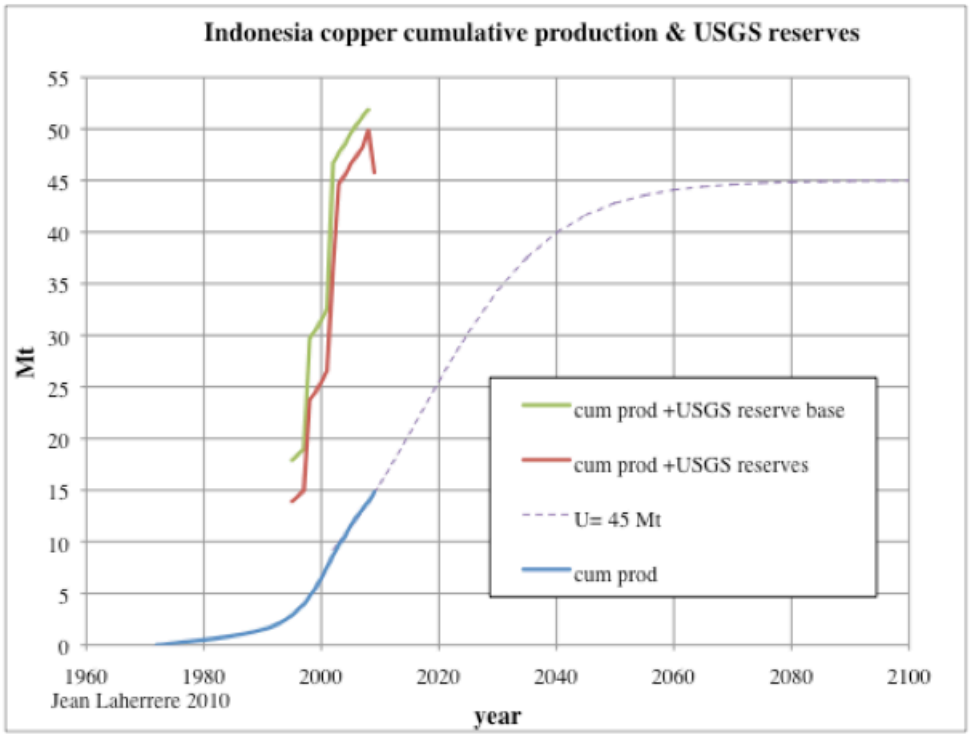


Hubbert linearization plot trends towards infinite!

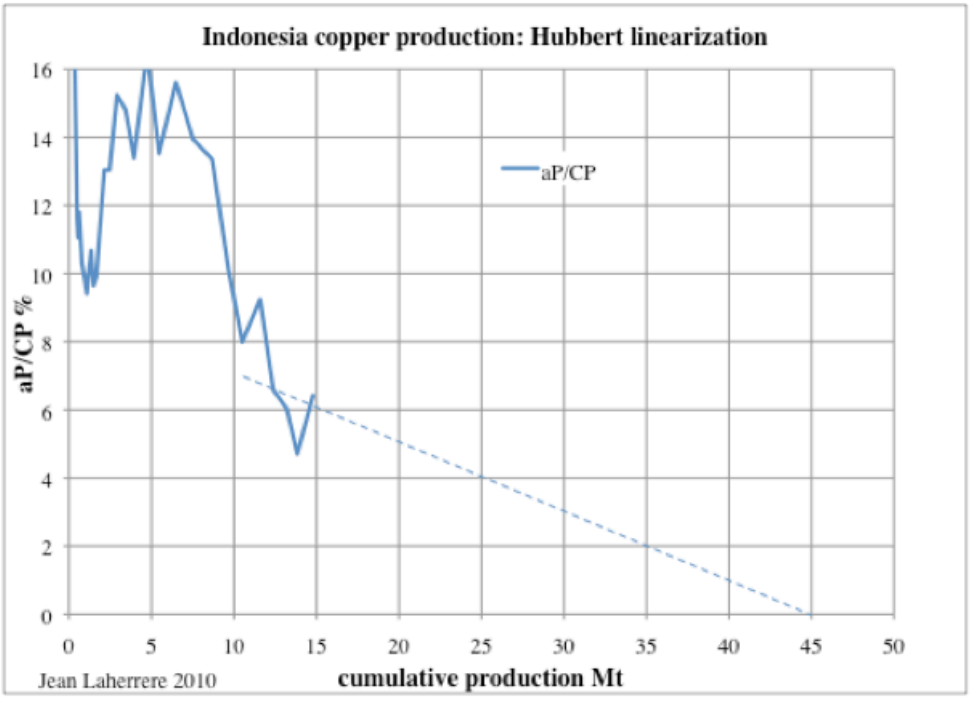
The annual production should peak around 2020 at 1.2 Mt
Figure 20: China copper annual production & forecast for an ultimate of 50 Mt



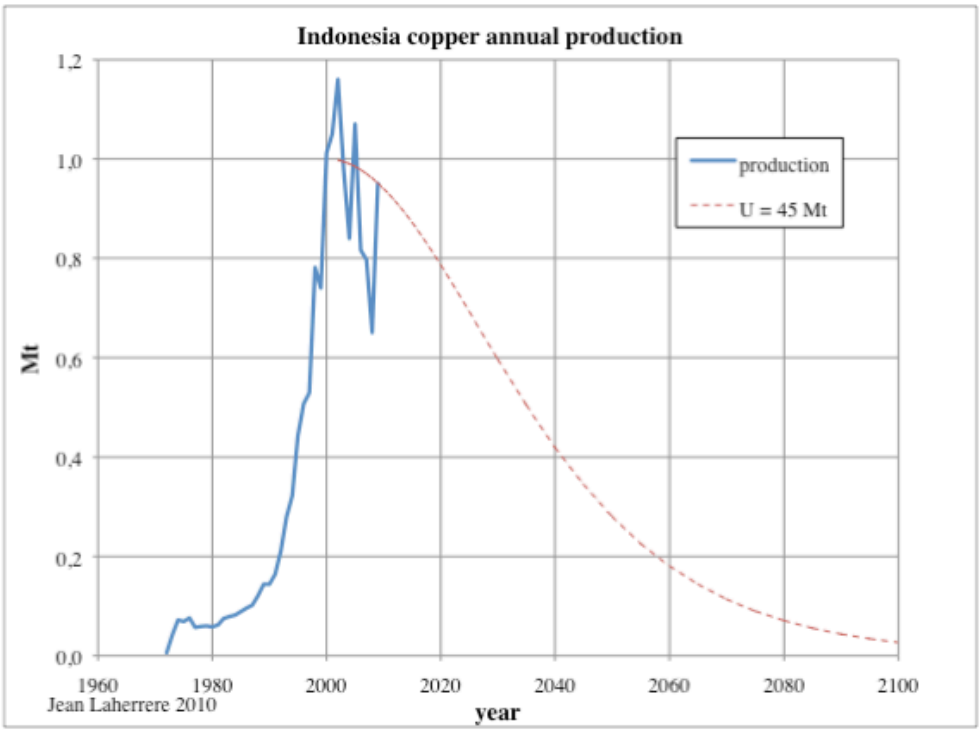
-Indonesia
The USGS has sharply increased Indonesia's reserves around 2000, but reduced them last year. We have taken an ultimate of 45 Mt.
Figure 21: Indonesia copper cumulative production, USGS reserves & forecast for an ultimate of 45 Mt



