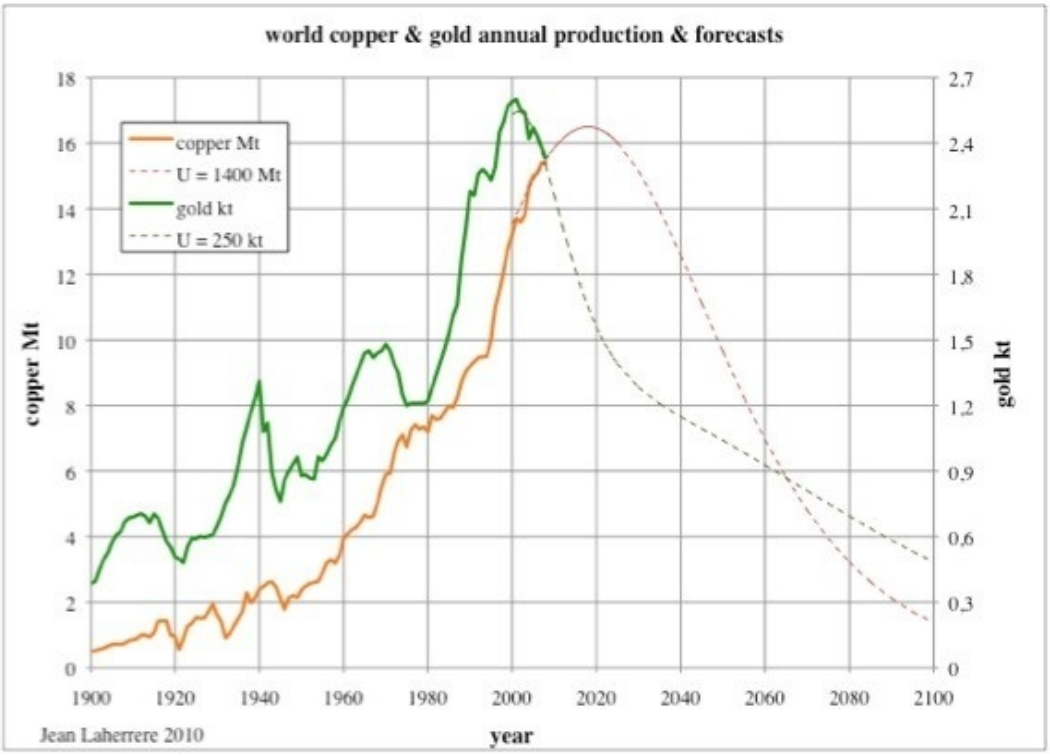
The Oil Drum: Europe
DISCUSSIONS ABOUT ENERGY AND OUR FUTURE

Copper Peak

Posted by Luis de Sousa on March 31, 2010 - 2:21pm in The Oil Drum: Europe
Topic: Geology/Exploration
Tags: copper, jean laherrère, mineral depletion, original, peak minerals [list all tags]

This is a guest post by Jean Laherrère.



As is his nature, Jean speaks more with graphs than words. This posts contains over 40 images amounting to 2 Mbytes of data; keep this in mind when proceeding.

Copper has been an important mineral in the world growth, in use for at least 10 000 years. The Bronze Age is well known for 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 most important metal used by man after iron and aluminium (Radetzki 2009). Its use is challenged by new substitutes, but copper production will peak because it is a limited resource amounting to around 1400 Mt. Unlike oil, copper can be recycled, but developing countries' needs are huge.

What follows is an evaluation of world copper production, then an analysis country by country--there are many charts and graphs so that we may try to understand where we are with regard to future copper production.

I found it fairly easy to model gold production both for the world and the main producers in my 2009 post The gold peak, easier to model than the oil peak (part II). In this post, I have tried to do the same for copper production.

The best source of data is the USGS which provides complete time-series since 1900 for the 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 in old reports. The USGS should compile the country by country copper production data 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.

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. The world copper cumulative production can be easily modelled with a logistic curve for ultimates of 1200 Mt and 1600 Mt fitting the USGS estimates.

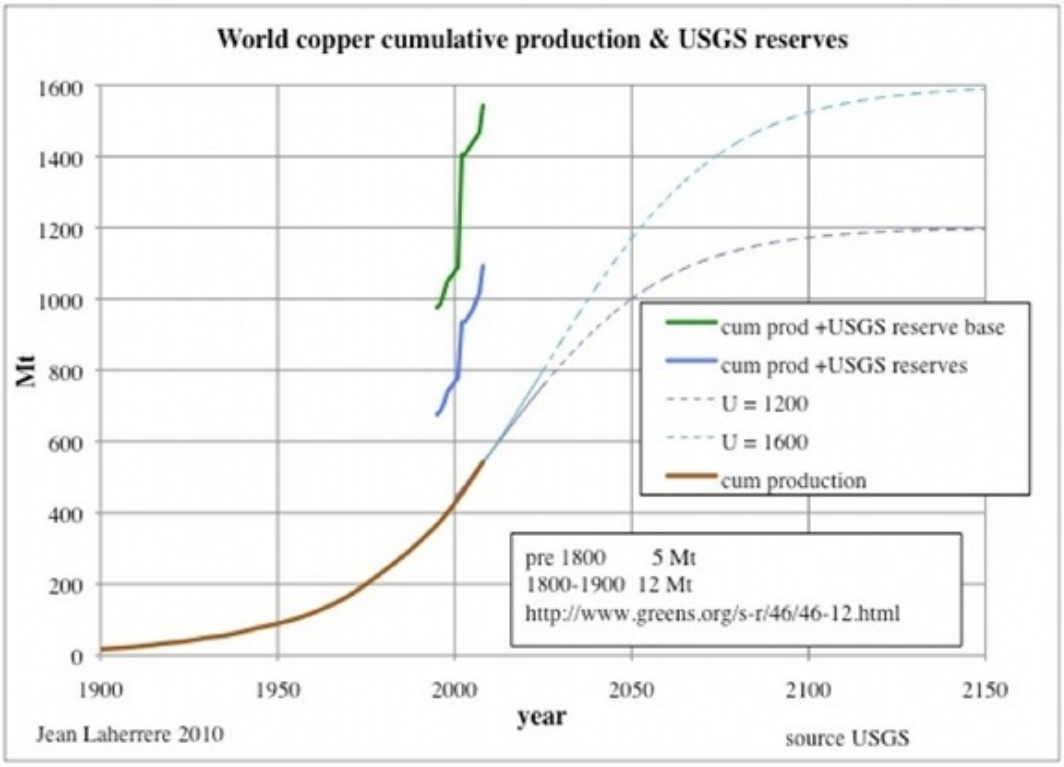


Figure 1: world copper cumulative production, USGS reserves and forecast for ultimates of 1200 Mt and 1600 Mt.

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

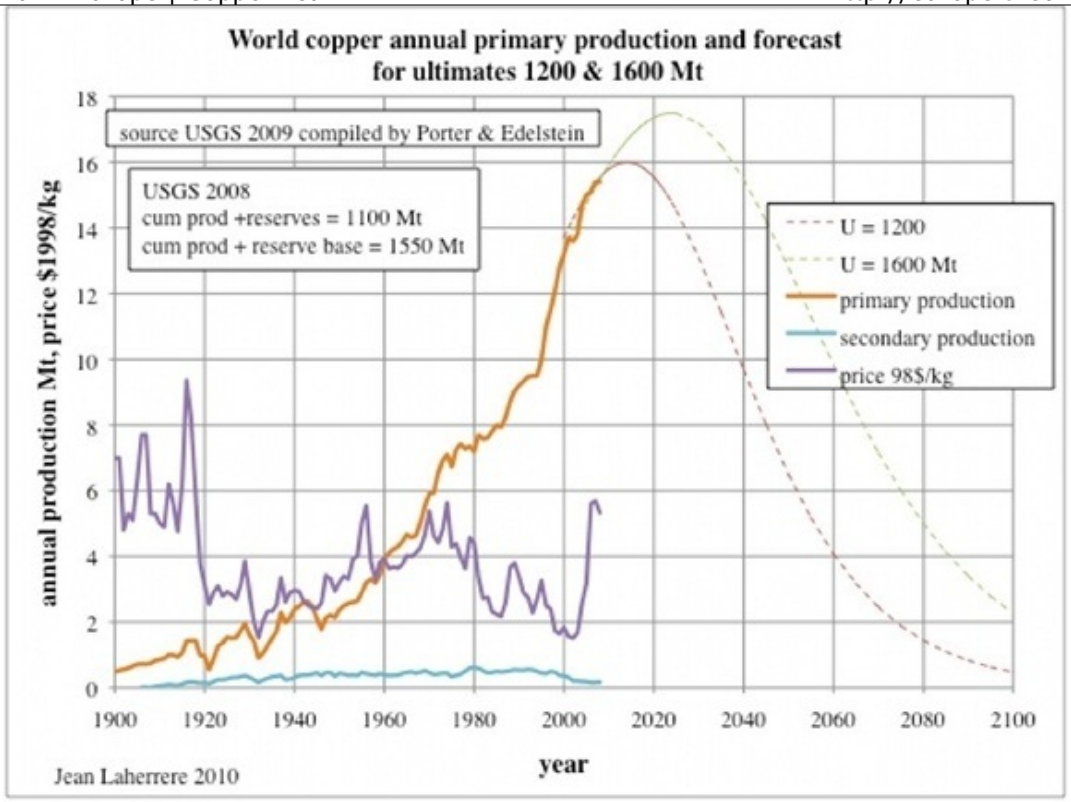


Figure 2: world copper annual production and forecasts for ultimates of 1200 Mt and 1600 Mt and price.

The eight 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 eight producers have an ultimate of 820 Mt that is about 60% of the world's ultimate.

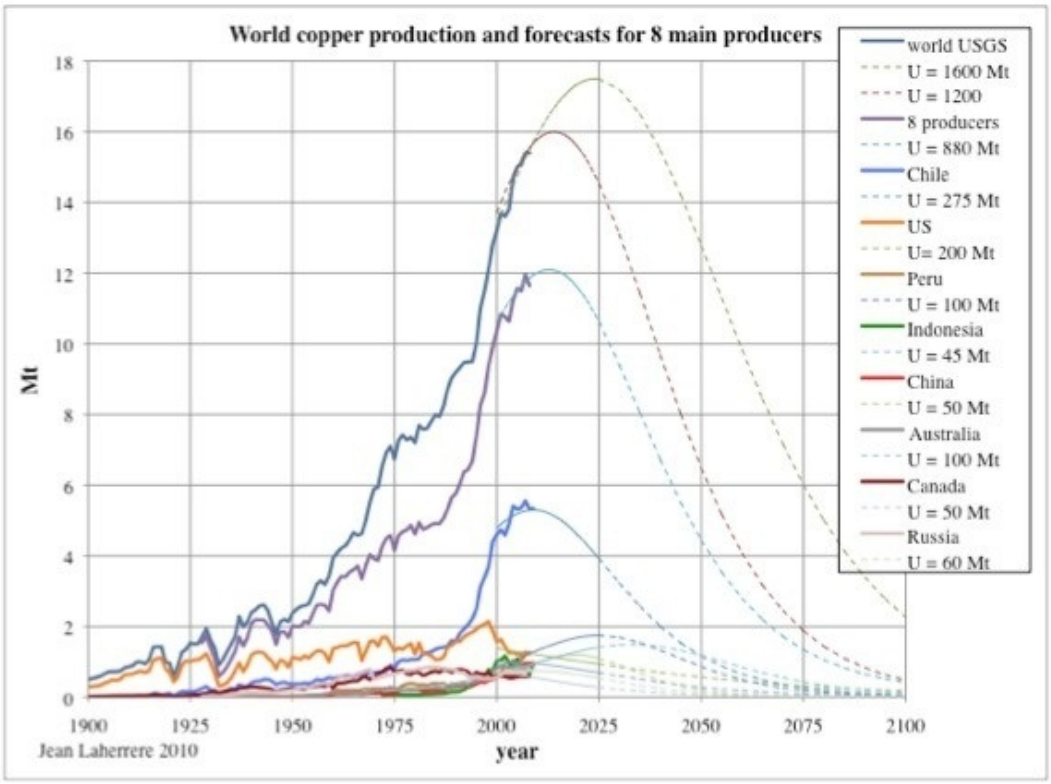


Figure 3: world copper annual production and forecasts for the eight main producers 1900-2100.

Gavin Mudd in Historical trends in base metal mining: back casting to understand the sustainability of mining[pdf!], a publication from 2009, shows annual copper production starting in 1840.

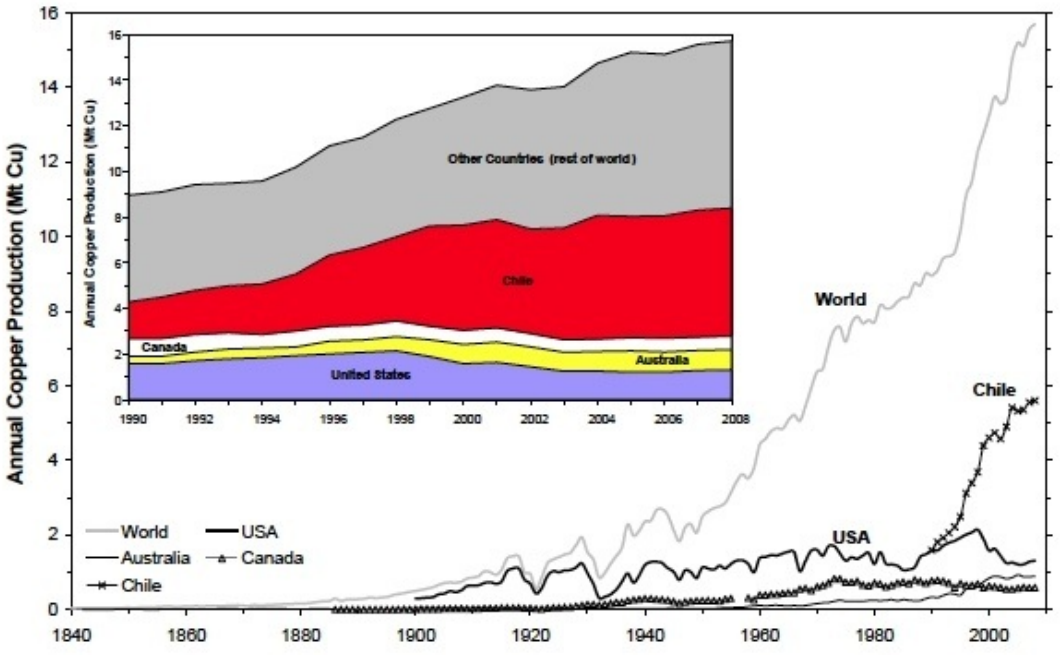


Figure 1 – Mined copper production over time by country (data sourced from [2-10])

Figure 4: world copper annual production from G.Mudd 1840-2008.

