Jean Laherrere 24 August 2023

Updated metal peaks

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My 2021 metal peaks « World metal peaks” https://aspofrance.org/2021/05/23/world-metal-peaks/ https://www.gostatit.com/s/aspo_france/ASPO_metals/JHL is updated with new data and new graphs. The forecast is based on the ultimate estimated from the HL (Hubbert linearization) of past productions (USGS = US Geological Survey and BGS = British Geological Survey) and USGS remaining reserves

-Sources

USGS 2023 reports the following list of commodities:

MINERAL COMMODITY SUMMARIES 2023

Abrasives	Fluorspar	Mercury	Silicon
Aluminum	Gallium	Mica	Silver
Antimony	Garnet	Molybdenum	Soda Ash
Arsenic	Gemstones	Nickel	Stone
Asbestos	Germanium	Niobium	Strontium
Barite	Gold	Nitrogen	Sulfur
Bauxite	Graphite	Palladium	Talc
Beryllium	Gypsum	Peat	Tantalum
Bismuth	Hafnium	Perlite	Tellurium
Boron	Helium	Phosphate Rock	Thallium
Bromine	Indium	Platinum	Thorium
Cadmium	Iodine	Potash	Tin
Cement	Iron and Steel	Pumice	Titanium
Cesium	Iron Ore	Quartz Crystal	Tungsten
Chromium	Iron Oxide Pigments	Rare Earths	Vanadium
Clays	Kyanite	Rhenium	Vermiculite
Cobalt	Lead	Rubidium	Wollastonite
Copper	Lime	Salt	Yttrium
Diamond	Lithium	Sand and Gravel	Zeolites
Diatomite	Magnesium	Scandium	Zinc
Feldspar	Manganese	Selenium	Zirconium

USGS
science for a changing world

Uranium is missing, as uranium was excluded by its definition as mineral fuels in the Mining and Minerals Policy Act of 1970 [30 U.S.C. 21(a)]. Uranium is with fossils fuels

BGS

Commodity Index

Mine production of many metals is expressed in terms of metal content. This is clearly indicated at the head of the table, adjacent to the unit used. For aluminium, cobalt, copper, iron, lead, nickel, tin and zinc, mine production and metal production are shown in separate tables.

Only a certain number of metals are studied in this paper.

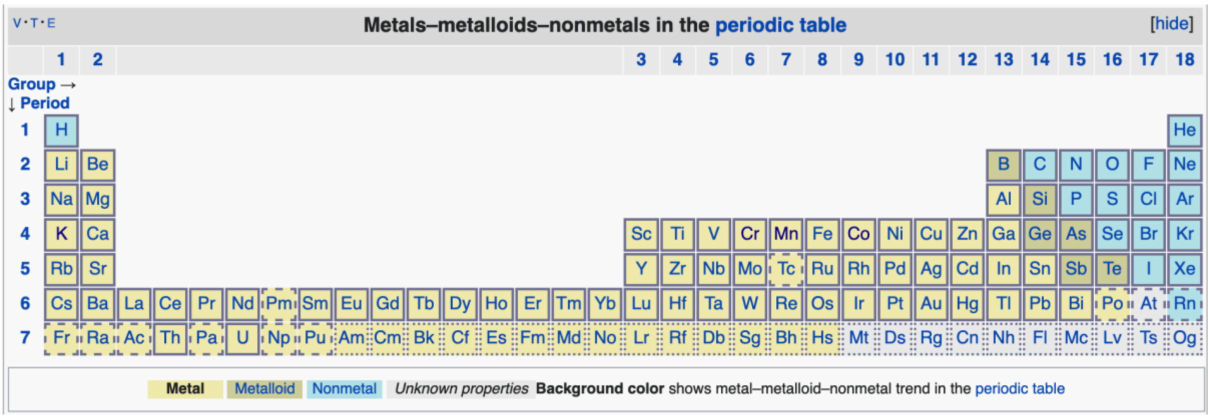
-definition

The metal definition varies but metal is related to be a good electricity and heat conductor, without defining good!
Oxford: *a solid material which is typically hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity (e.g. iron, gold, silver, and aluminium, and alloys such as steel).*
Cambridge: *a chemical element, such as iron or gold, or a mixture of such elements, such as steel, that is generally hard and strong, and through which electricity and heat can travel.*
Webster: *any of various opaque, fusible, ductile, and typically lustrous substances that are good conductors of electricity and heat, form cations by loss of electrons, and yield basic oxides and hydroxides.*
Wikipedia: *A metal (from Ancient Greek μέταλλον métallon 'mine, quarry, metal') is a material that, when freshly prepared, polished, or fractured, shows a lustrous appearance,*

and conducts electricity and heat relatively well. Metals are typically ductile (can be drawn into wires) and malleable (they can be hammered into thin sheets). These properties are the result of the metallic bond between the atoms or molecules of the metal.