Hubbert linearization plot is impossible to extrapolate
Figure22: Indonesia copper production: Hubbert linearization



Indonesia copper production has peaked in 2001 and will decline slowly until 2100.
Figure 23: Indonesia copper annual production & forecast for an ultimate of 45 Mt



-Australia

In the US, Wall Street (SEC) dominates reserves definition and it is good to see a country with a better scientific approach.

Australia is a good choice to compare USGS estimate with Geosciences Australia estimate (http://www.ga.gov.au/image_cache/GA16013.pdf).

Australia has a better reserve definition for minerals (EDR = Economic demonstrated resources)

Figure 24: Australia's resources from Geosciences Australia 2009 report

Table 1. Australia's resources of major minerals and world figures as at 31 December 2008.

COMMODITY	UNITS	AUSTRALIA							WORLD	
		Demonstrated Resources			Inferred Resources (a)	Accessible EDR (AEDR)(b)	JORC Reserves(c) (% of AEDR)	Mine Production(d) 2008	Economic Demonstrated Resources(e)	Mine Production(f) 2008
		Economic (EDR)	Subeconomic: Para-marginal	Subeconomic: Sub-marginal						
Antimony	kt Sb	136	43	36	60	136	96 (70%)	–	2100	135
Bauxite	Gt	6.2	0.2	1.4	0.91	5.4	1.9 (35%)	0.064	27	0.205(e)
Black coal - In situ	Gt	56.2	3.0	10.3	106.0					
Black coal - Recoverable	Gt	39.2	1.5	6.7	66.7	39.1	13.4(g) (34%)	0.425(h)	681(i)	5.7(i)(j)
Brown coal - In situ	Gt	44.3	43.1	18.1	112.3					
Brown coal - Recoverable	Gt	37.2	38.8	16.3	101.1	32.2	4.8(g) (15%)	0.066(i)	147(i)	0.87(i)
Cadmium	kt Cd	60.8	10.0	10.2	0.3	60.8	51.3 (84%)	0.46	490	19.9(m)
Cobalt	kt Co	1495	154	101	1915	1495	485 (32%)	4.79	7095	70.3
Copper	Mt Cu	77.8	6.6	1.0	34.2	77.8	19.8 (25%)	0.89	603	15.7
Diamond - Gem & near gem	Mc	91.9	99.7	0	14.3	91.9	91.2 (99%)	7.7	–	101
Diamond - Industrial	Mc	95.7	103.8	0	14.9	95.7	94.9 (99%)	8.0	586	67
Fluorine	Mt F	–	0.5	0.1	2.8	–	–	–	117(k)	2.7
Gold	t Au	6255	1478	123	4596	6130	3409 (54%)	215	48 655	2407

The sharp increase in Australia's copper reserves comes mainly from the huge Olympic Dam field (copper and uranium) in South Australia. K.F.Bampton « Copper mining and treatment in South Australia » (http://www.pir.sa.gov.au/__data/assets/pdf_file/0016/10906/mj28_copper.pdf)

Displays (in log scale) the up and down copper production in South Australia starting around 1840.

Figure 25: South Australia copper production

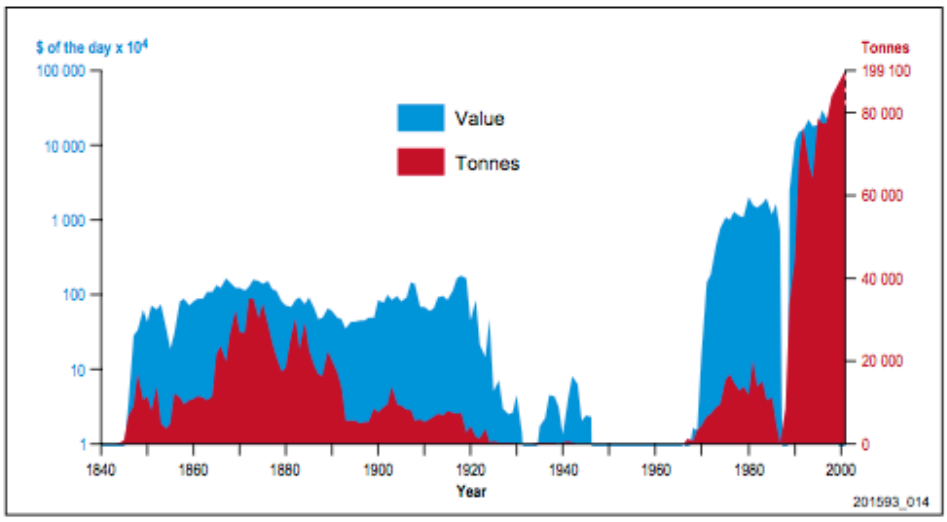
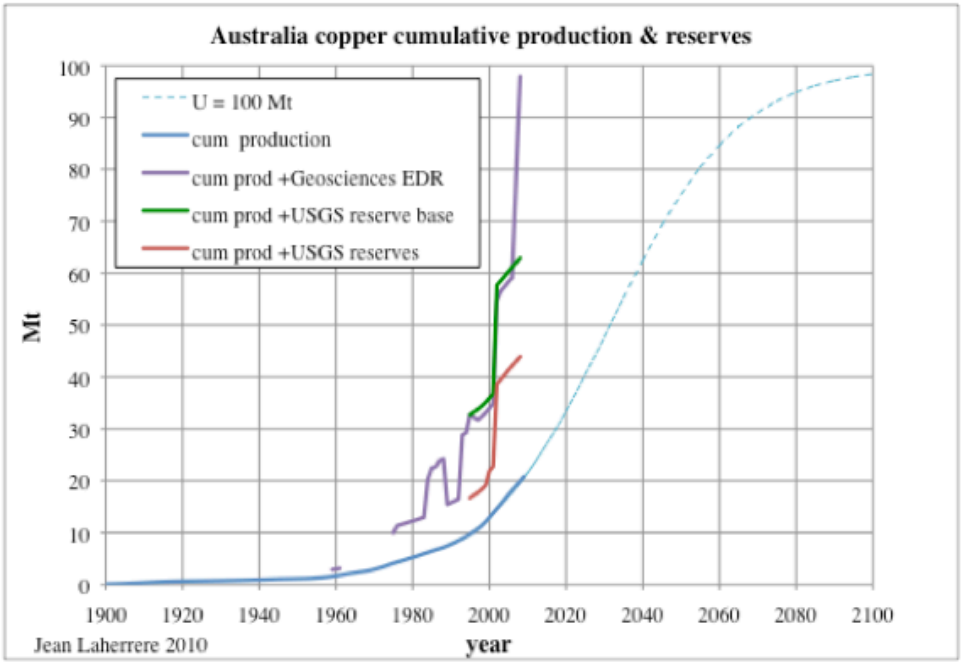