The details for the eight main copper producers are presented below.

World

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

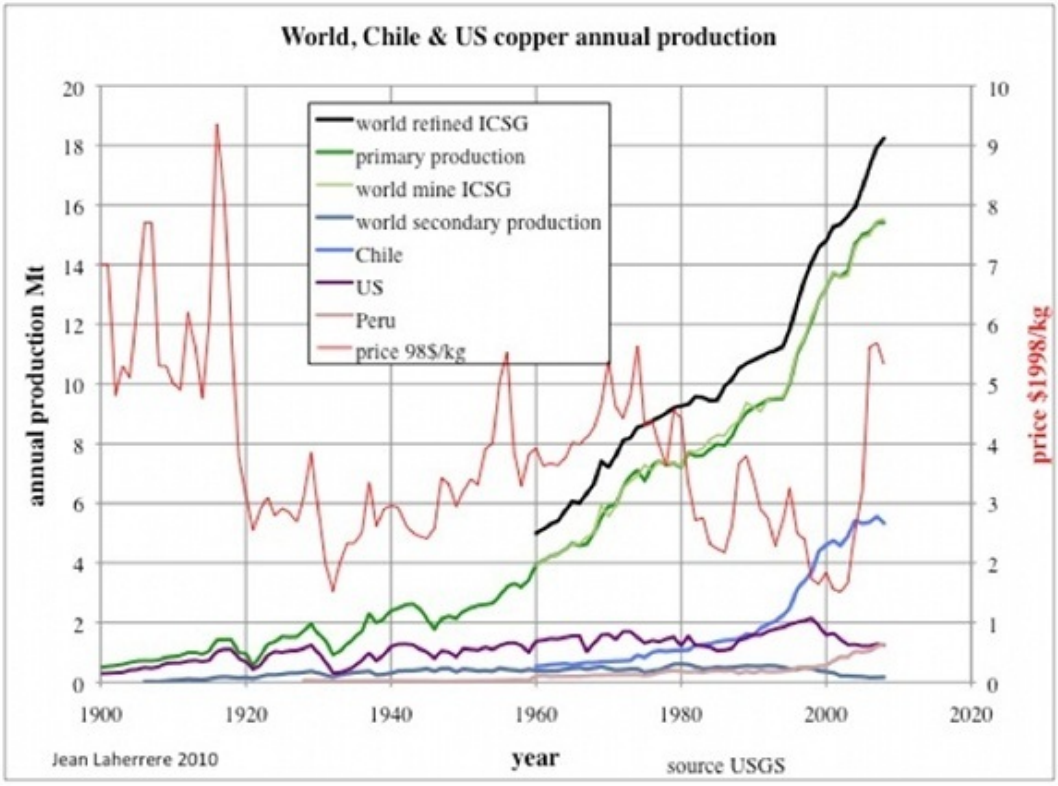


Figure 5: world, Chile, Peru and US annual copper production and copper price.

The Hubbert linearisation of production data - being the growth of production (or annual/cumulative in %) versus cumulative production - is extrapolated with a linear trend with the aim of estimating 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 onwards, which can be extrapolated towards 1600 Mt (present cumulative production plus USGS reserve base) but the previous declining trend (1975-1995) was pointing towards 1000 Mt.

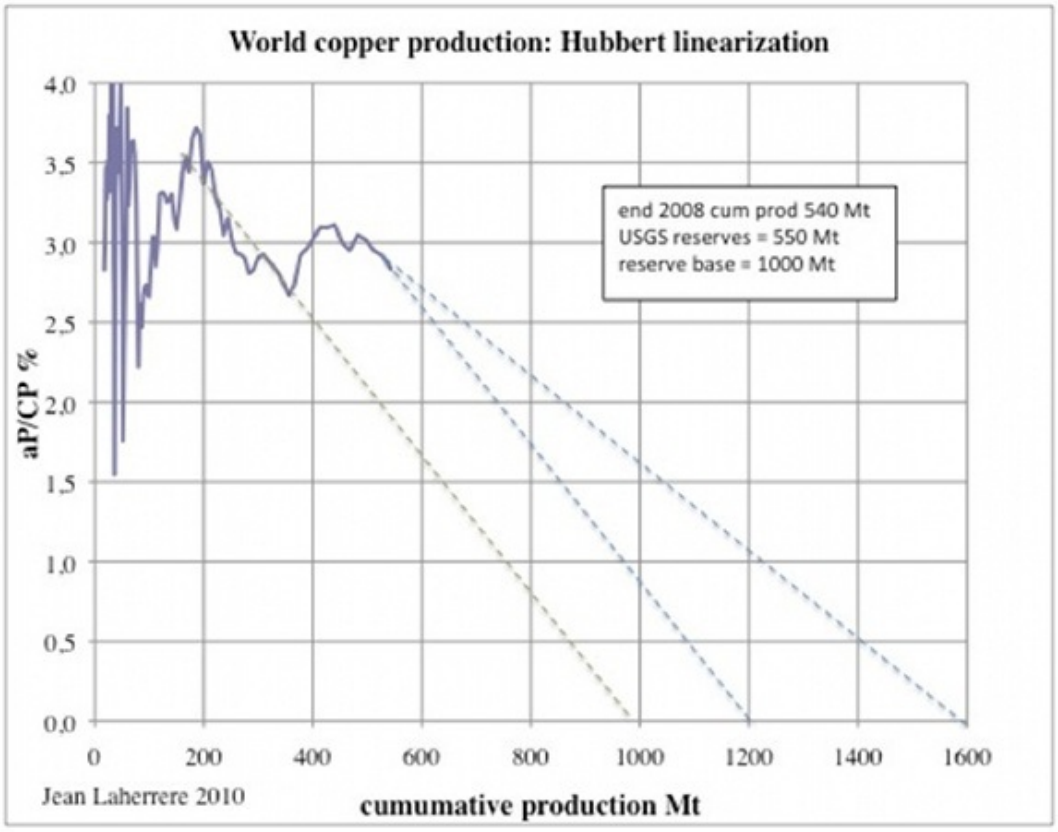


Figure 6: world copper production: Hubbert linearisation.

The best approach is to rely on the geological inventory of the world potential estimated by the USGS, 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 of probable reserves (now changed in 2010) the SEC rules for minerals (industry guide 7) allow to report proved and probable. The USGS only changes its data on copper reserves from time to time, when it shows the remaining discovered reserves, but it should be decreased when production isn't matched by new discovery. Only US and Canada reserves have decreased!

The reserves reported by the USGS since 1995 show a poor evolution when plotted in a log scale:

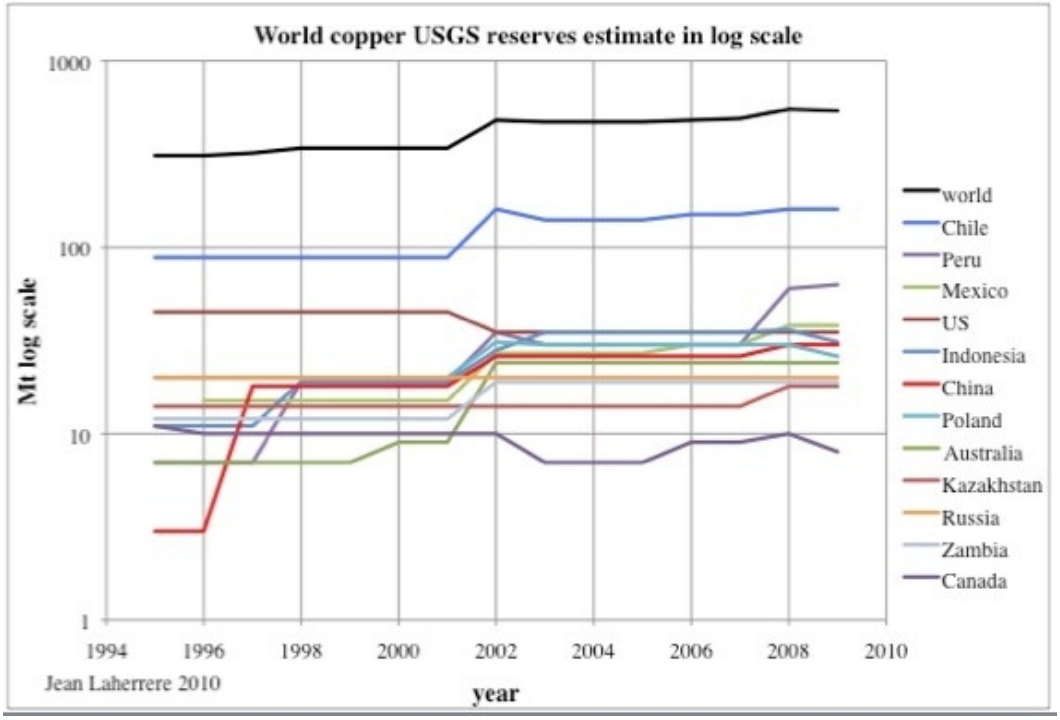


Figure 7: world and main producers copper reserves estimates by the USGS in log scale.

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 [pdf!] use a more precise definition of resources and report Economic Demonstrated Resources (EDR) for Australia and the world at the end 2008 being 78 Mt and 603 Mt respectively. In its turn 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 there should be an upper limit.

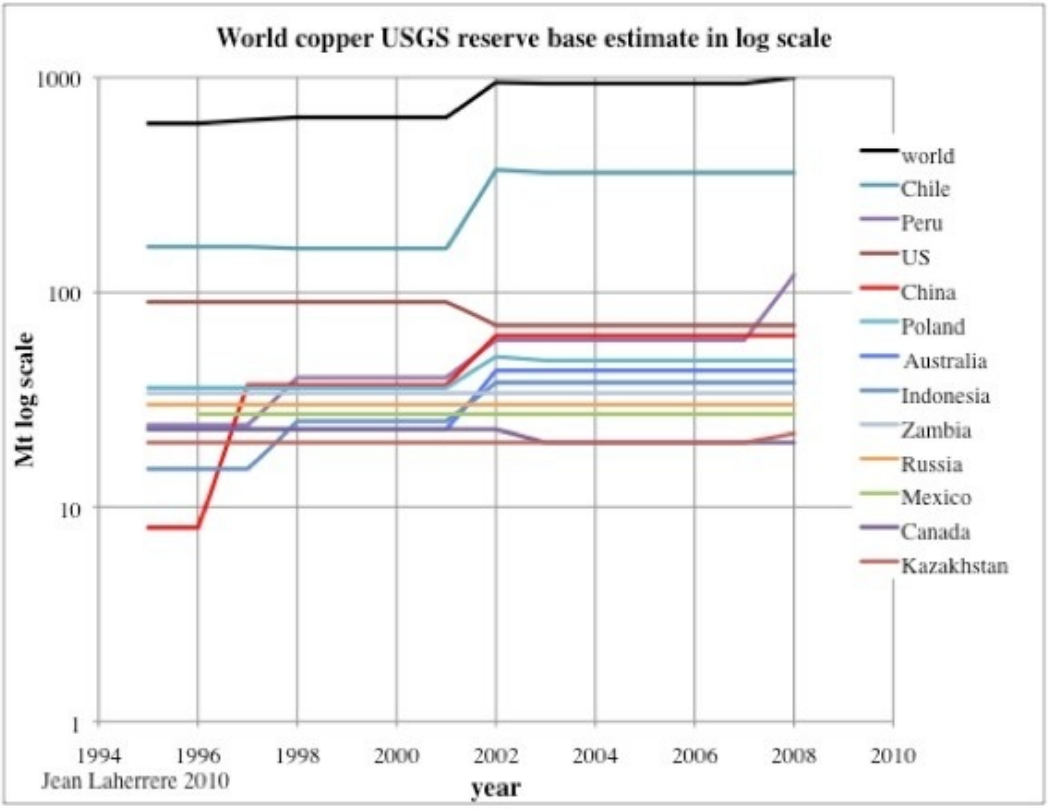


Figure 8: world and main producers copper reserves estimates by the USGS in log scale.

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. It is difficult to estimate the the point at which production ceases to be economic.

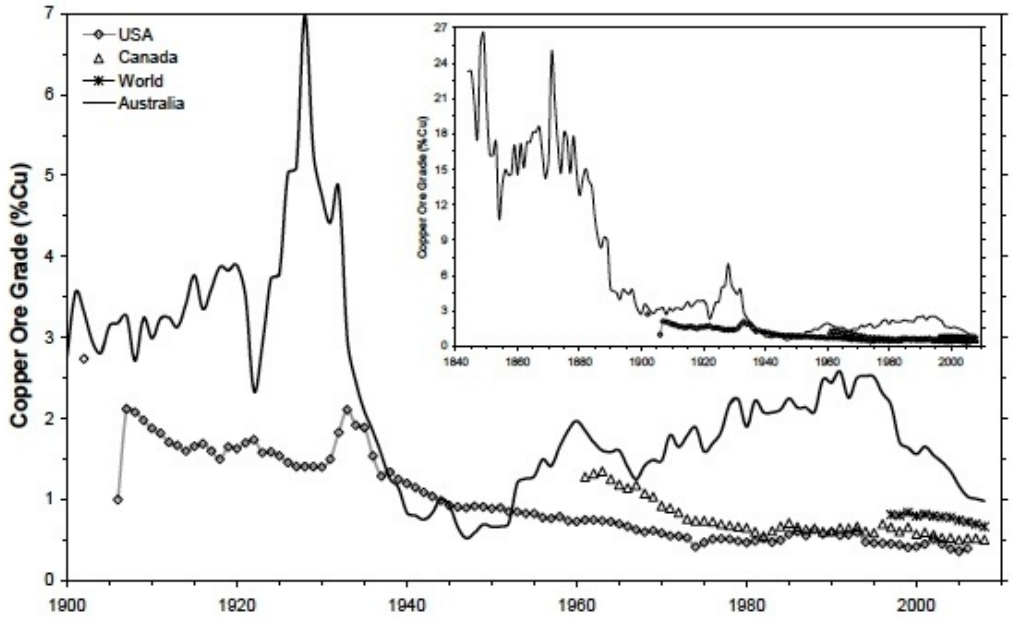


Figure 9: world, USA, Canada and Australia ore grade 1900-2008.