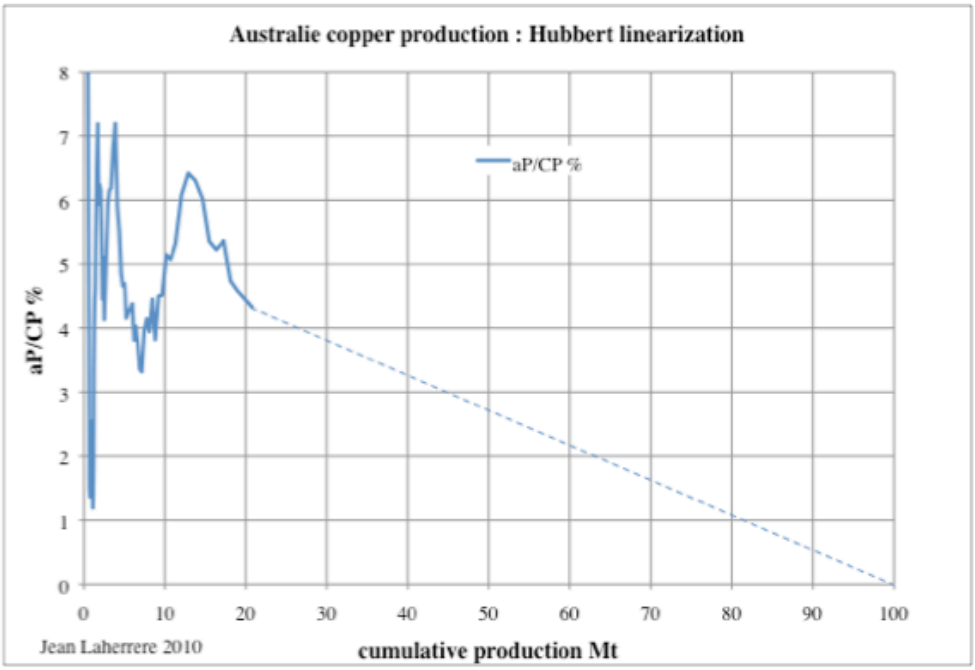
***Fig. 1** South Australian copper production, 1840–2000.*

Olympic Dam copper reserves are estimated at 32 Mt

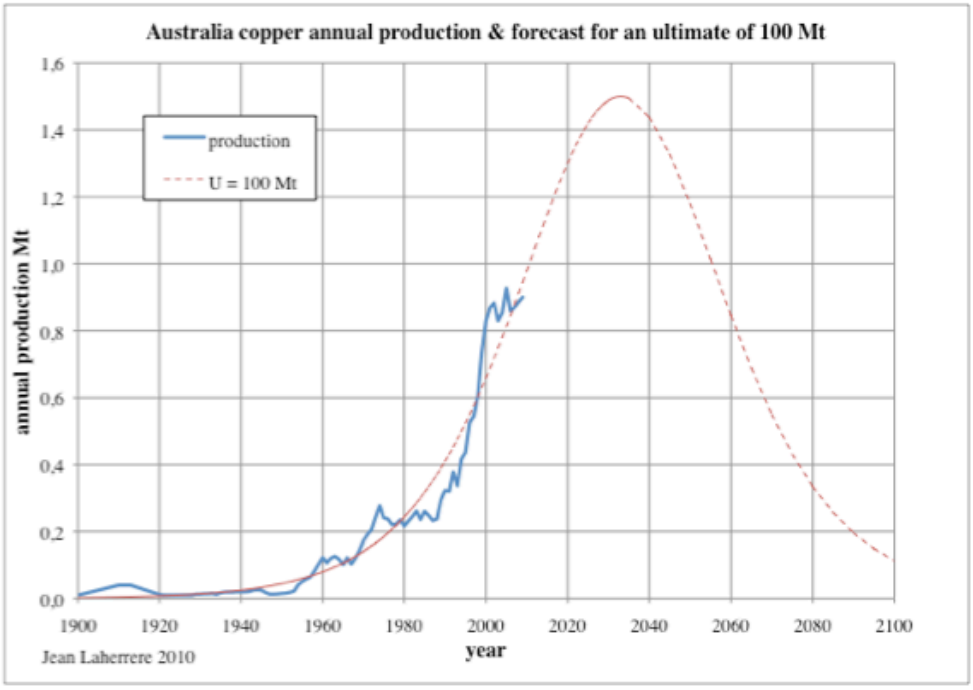
Australia copper ultimate is estimated at 100 Mt.
Figure 26: Australia copper cumulative production, USGS & Geosciences reserves with forecast for an ultimate of 100 Mt