United States

The cumulative US copper discovery (starting in 1545) from USGS 98-206A is 350 Mt at the end of 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.

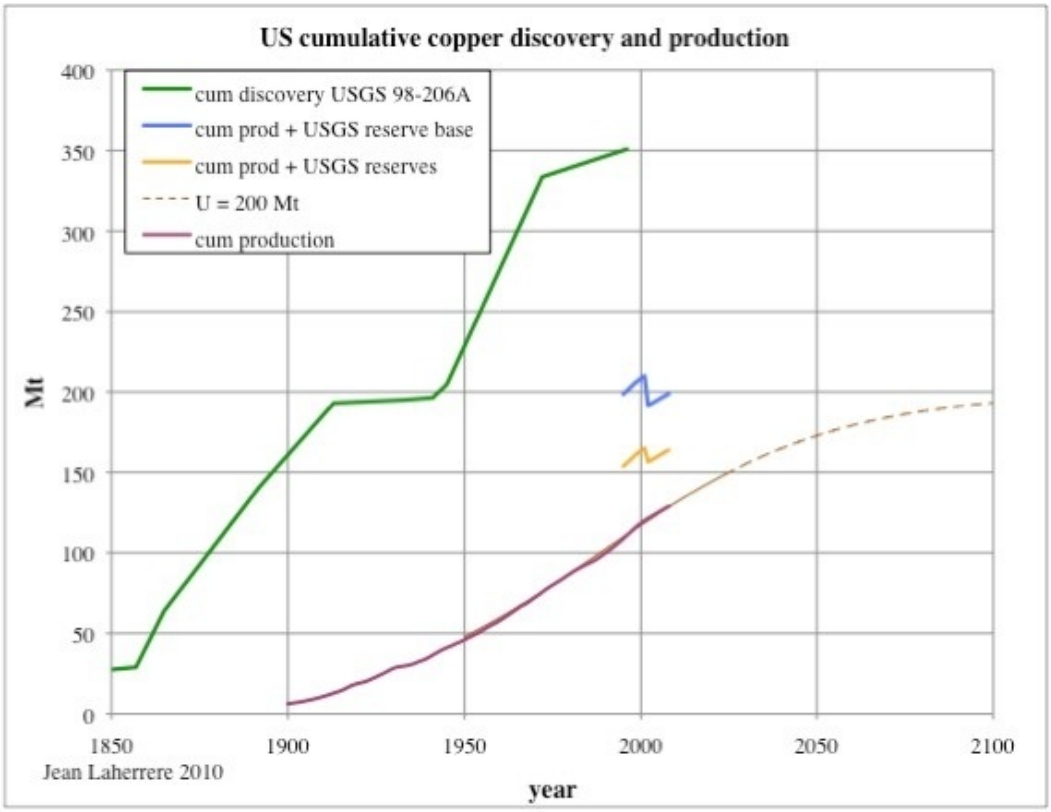


Figure 10: US copper cumulative discovery and production, USGS reserves and forecast for an ultimate of 200 Mt.

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

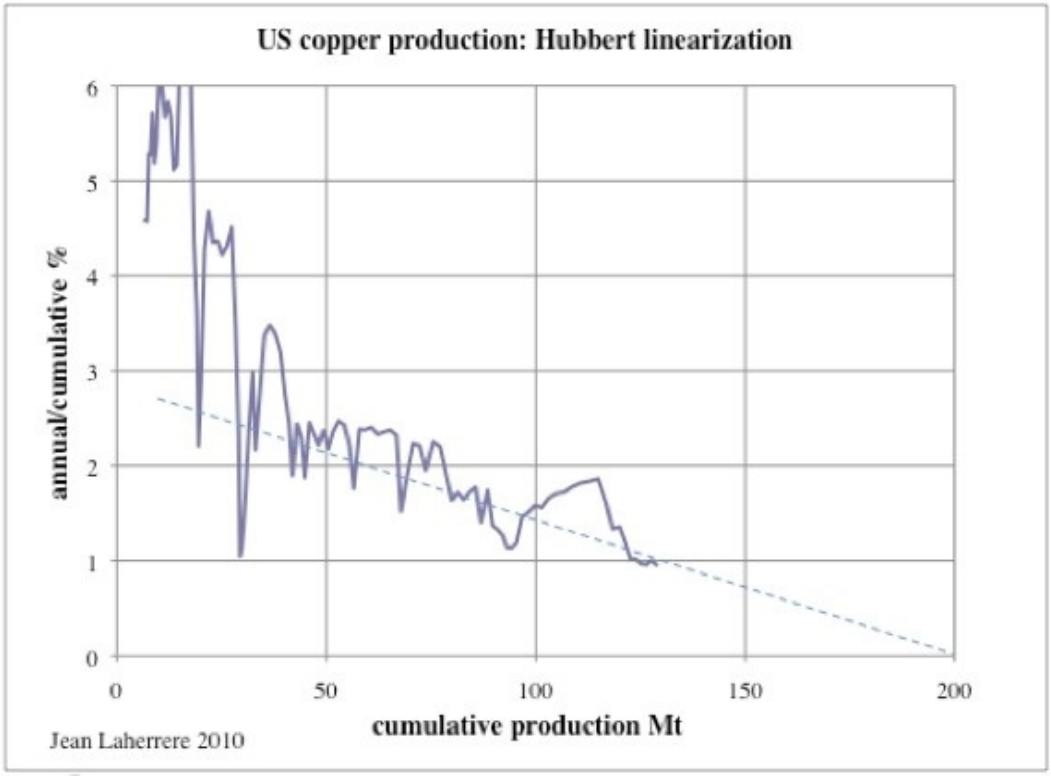


Figure 11: US copper production: Hubbert linearisation.

The US annual production of copper 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!

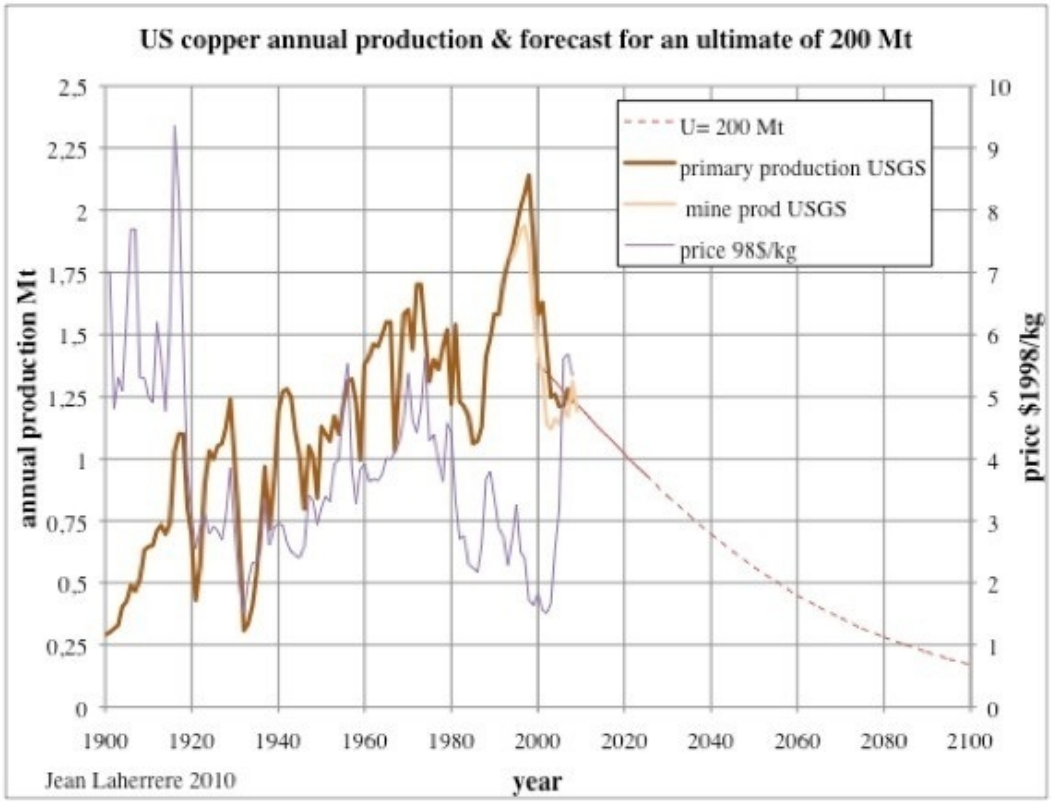


Figure 12: US copper annual production for an ultimate of 200 Mt.

Chile

The USGS has almost doubled Chile's copper reserves from 1995 to 2009.

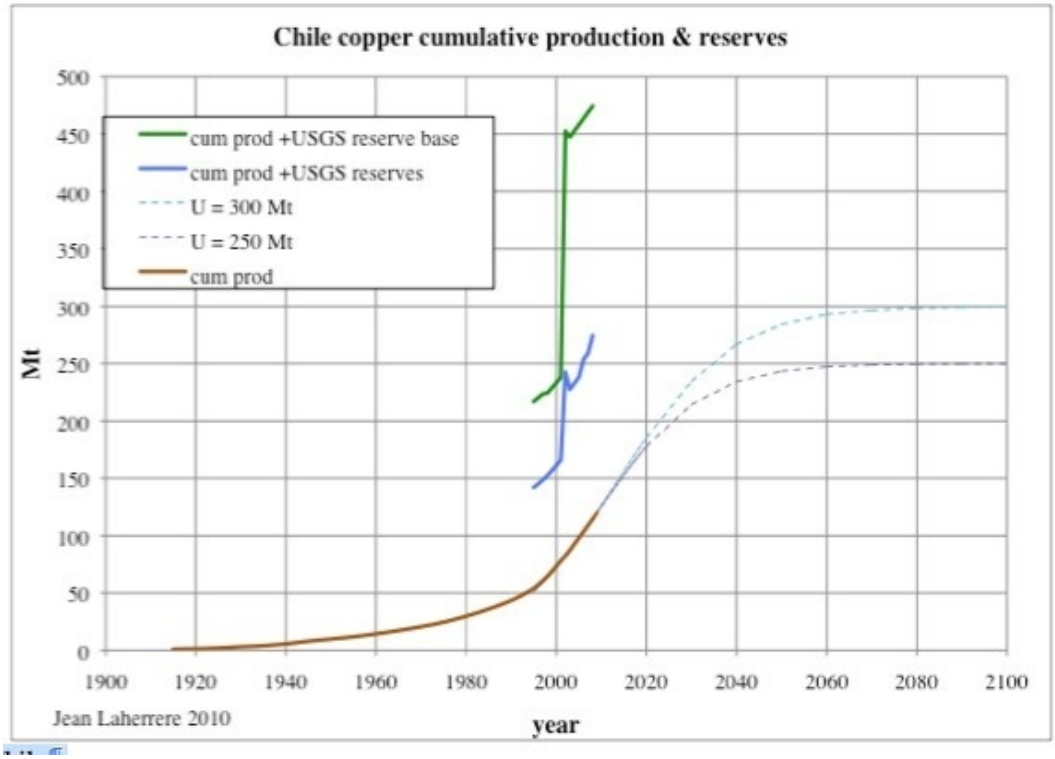


Figure 13: Chile copper cumulative production and USGS reserves andforecast for ultimates of 250 Mt &and 300 Mt.

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

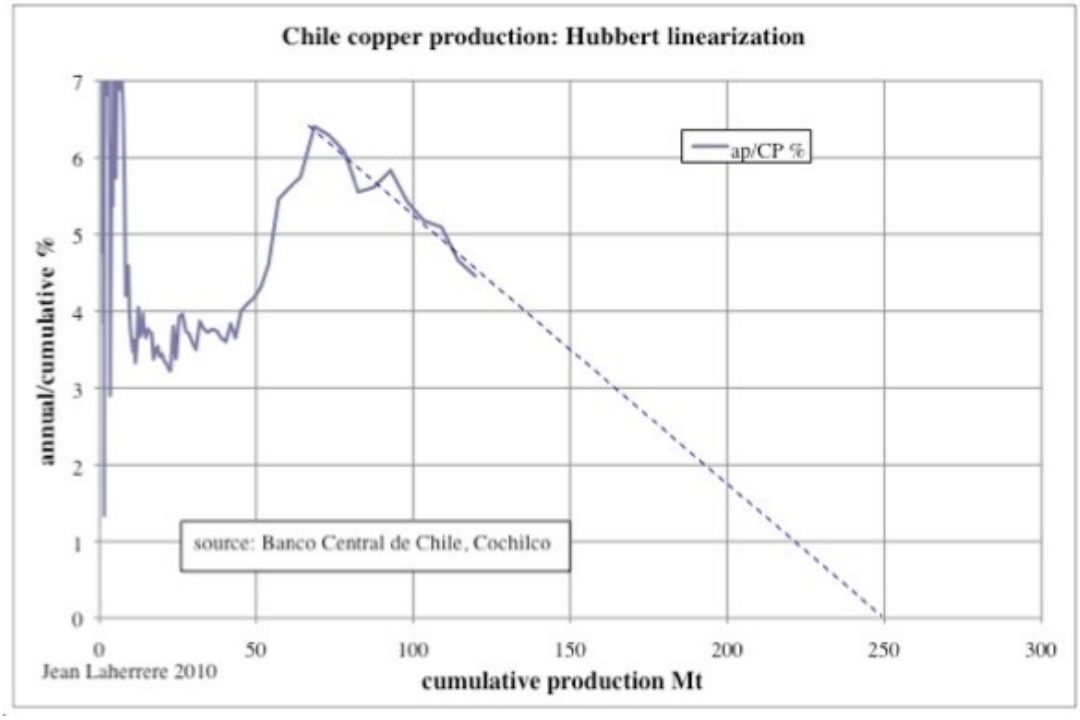


Figure 14: Chile copper production: Hubbert linearisation.

Chile copper production has peaked in 2007.

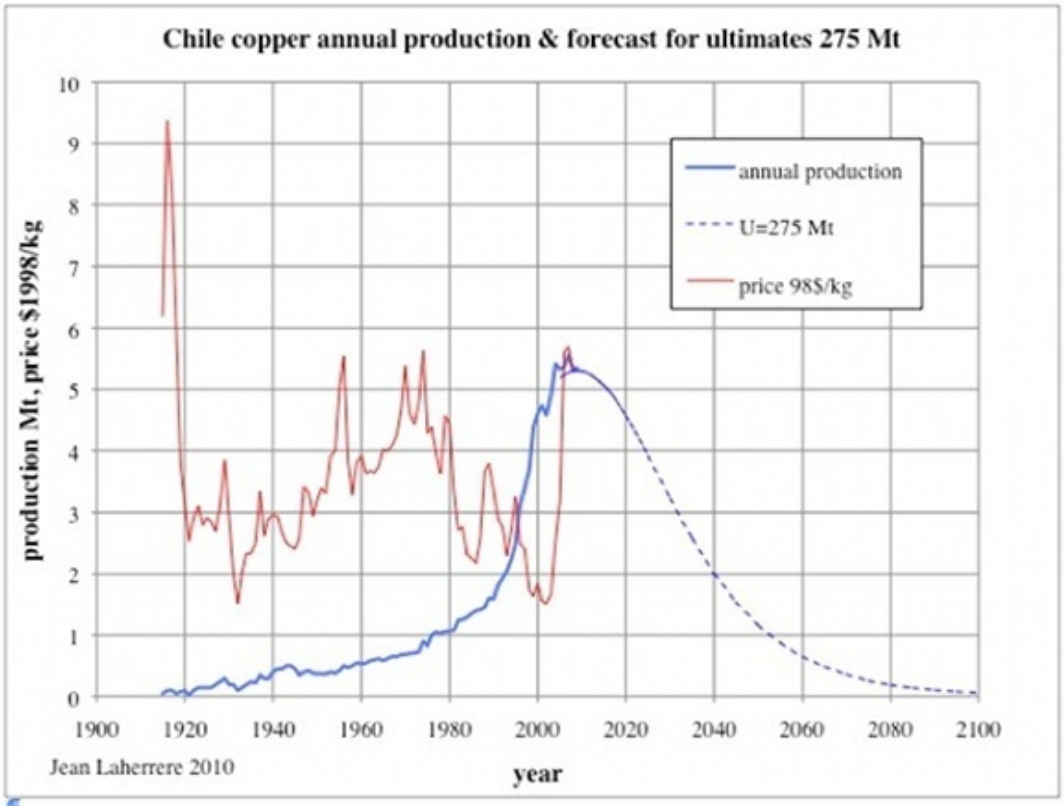


Figure 15: Chile copper annual production and forecast for an ultimate of 275 Mt.

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.

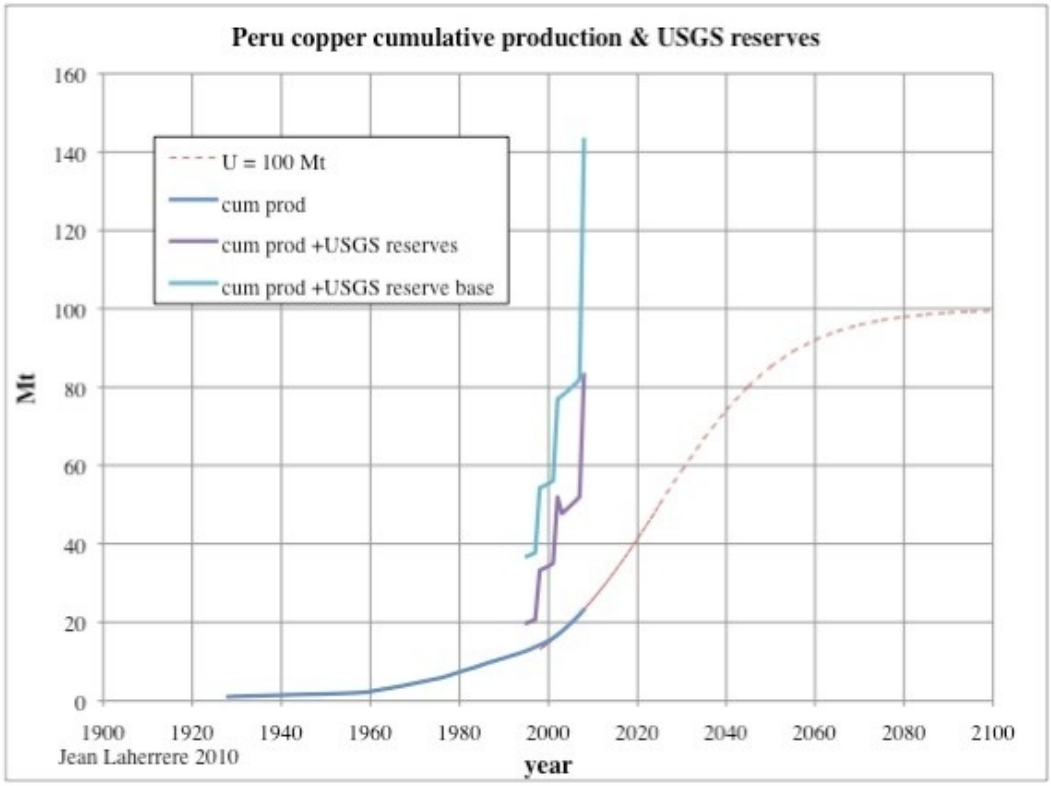


Figure 16: Peru copper cumulative production and USGS reserves & forecast for an ultimate of 100 Mt.

The Hubbert linearisation is hopeless, being far from peak.

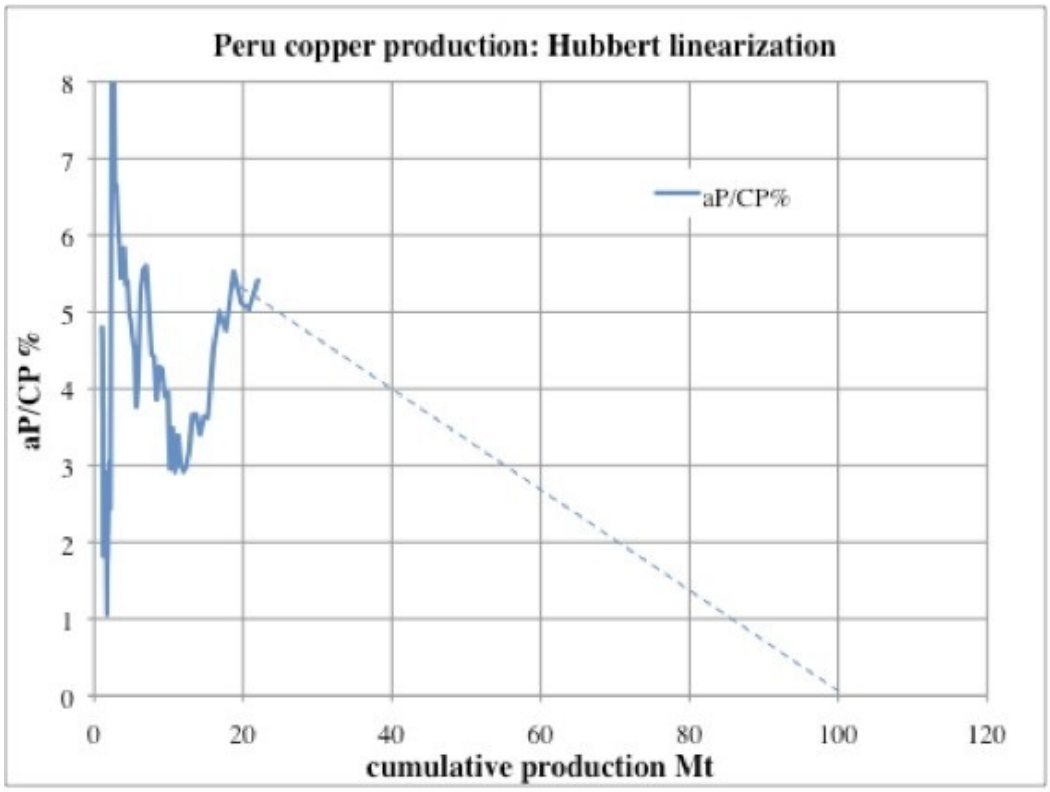


Figure 17: Peru copper production: Hubbert linearisation.

For an ultimate of 100 Mt, Peru's copper production will peak around 2025 at 1.7 Mt.

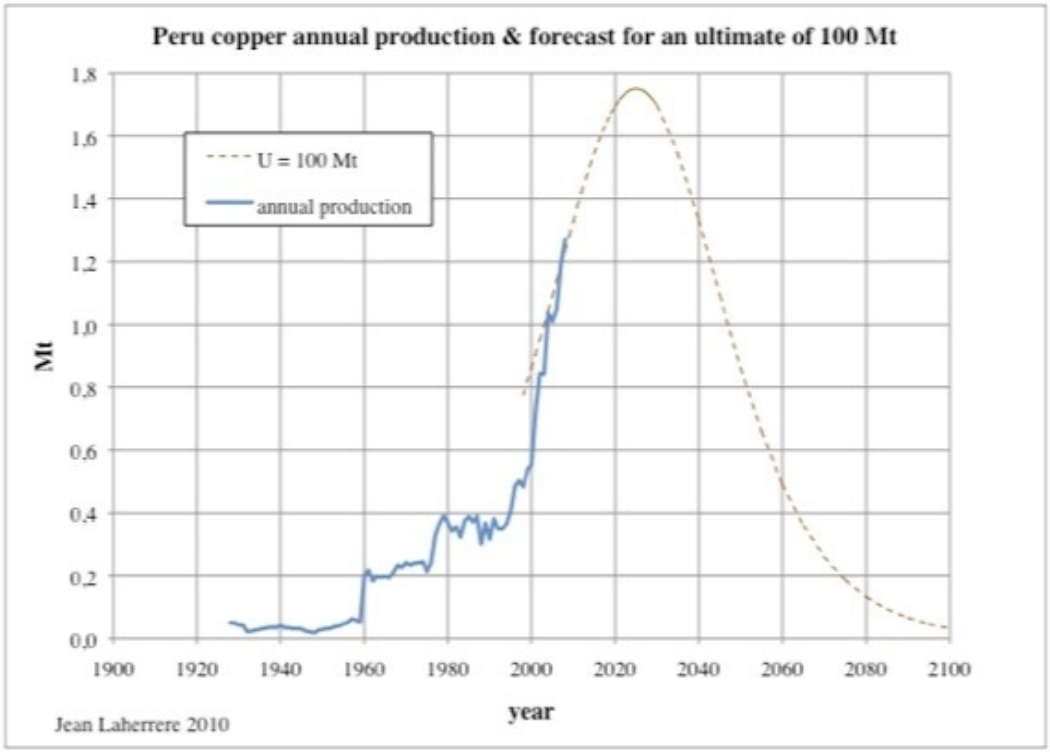


Figure 18: Peru copper annual production and forecast for an ultimate of 100 Mt.

China

Data for China is hard to check and the USGS has increased its reserves lately. We have taken an ultimate of 50 Mt.

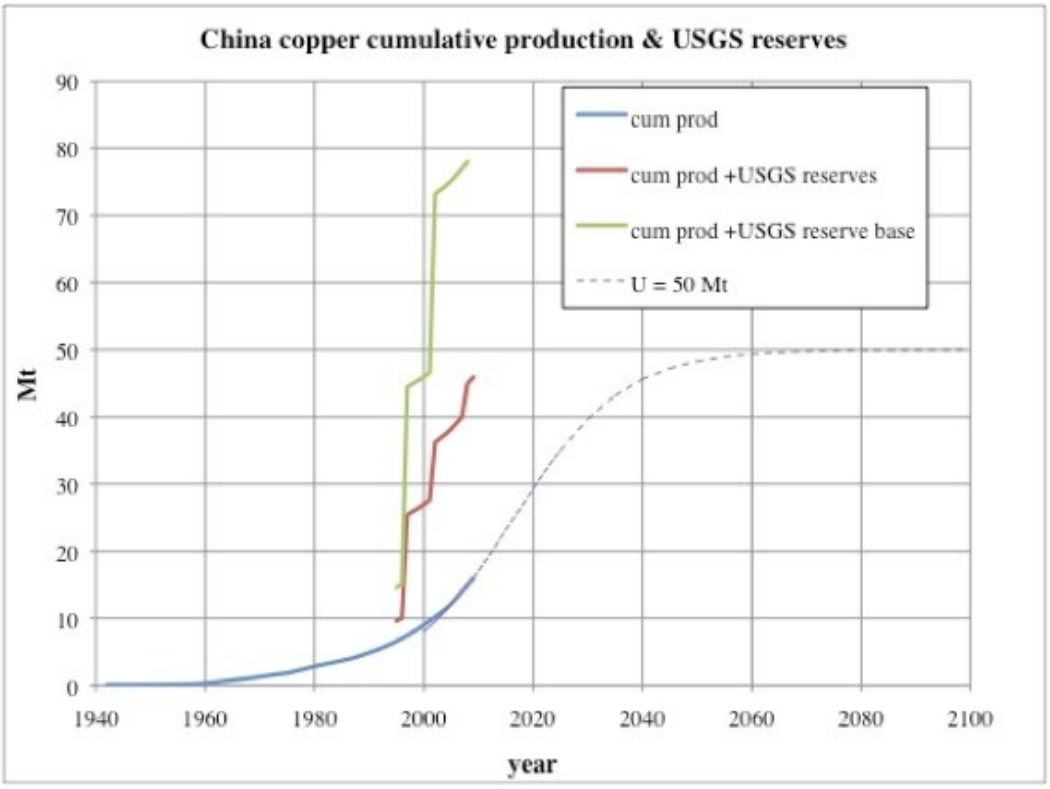


Figure 19: China copper cumulative production and USGS reserves and forecast for an ultimate of 50 Mt.

The Hubbert linearisation plot trends towards infinite!

The annual production should peak around 2020 at 1.2 Mt.