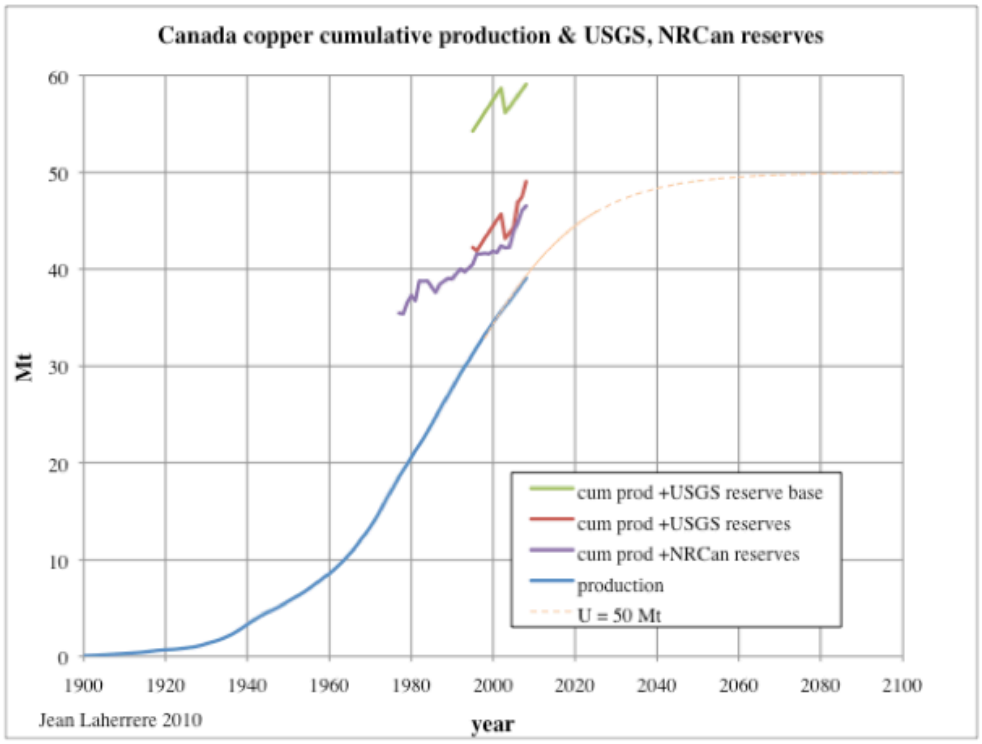
The Hubbert linearization is hard to extrapolate!
Figure27: Australia copper production: Hubbert linearization



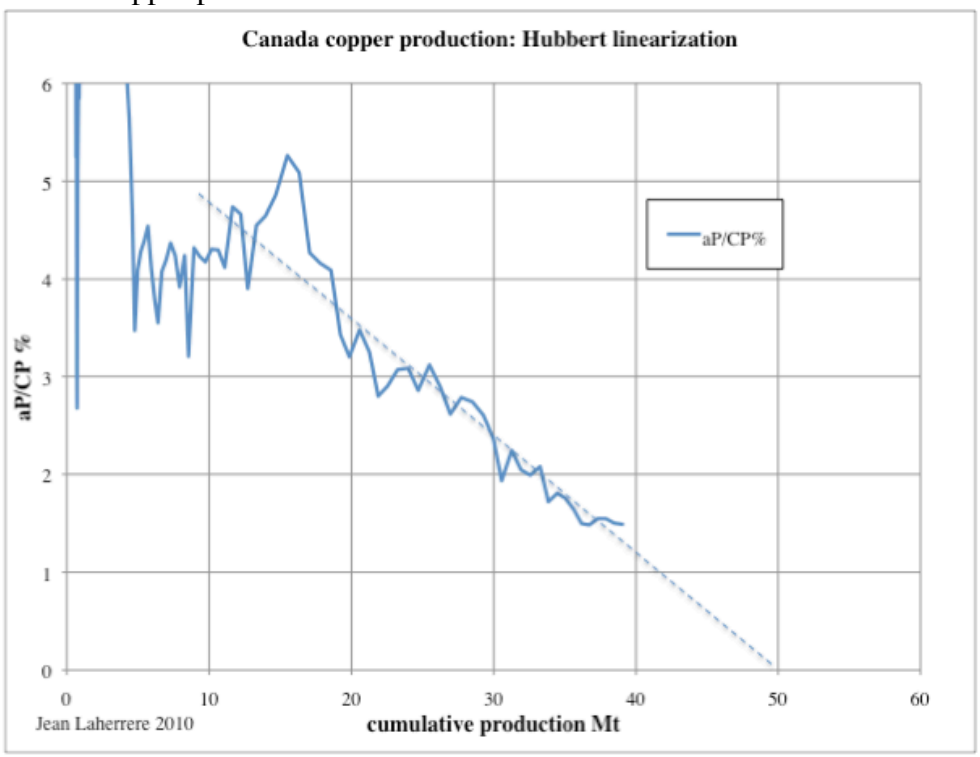
For an ultimate of 100 Mt Australia's copper production will peak around 2030 at 1.5 Mt.
But this optimistic future production increase is based only on geological constraints (reserves), yet above ground constraints (economy) could dampen this forecast into a more chaotic behaviour!
Figure 28: Australia's copper annual production & forecast for an ultimate of 100 Mt