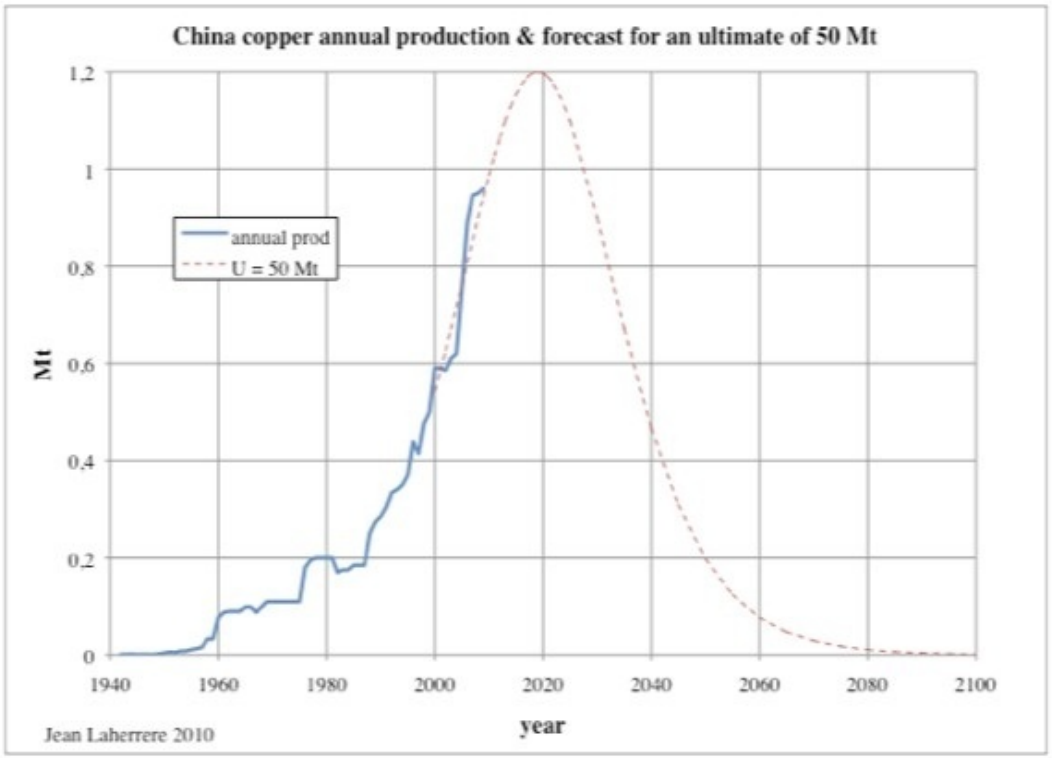


Figure 20: China copper annual production and forecast for an ultimate of 50 Mt.

Indonesia

The USGS has sharply increased Indonesia's reserves around 2000, but reduced them last year. We have taken an ultimate of 45 Mt.

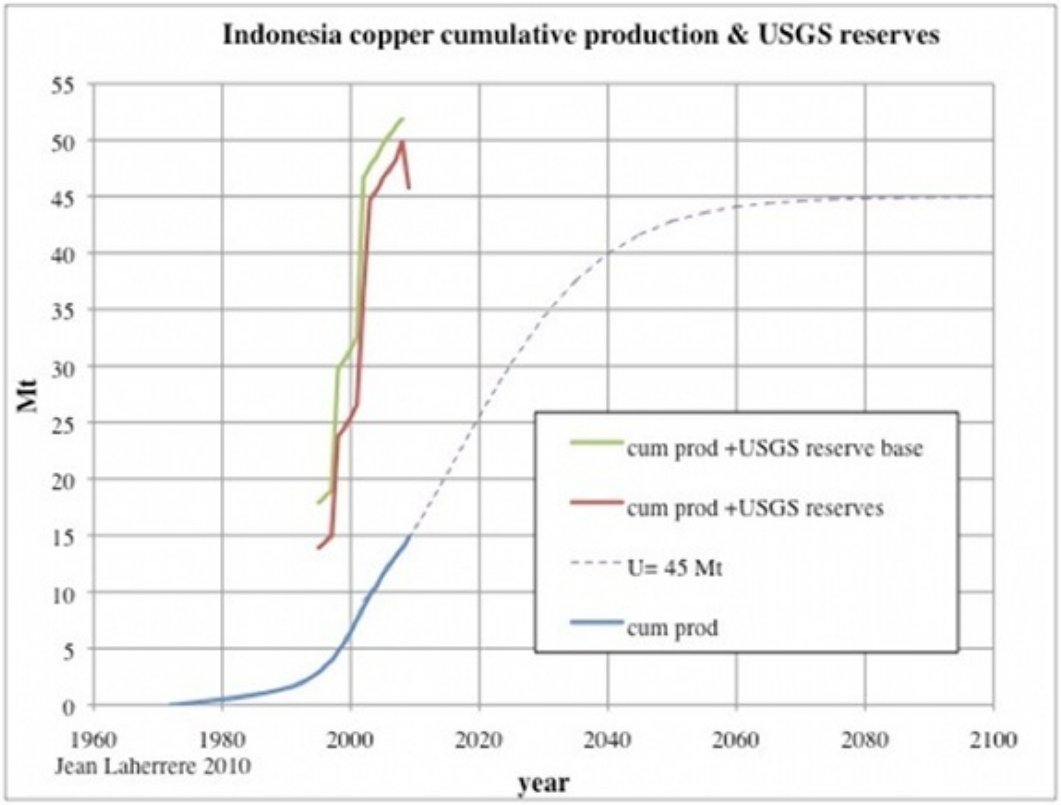


Figure 21: Indonesia copper cumulative production, USGS reserves and forecast for an ultimate of 45 Mt.

Hubbert linearisation plot is impossible to extrapolate.

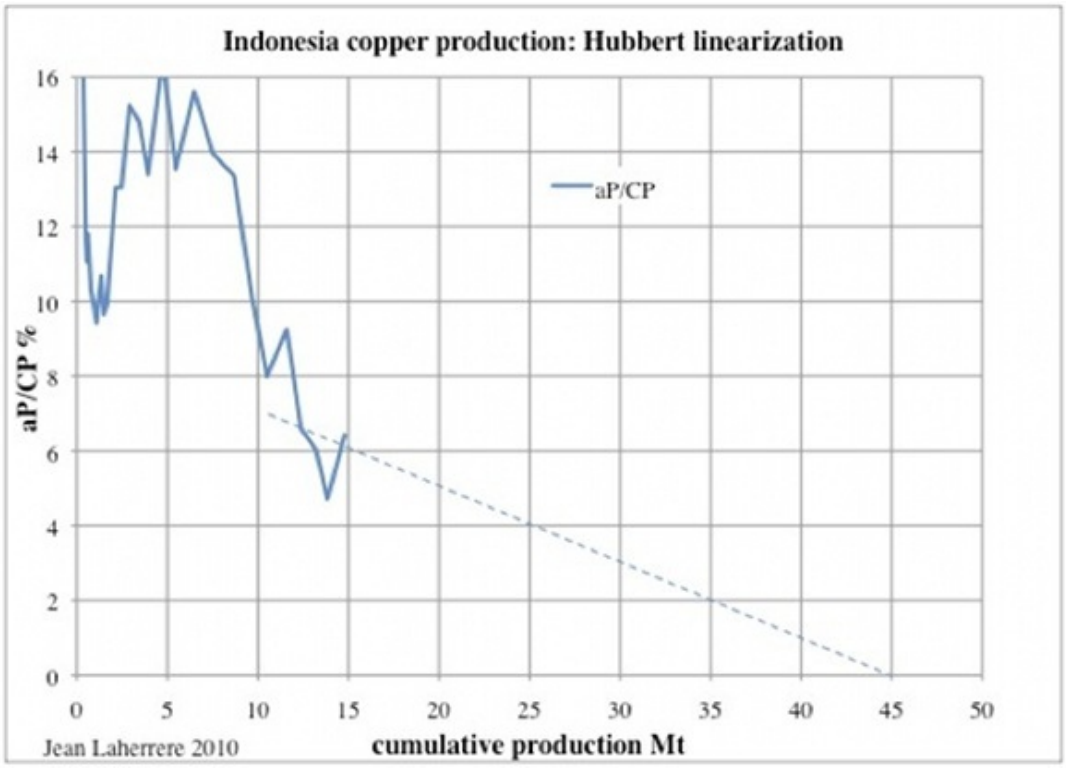


Figure 22: Indonesia copper production: Hubbert linearisation.

Indonesia copper production has peaked in 2001 and will decline slowly until 2100.

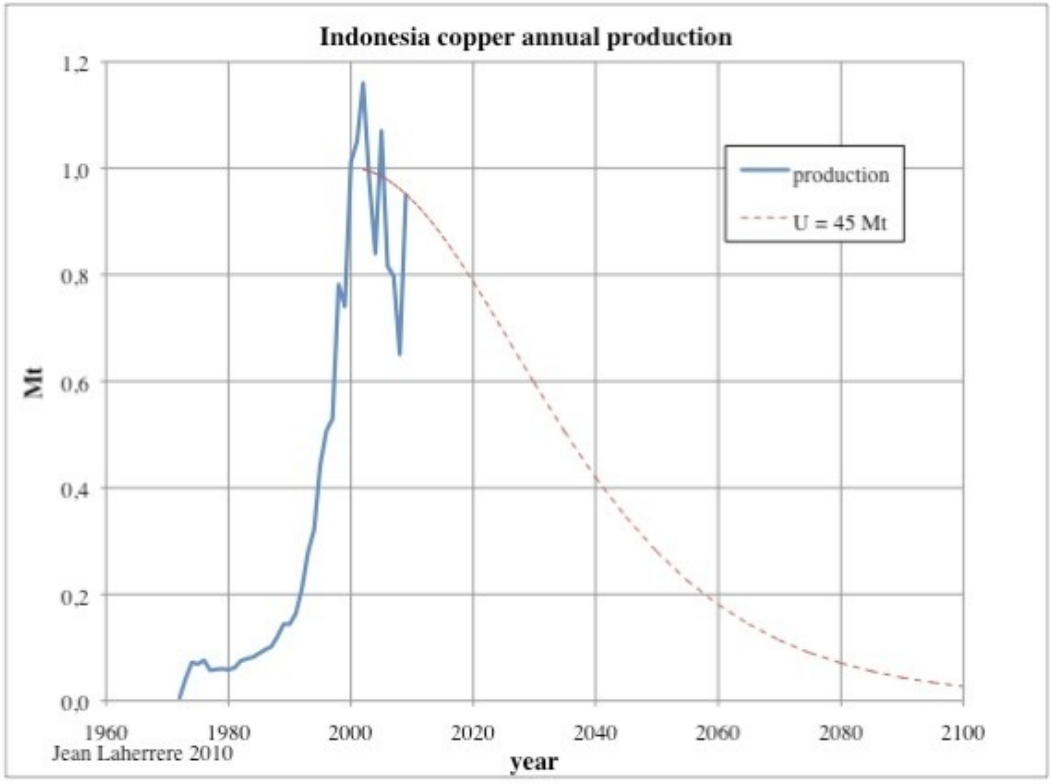


Figure 23: Indonesia copper annual production and forecast for an ultimate of 45 Mt.

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 the USGS estimate with Geosciences Australia's estimate [pdf!]. Australia has a better reserve definition for minerals (EDR = Economic Demonstrated Resources).

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 Pro-duction(d) 2008	Economic Demon-strated Resources(e)	Mine Pro-duction(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					
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					
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
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

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

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 in Copper mining and treatment in South Australia [pdf!] displays (in a logarithmic scale) the up and down copper production in South Australia starting around 1840.

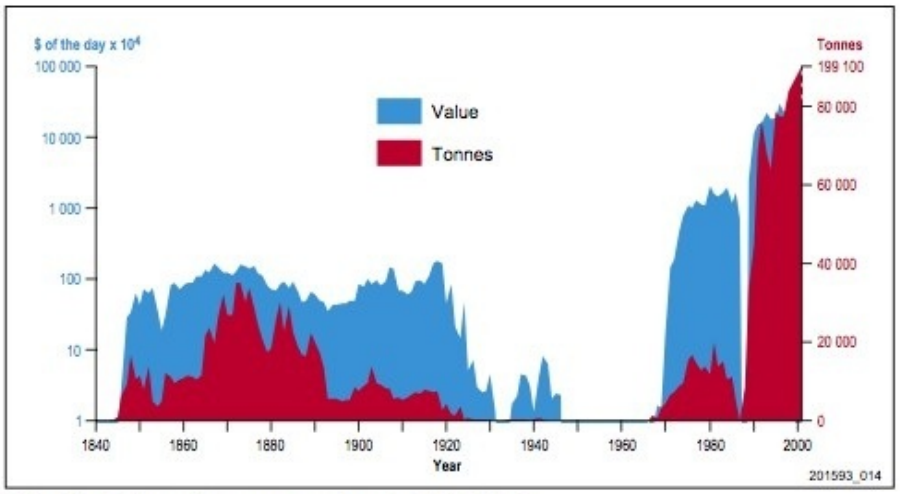


***Fig. 1** South Australian copper production, 1840–2000.*

Figure 25: South Australia copper production.

Olympic Dam copper reserves are estimated at 32 Mt. Australia copper ultimate is estimated at

100 Mt.

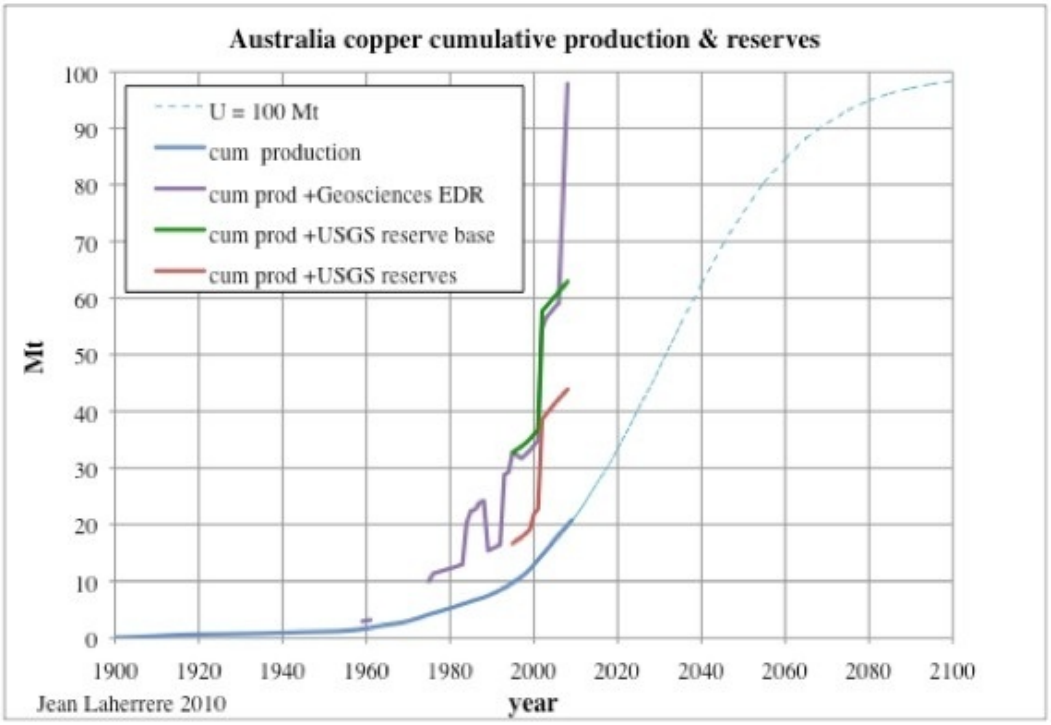


Figure 26: Australia copper cumulative production, USGS and Geosciences reserves with forecast for an ultimate of 100 Mt.