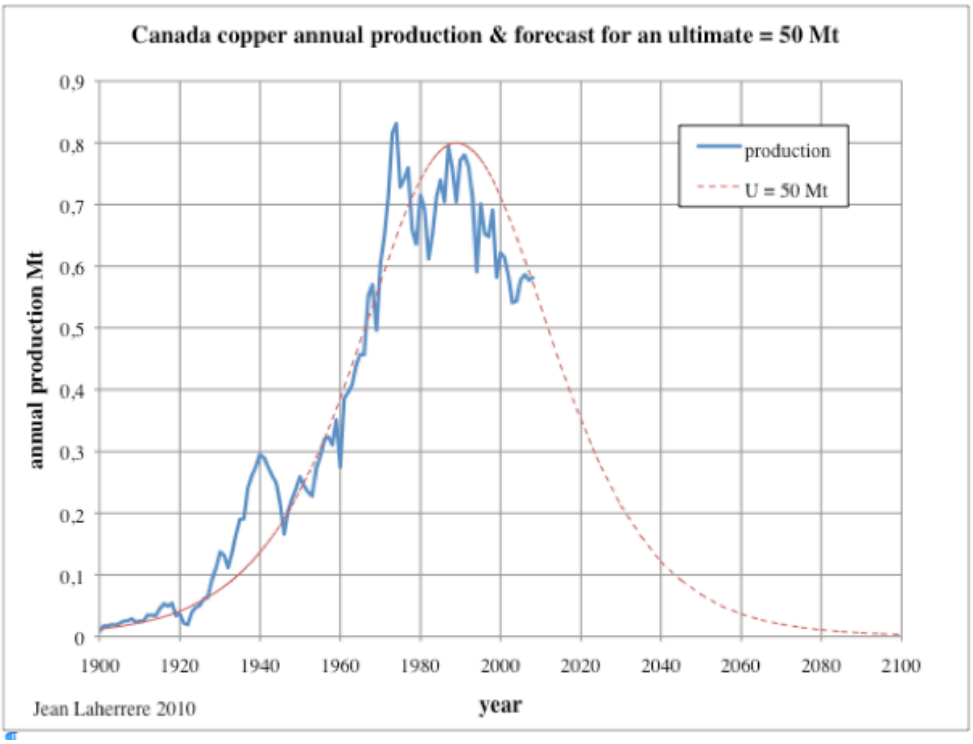
-Canada
Canada is another good place to compare USGS and Natural Resources Canada (NRCan) approaches. NRCan reserves are more complete and slightly lower than USGS reserves.
From NRCan we estimate Canada copper ultimate at 50 Mt.
Figure 29: Canada copper cumulative production, USGS & NRCan reserves with forecast for an ultimate of 50 Mt



The Hubbert linearization seems to be trending towards 50 Mt since 1970.
Figure30: Canada's copper production: Hubbert linearization



Canada's copper production has peaked in 1974 and will be producing at half peak around 2015.
Figure 31: Canada's copper annual production & forecast for an ultimate of 50 Mt

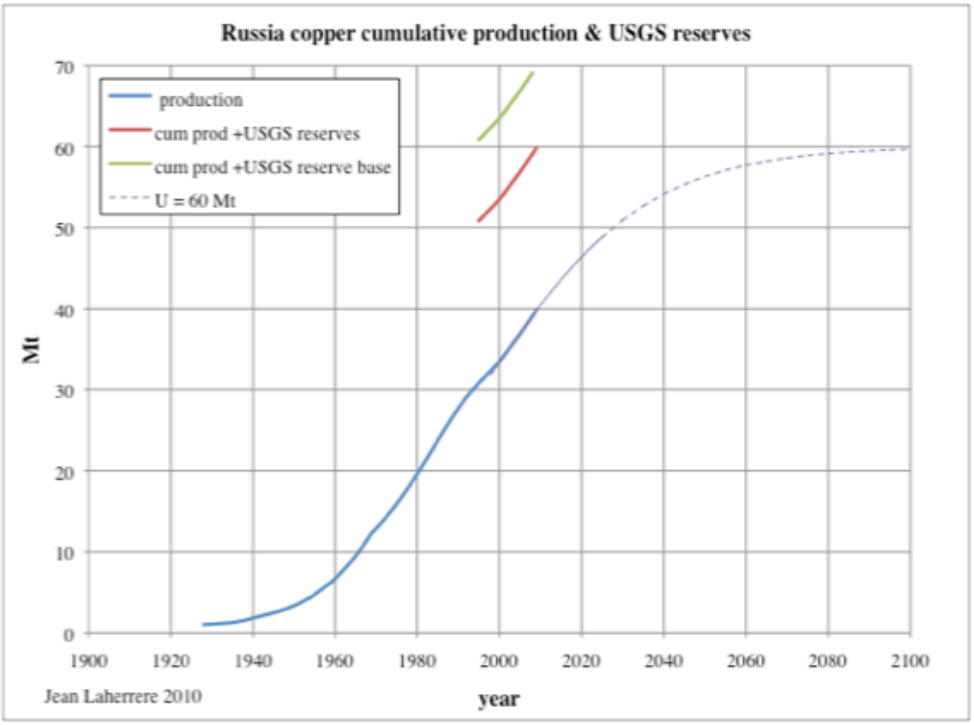


-Russia

Russia is a difficult country to get reliable data, because before the break up of the USSR the data was global and because the cold war data was very imprecise. We have assumed the copper production of Russia during the period of the FSU by taking a certain percentage of FSU data. The USGS reserves have not changed from 1995 to now, despite production, indicating the difficulty of the estimate. The largest field is Udokan in Eastern Siberia, which displays some negative growth (from 20 to 14 Mt), and was sold in 2008 to be developed and is planned to produce 0.5 Mt by 2016.

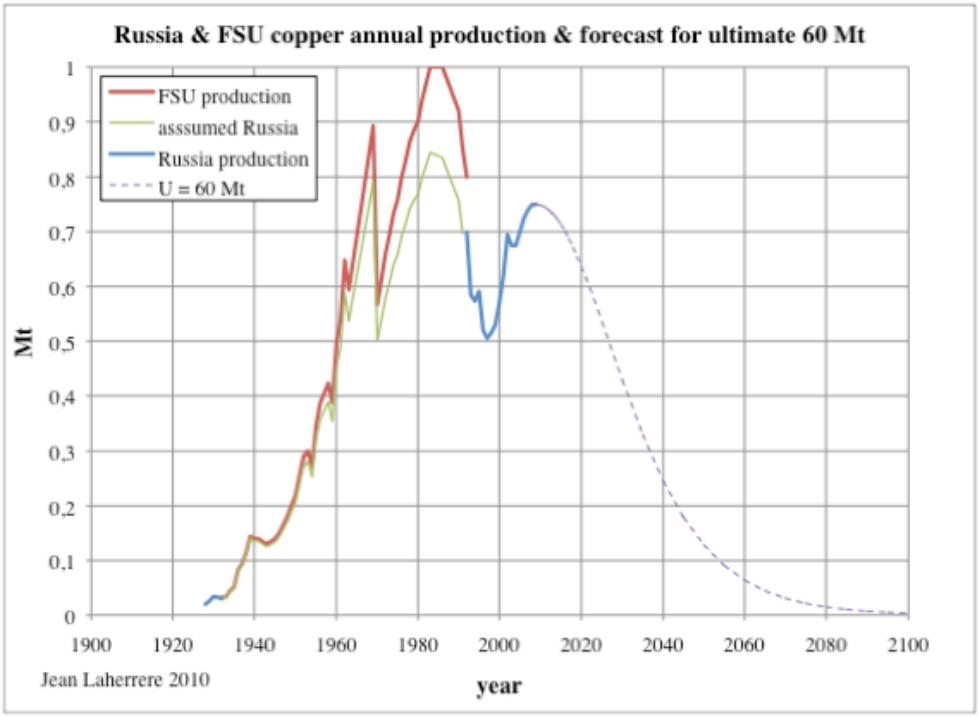
We have assumed Russia's copper ultimate to be 60 Mt.