The Hubbert linearisation is hard to extrapolate!

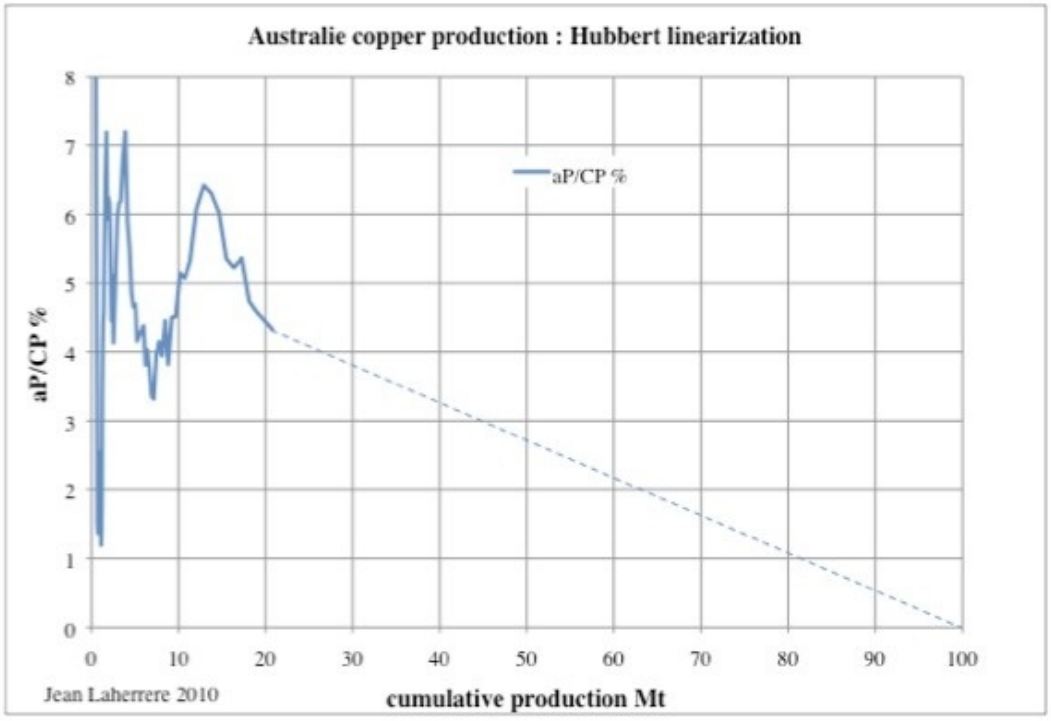


Figure 27: Australia copper production: Hubbert linearisation.

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!

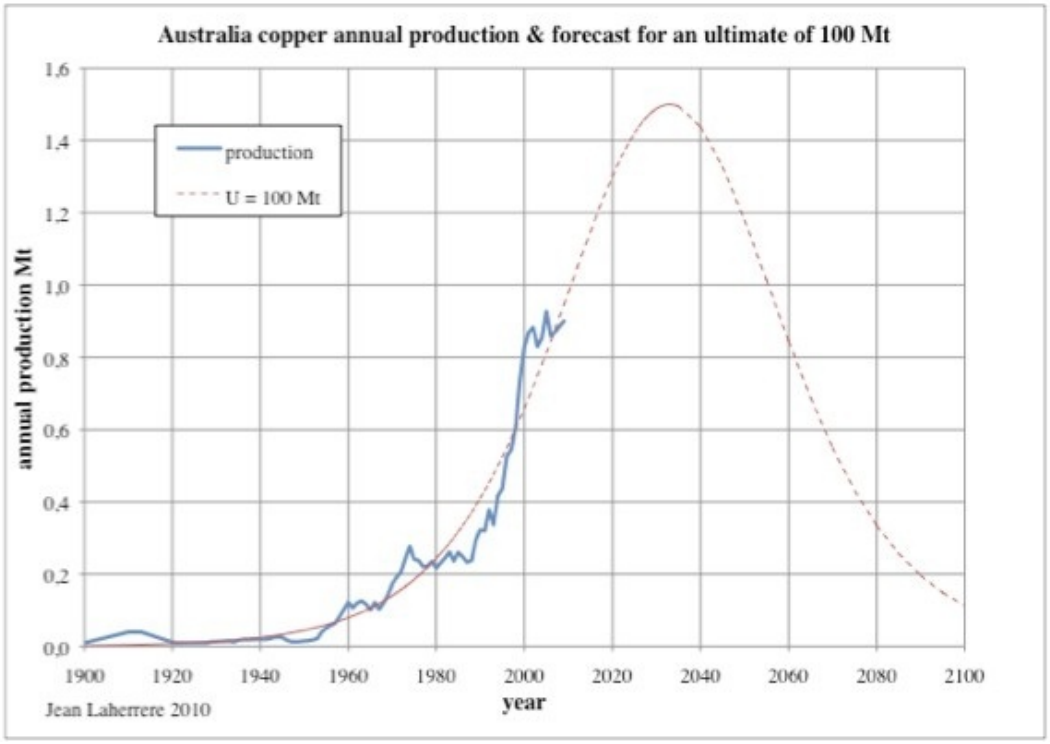


Figure 28: Australia's copper annual production and forecast for an ultimate of 100 Mt.

Canada

Canada is another good place to compare USGS and Natural Resources Canada (NRCan) approaches. NRCan reserves are more complete and slightly lower than the USGS reserves. From NRCan we estimate Canada's copper ultimate at 50 Mt.

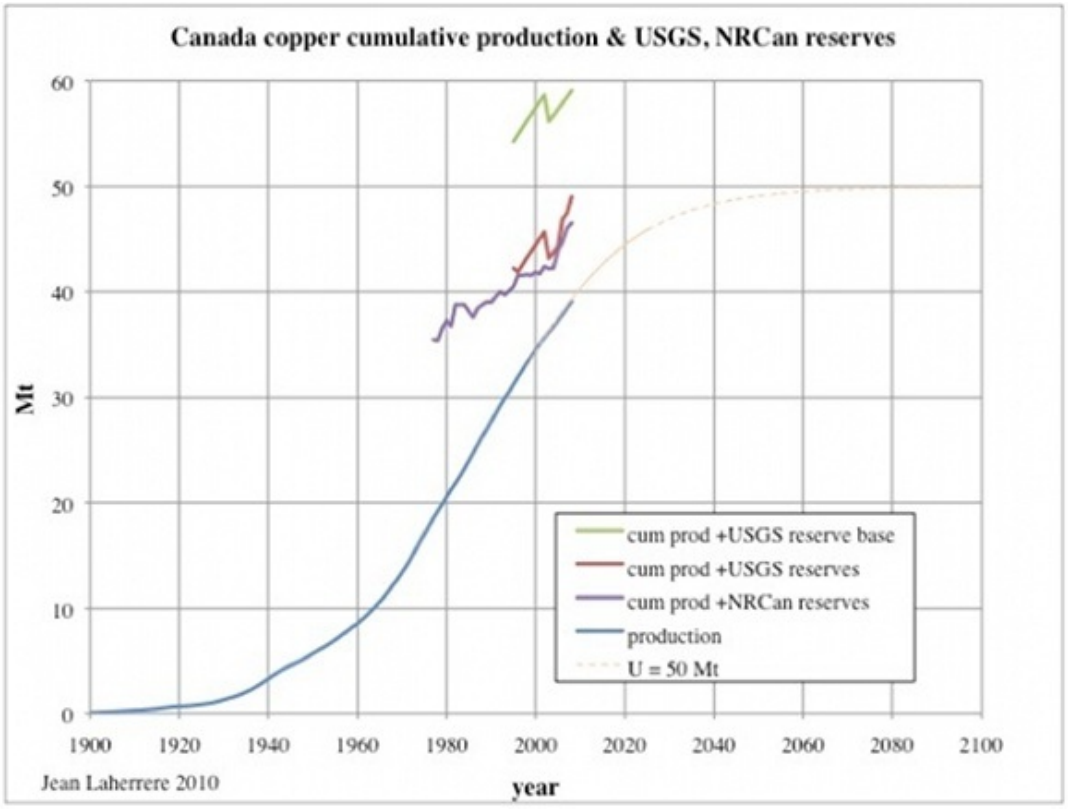


Figure 29: Canada copper cumulative production, USGS and NRCan reserves with forecast for an ultimate of 50 Mt .

The Hubbert linearisation seems to be trending towards 50 Mt since 1970.

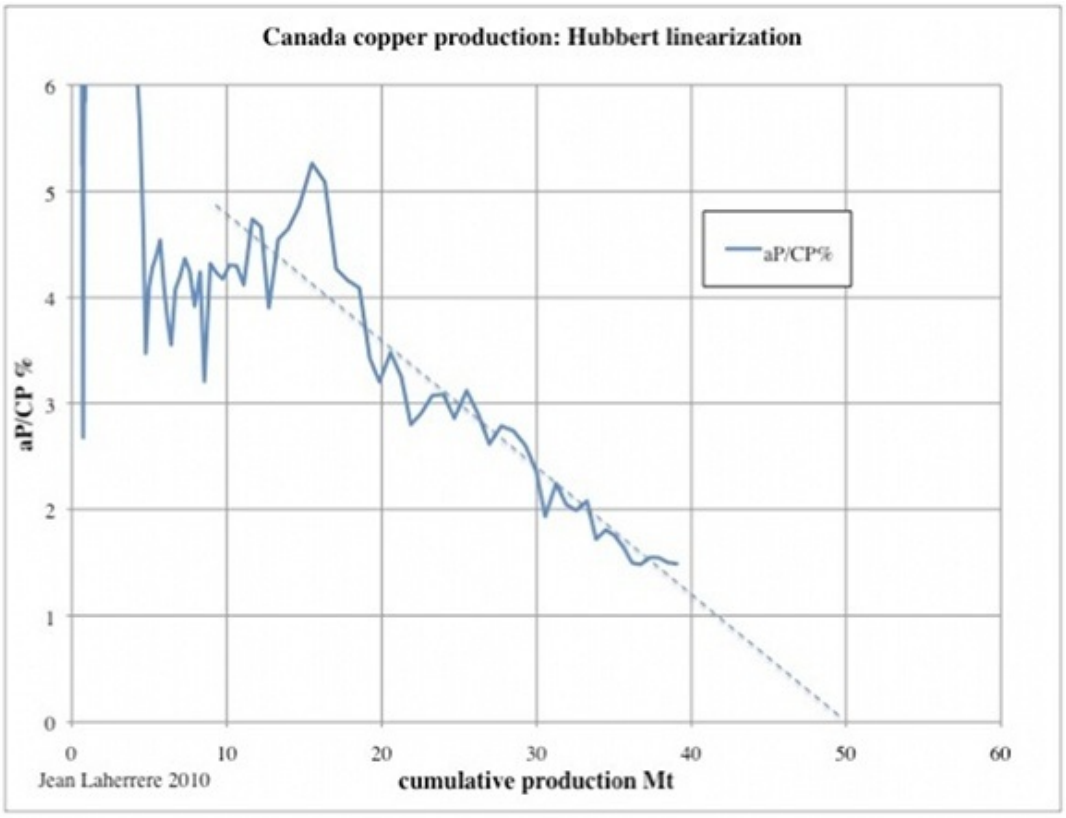


Figure 30: Canada's copper production: Hubbert linearisation.

Canada's copper production has peaked in 1974 and will be producing at half peak around 2015.

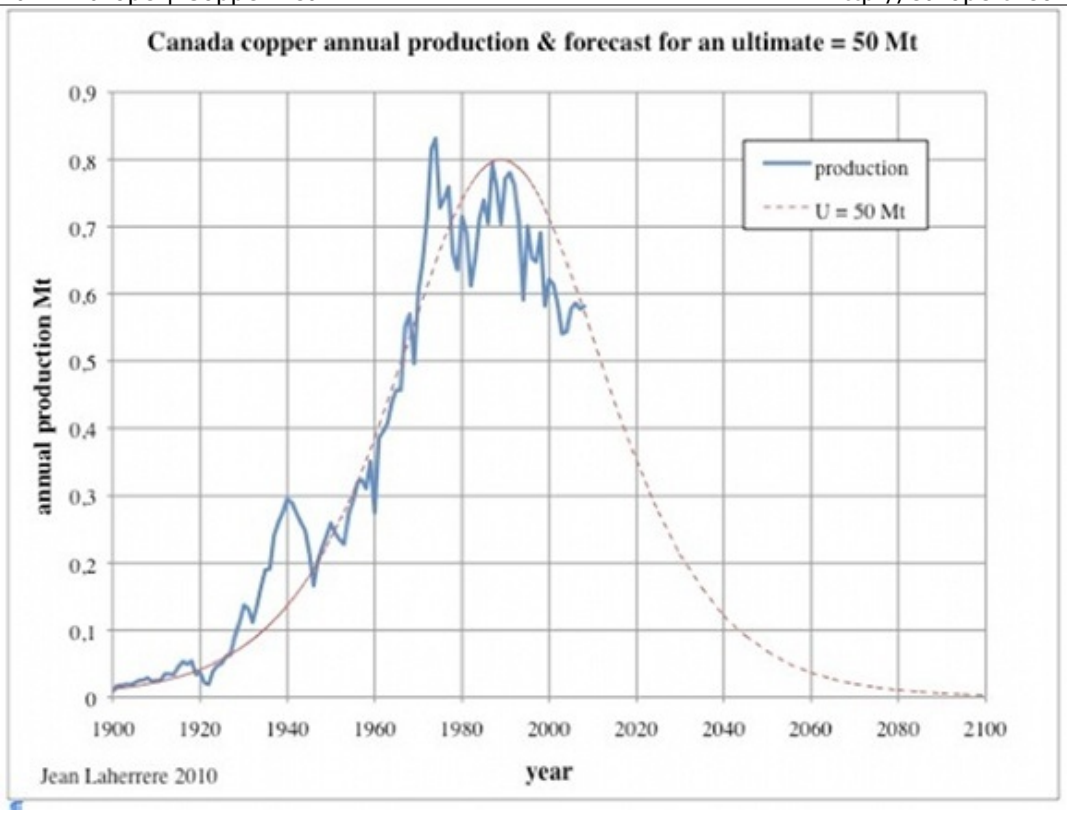


Figure 31: Canada's copper annual production and forecast for an ultimate of 50 Mt.

Russia

Russia is a difficult country to get reliable data from, 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 uncertainty of the estimate. The largest field is Udokan in Eastern Siberia, which displays some negative growth (from 20 to 14 Mt); it was sold in 2008 to be developed and is planned to be producing 0.5 Mt by 2016. We have assumed Russia's copper ultimate to be 60 Mt.

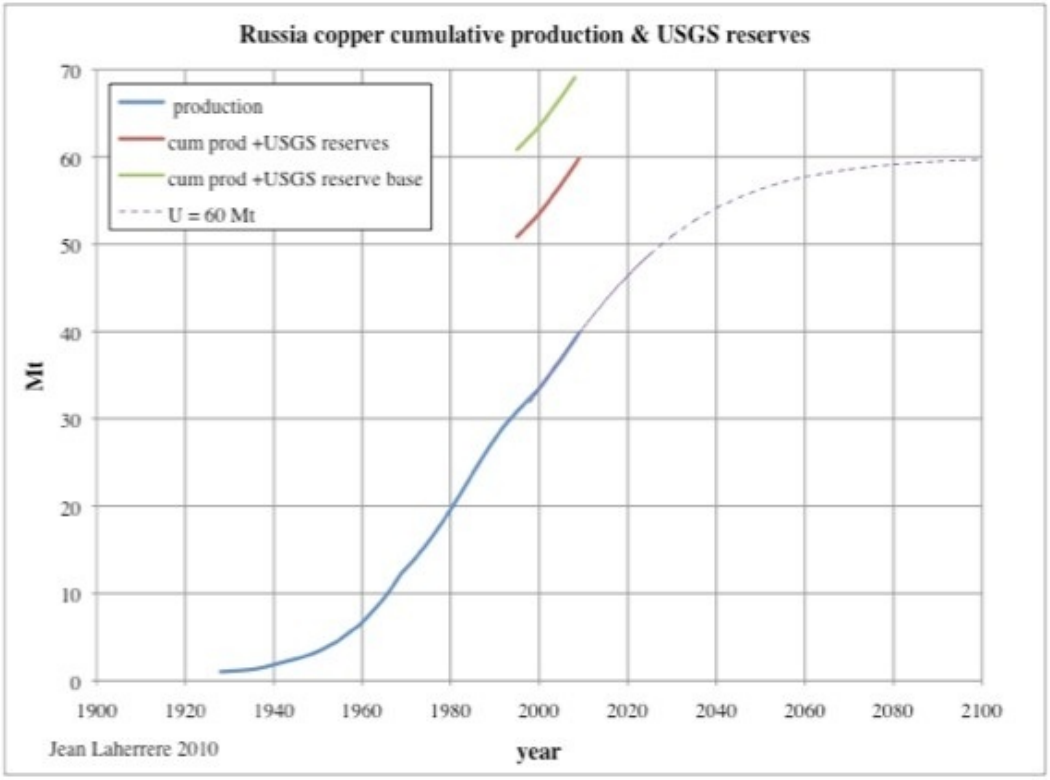


Figure 32: Russia's copper cumulative production, USGS reserves with forecast for an ultimate of 60 Mt .

The Hubbert linearisation could be extrapolated towards 60 Mt but it is not reliable!

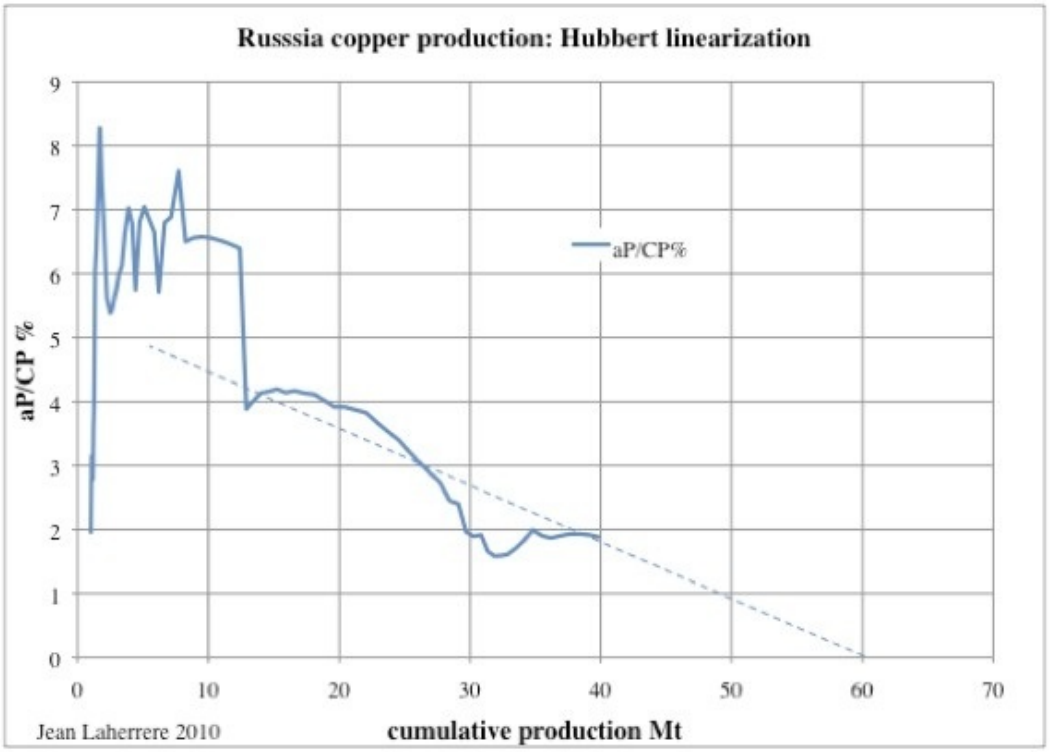


Figure 33: Russia's copper production: Hubbert linearisation.

Russia's copper production has dropped sharply with the break up of the FSU, and is likely peaking now.

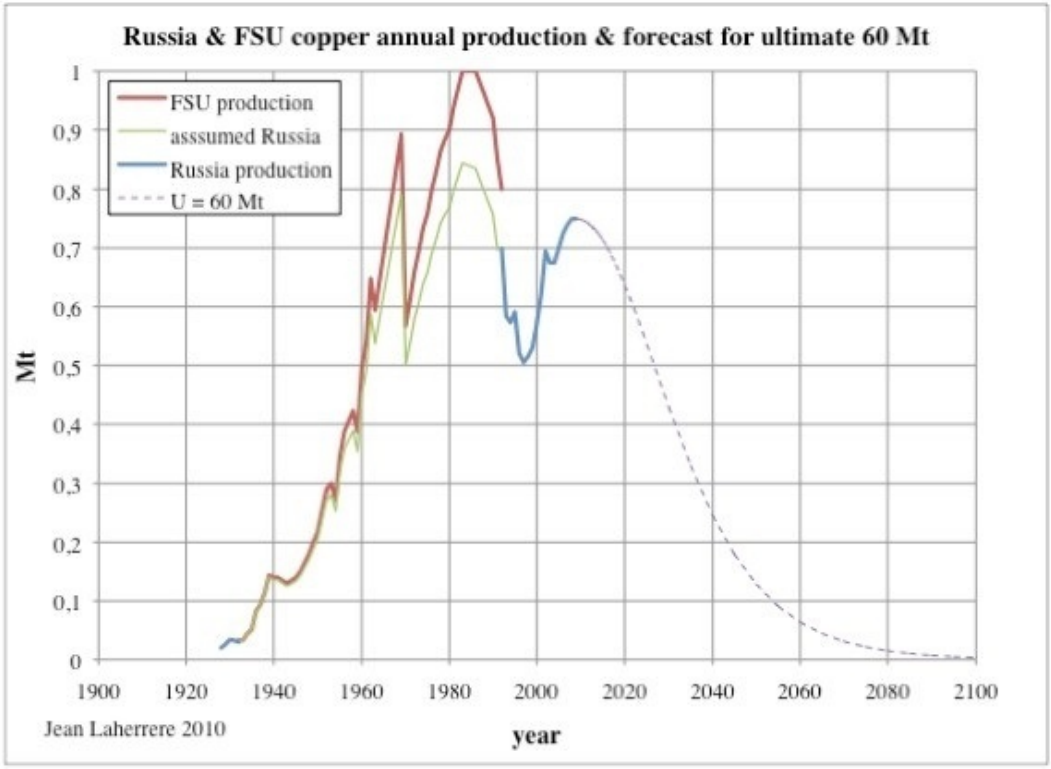


Figure 34: Russia (and FSU) copper annual production with forecast for an ultimate of 60 Mt.

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.

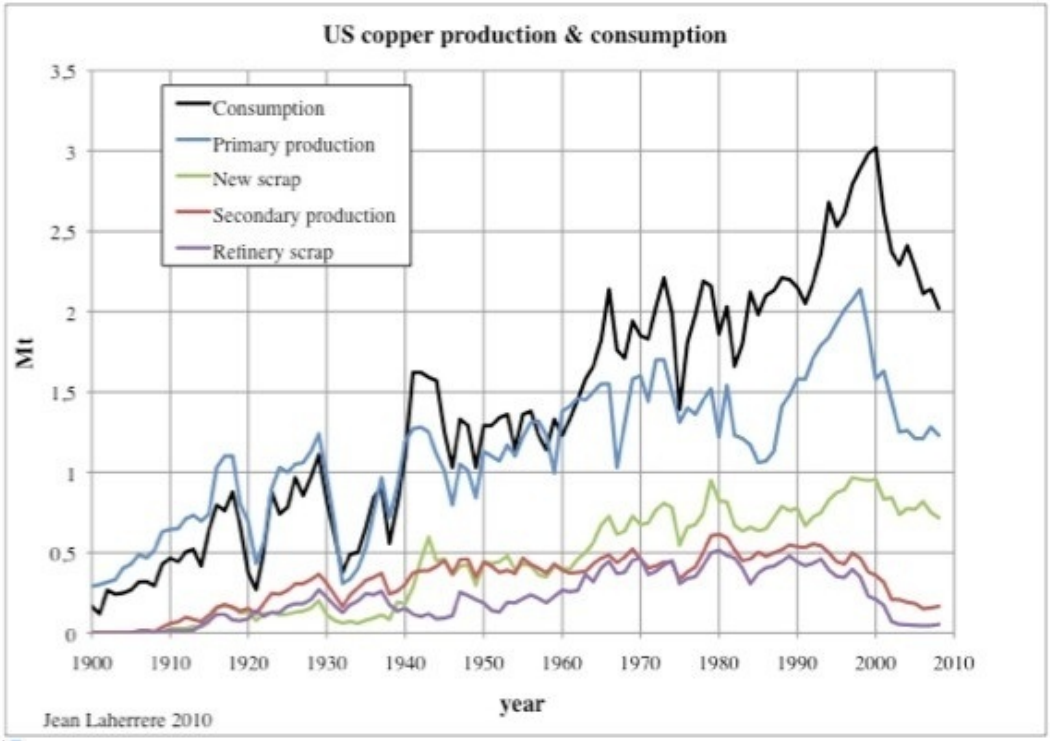


Figure 35: US copper consumption & production 1900-2008.

The world copper consumption (N. Brewster, Rio Tinto, Outlooks for commodity markets [pdf!] displays a harmonious increase since 1850 but a possible peak in 2006, or just a bump! The real

(in 2009 dollars) copper price displays an opposite trend!

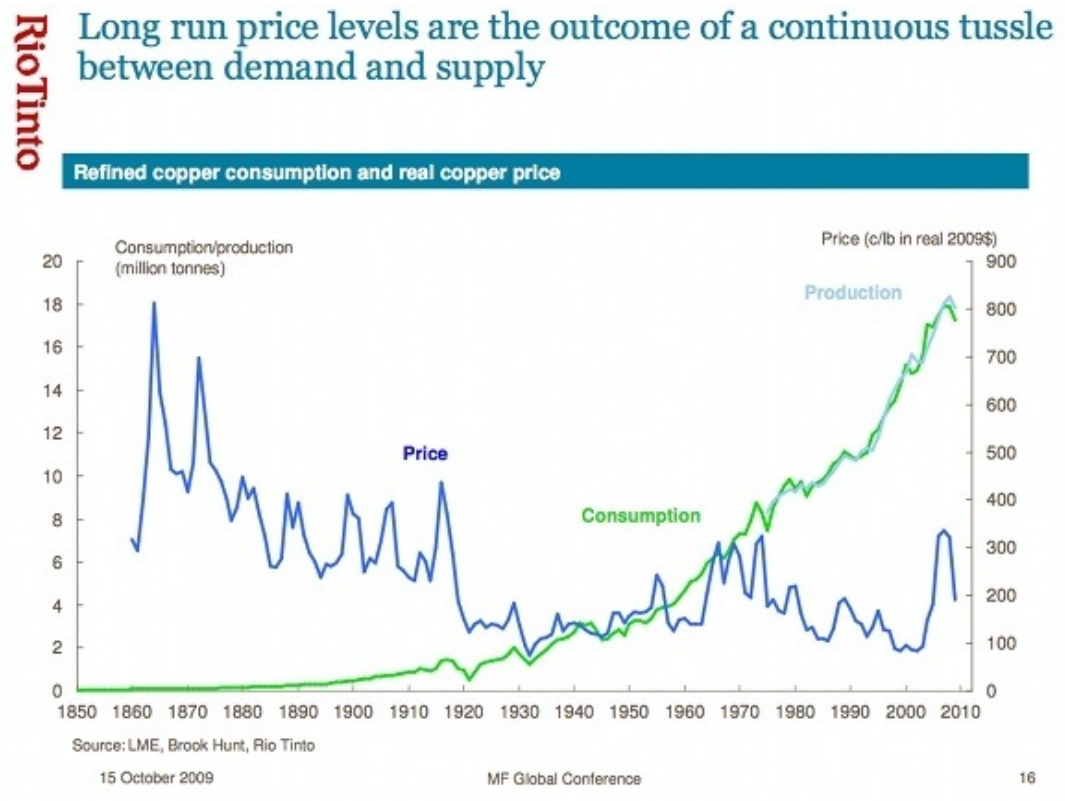


Figure 36: world copper consumption and real price 1850-2008 from Rio Tinto.