Figure 32: Russia's copper cumulative production, USGS reserves with forecast for an ultimate of 60 Mt

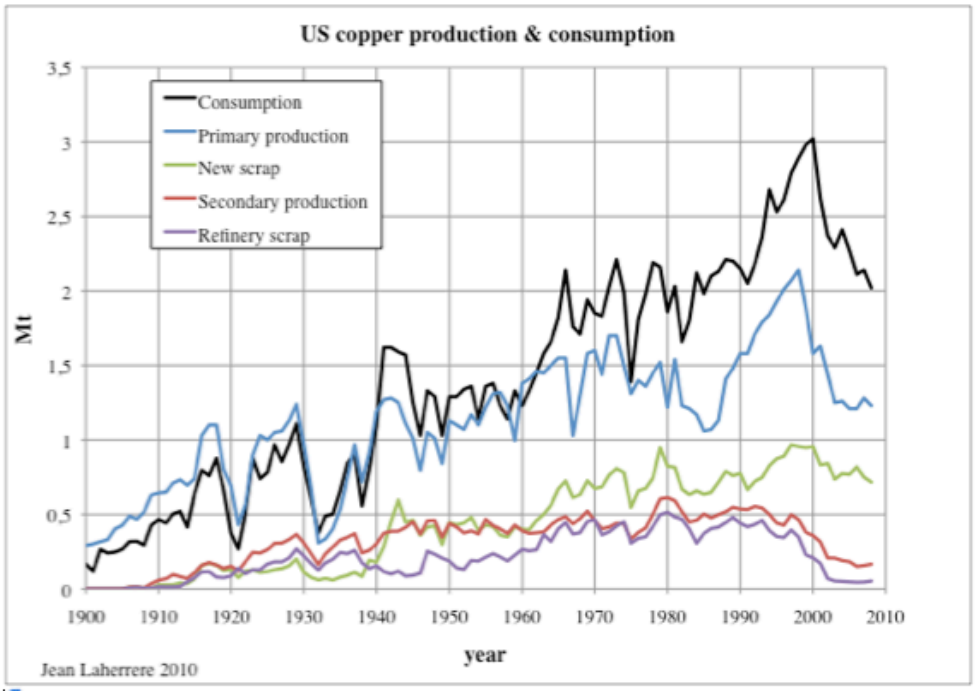


The Hubbert linearization could be extrapolated towards 60 Mt but it is not reliable!
Figure33: Russia's copper production: Hubbert linearization

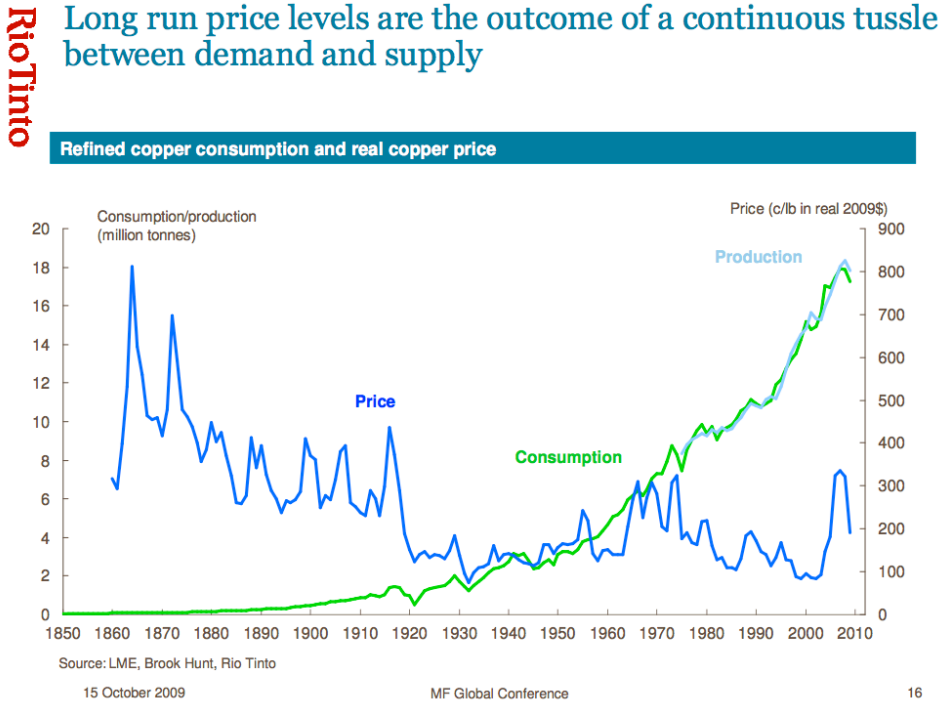
Russia's copper production g has dropped sharply at the FSU break up, and is likely peaking now.
Figure 34: Russia (& FSU)'s copper annual production with forecast for an ultimate of 60 Mt