It is hard to find a good graph of the distribution of the world copper use.
This Russian graph (from Copper industry: world production – Part I) shows the large range of use by industry:

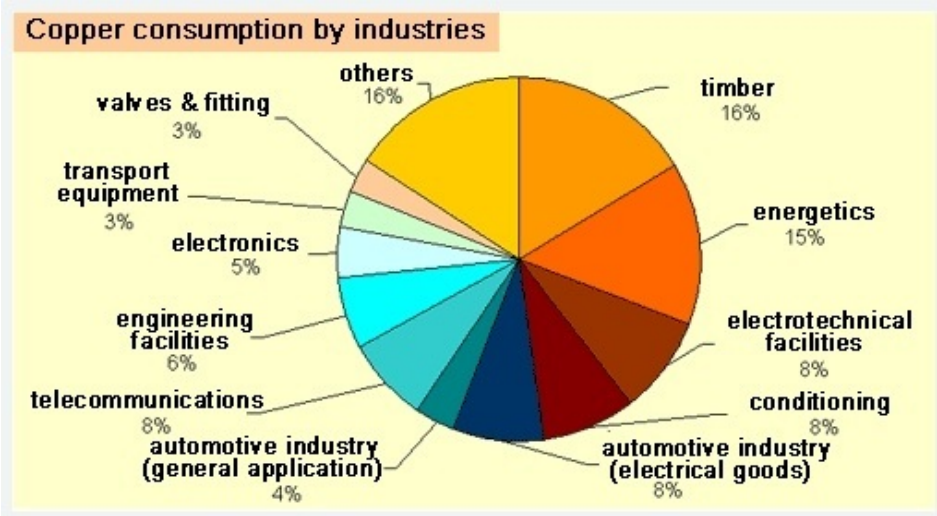


Figure 37: world copper consumption by industry.

Another good graph on US copper use:

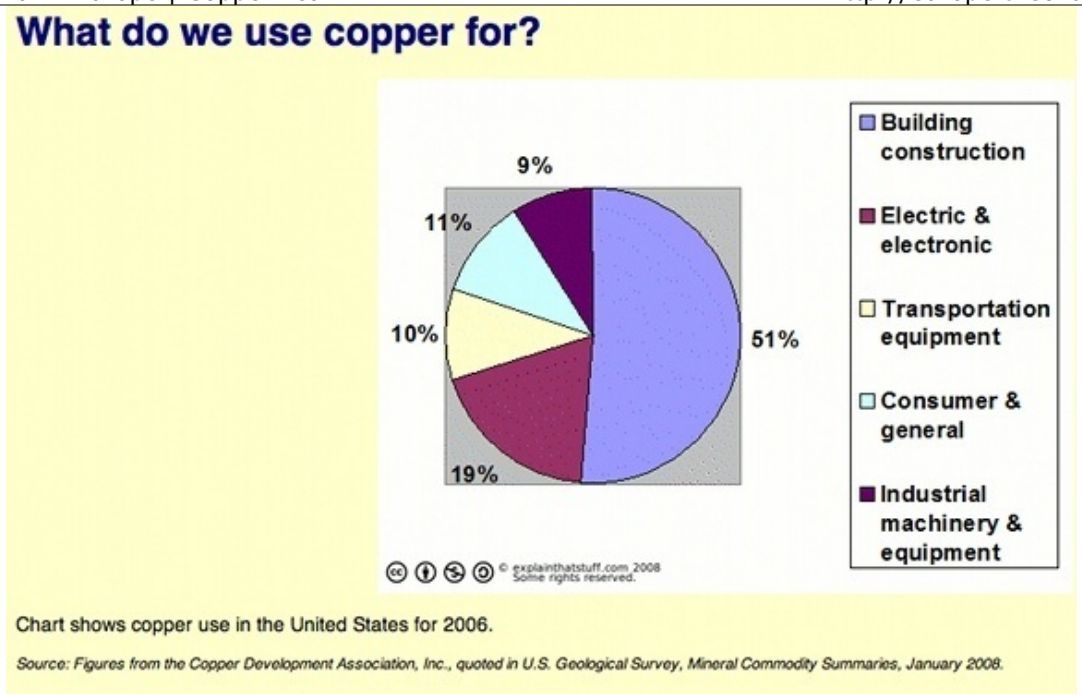


Figure 38: US copper use for 2006.

Copper & gold & oil

Gold production has peaked in 2000 and copper will likely peak in 2020. Their growth was roughly parallel (with a 20 years gap).

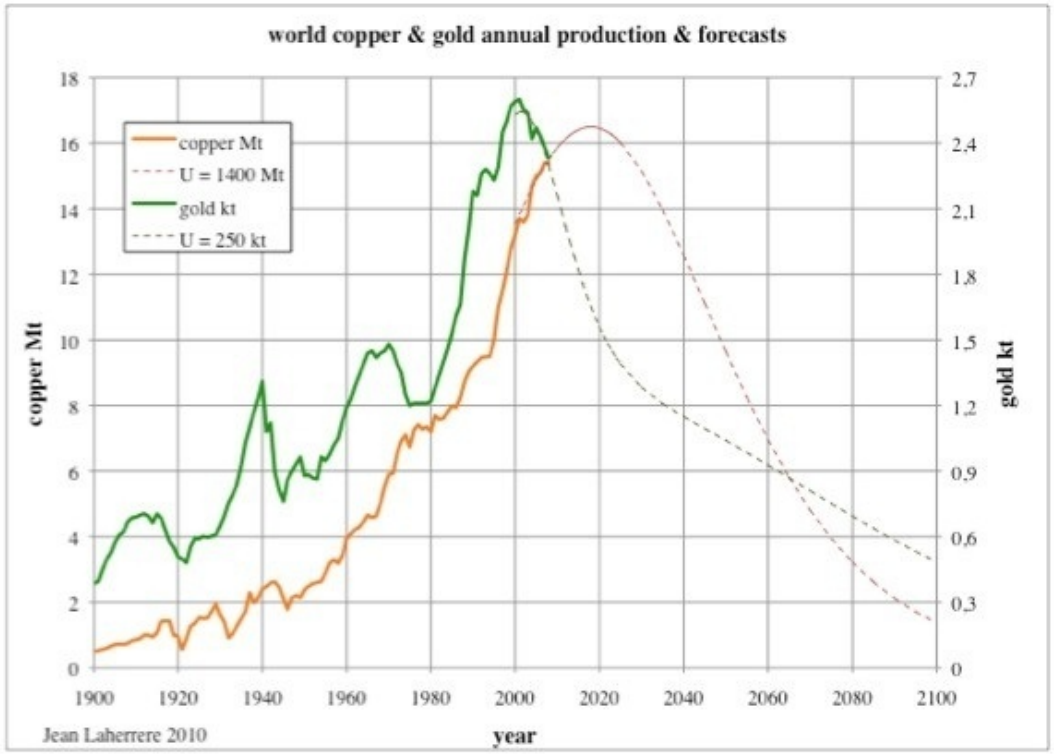


Figure 39: world copper and gold annual production.

Copper's price in 1998 dollars has been chaotic with a sharp increase in 2006 (still, lower than in 1900!), but the gold price was also chaotic.

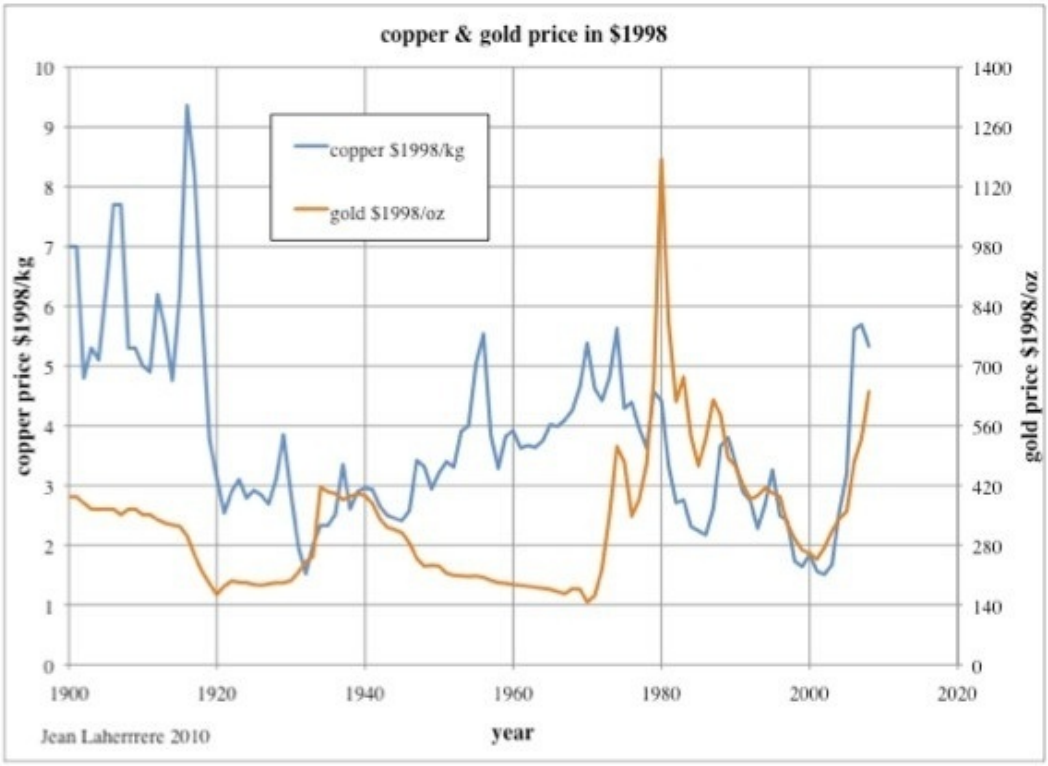


Figure 40: world copper and gold price in 1998 US dollars.

Since 1980 the copper price has been following the oil price.

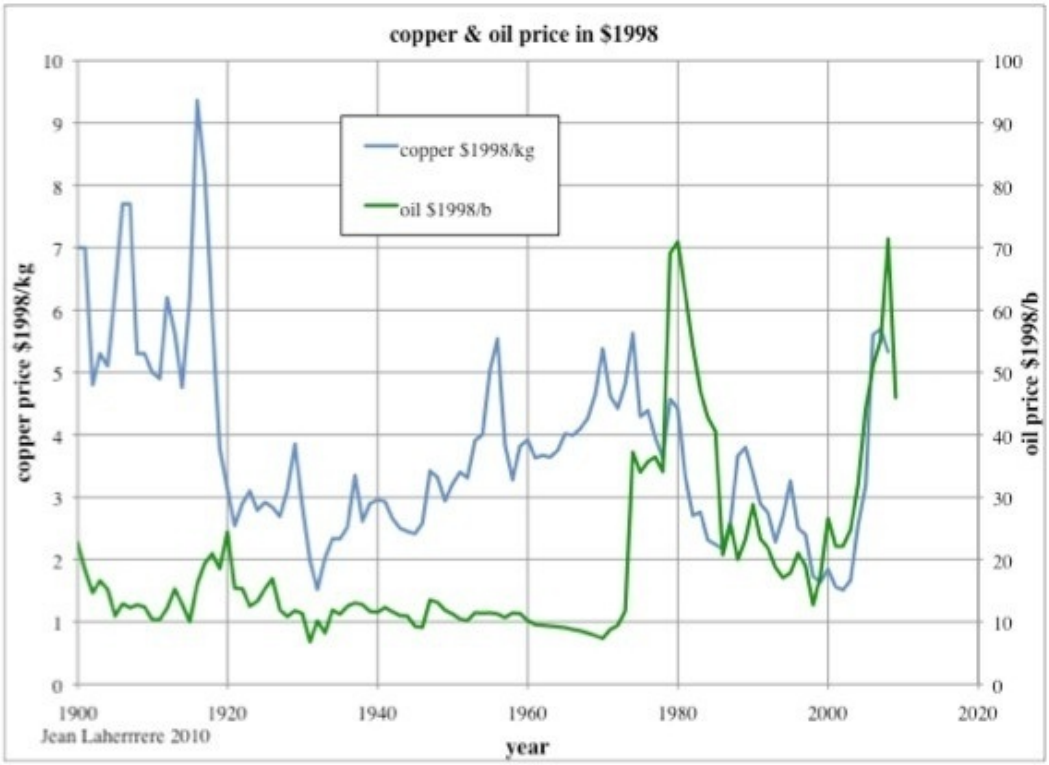


Figure 41: world copper and oil price in 1998 US dollars.

Conclusions

Copper has been an important mineral in the world growth, in use for at least 10 000 years. The Bronze Age is well known for 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 most important metal used by man after iron and aluminium (Radetzki 2009). Its use is challenged by new substitutes, but copper production will peak because it is a limited resource amounting to around 1400 Mt. Unlike oil, copper can be recycled, but developing countries' needs are huge.

Chile and China dominate the world's copper production. But Chile's production peaked in 2007 and China will likely peak around 2020. The future of copper is uncertain!

The *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 91 400 quotes; *peak copper* finds 53 100 quotes, but *copper peak* only 24 100 quotes.

The Copper peak is not something new! The only question is when.

Jean has long been a friend and contributor to TheOilDrum, providing insights on such issues as Methane Hydrates, Oil Prices or Gold Depletion. His posts can be browsed here.