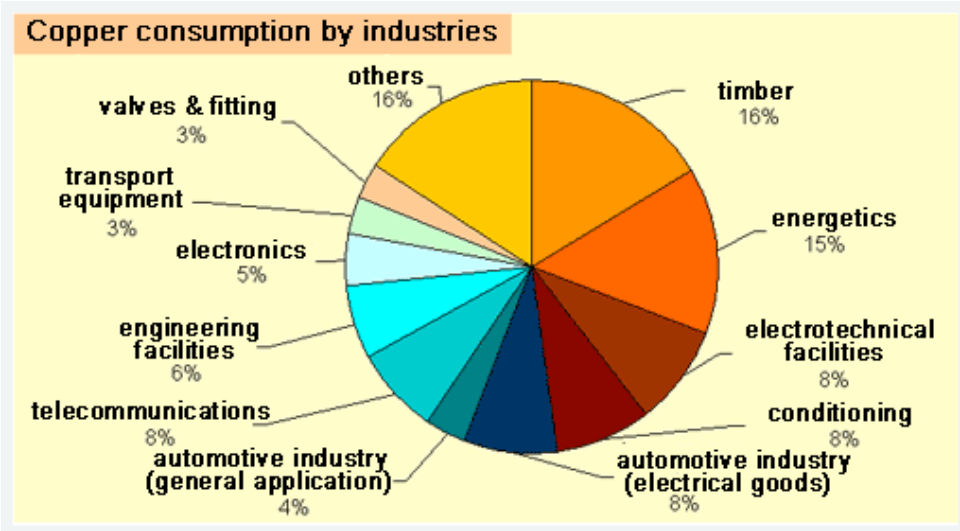
-Copper consumption
The US copper consumption displays a chaotic constant increase from 1900 to 2000, and then a decline. The US consumption peak follows the US production peak
Figure 35: US copper consumption & production 1900-2008



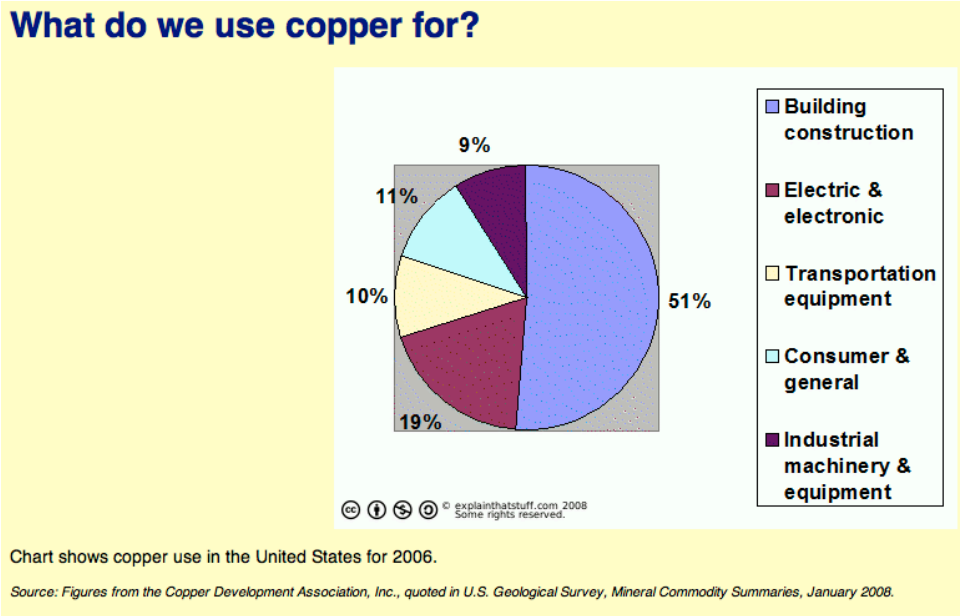
The world copper consumption (N.Brewster Rio Tinto « Outlooks for commodity markets » http://www.riotinto.com/documents/Media-Speeches/MF_Global_Seminar_15_October_2009.PDF displays a harmonious increase since 1850 but a possible peak in 2006, or just a bump!
The real ($2009) copper price displays an opposite trend!
Figure 36: world copper consumption & real price 1850-2008 from Rio Tinto



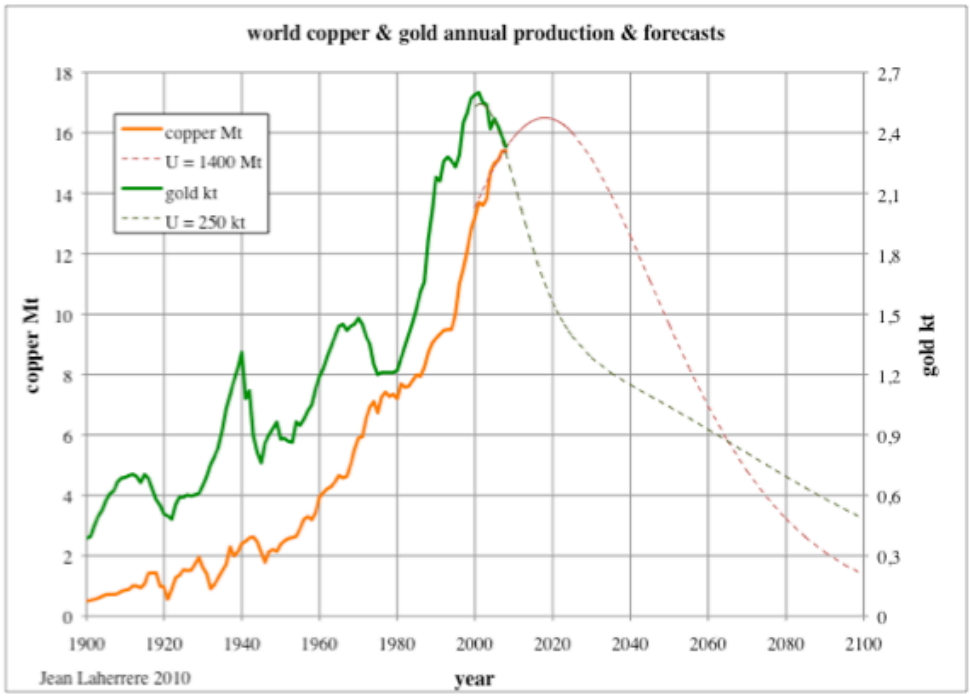
It is hard to find a good graph of the distribution of the world copper use.
This Russian graph (http://www.metal.com.ru/analytics/color.php?id=63 Copper industry: world production – Part I) shows the large range of use by industry
Figure 37: world copper consumption by industry



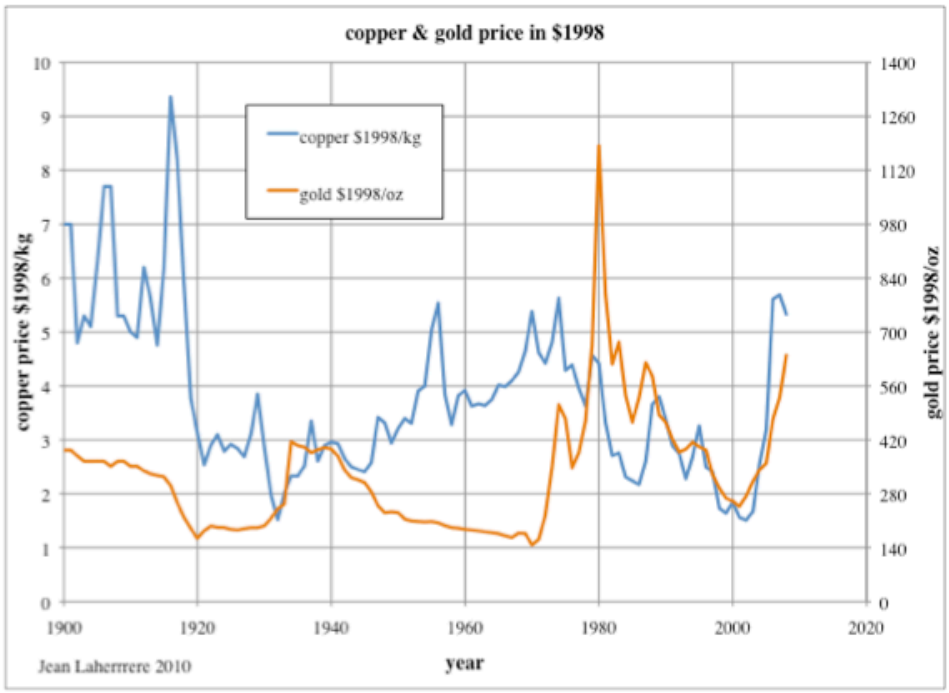
Another good graph on US copper use (http://www.explainthatstuff.com/copper.html)
Figure 38: US copper use for 2006



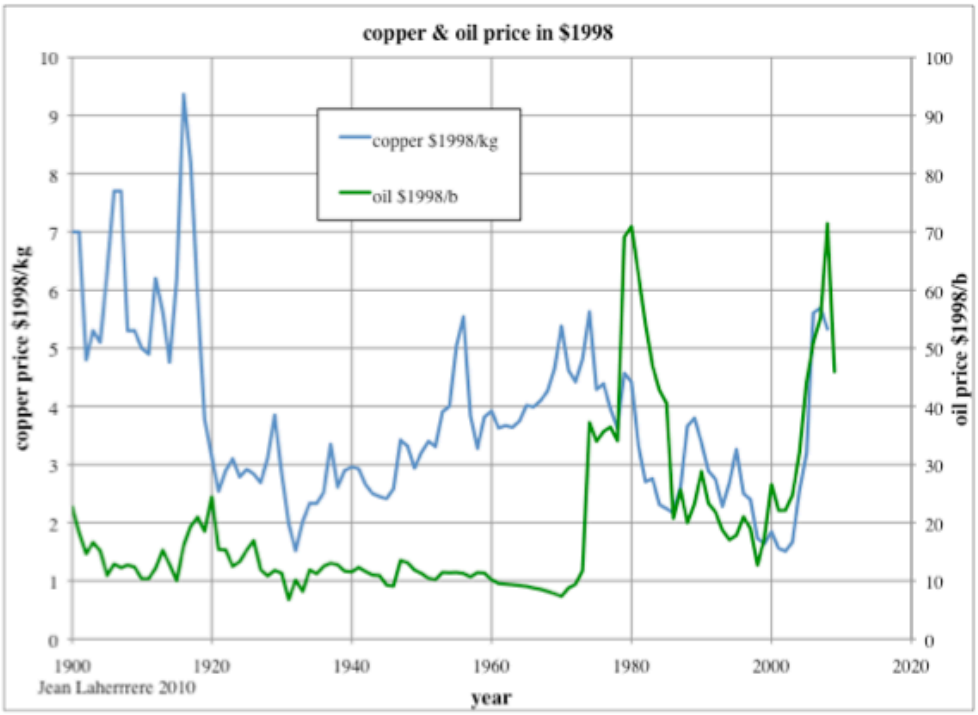
-Copper & gold & oil
Gold production has peaked in 2000 and copper will likely peak in 2020.
Their growth was roughly parallel (20 years gap).
Figure 39: world copper & gold annual production



Copper price in $1998 has been chaotic with a sharp increase in 2006 (but being lower than in 1900!), but gold price was also chaotic.
Figure 40: world copper & gold price in $1998



Since 1980 copper price has been following oil price
Figure 41: world copper & oil price in $1998



-Conclusions
Copper has been an important mineral in the world growth, in use for at least 10 000 years.
Bronze Age is well known as having replaced the Stone Age, and bronze is the alloy of copper and tin.
Copper has the second highest electrical conductivity after silver. Its price went so high that copper cables are now often stolen, disturbing telephone and Internet communications.
Copper is used in piping (water supply, refrigeration and air conditioning).
Measured by weight, it is the third important metal used by man after iron and aluminium (Radetzki 2009).
Its use is challenged by new substitutes, but copper production will peak because its limited resource being around 1400 Mt.
Unlike oil, copper can be recycled, but developing countries' need is huge.
Chile and China dominate the copper world.
But Chile production has peaked in 2007 and China will likely peak around 2020.
The future of copper is uncertain!
Copper peak seems a real concern for many and there are several «*Peak Copper*« sites:
The use of *peak xxx* has become a fashion following the introduction of the term *Peak oil* by Colin Campbell in 2001. Peak fat is described by Ugo Bardi.
From Goggle (February 2010) *peak oil* finds 2 080 000 quotes but *oil peak* only 91400 quotes,
Peak copper finds 53 100 quotes, but copper peak only 24 100 quotes.
Copper peak is not something new!
The only question is when.