https://science.jrank.org/pages/4260/Metal-Production-Reduction.html
Metals always occur in their oxidized state in ores, often as the oxide or sulfide of the metal. In order to convert an ore to its elemental state, therefore, it must be reduced. Reduction is a chemical reaction that is the opposite of oxidation.

Metals can be separated in two groups: ferrous (comprised by iron), like iron and steel, and non-ferrous, like aluminum, copper and heavy metals (lead, nickel, zinc and mercury).



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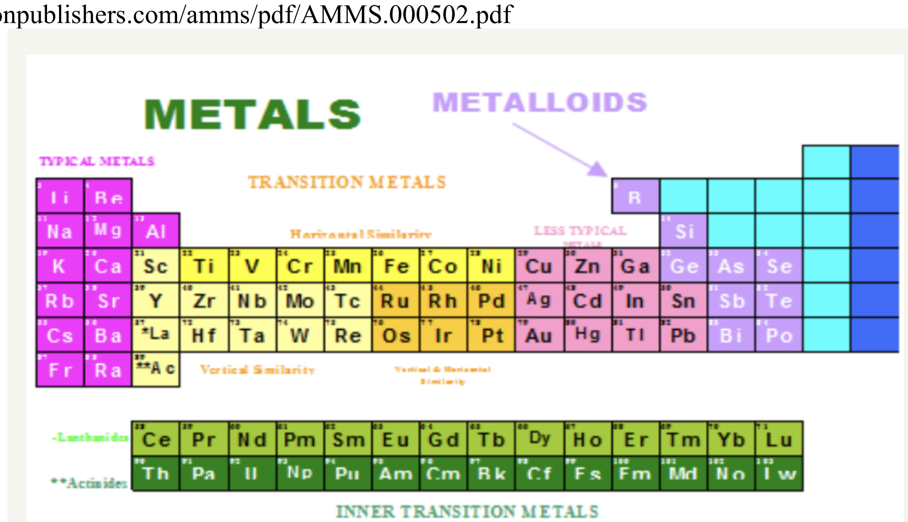


Figure 2: Metals and metalloids obtained from ores.

Oxides, Hydroxides and Carbonates	Aluminium	Gibbsite	$Al(OH)_3$
		Böhmite	AlOOH
		Diaspore	AlOOH
	Copper	Cuprite	Cu_2O
		Tenorite	CuO
		Malachite	$CuCO_3 \bullet Cu(OH)_2$
		Azurite	$2CuCO_3 \bullet Cu(OH)_2$
	Iron	Magnetite	Fe_3O_4
		Hematite	Fe_2O_3
		Ilmenite	$Fe_2O_3 \bullet nH_2O$
		Goethite	FeOOH
			$FeCO_3$
	Magnesium	Dolomite	$(Ca,Mg)CO_3$
	Manganese	Pyrolusite	MnO_2
		Manganite	$Mn_2O_3 \bullet H_2O$
		Hausmannite	Mn_3O_4
	Rare earths	Bastnasite	$LnFCO_3$ (Ln=lanthanide)
	Tin	Cassiterite	SnO_2
	Titanium	Rutile	TiO_2
	Uranium	Pitchblende	U_3O_8
		Uraninite	UO_2
	Zinc	Zincite	ZnO
		Hydrozincite	$ZnCO_3 \bullet 2Zn(OH)_2$
		Smithsonite	$ZnCO_3$
Complex Oxides	Chromium	Chromite	$Cr_2O_3 \bullet FeO$
	Niobium	Columbite	$Nb_2O_5 \bullet (Fe,Mn)O$
		Pyrochlore	$Nb_2O_5 \bullet (Ca,Ba)O \bullet NaF$
	Tantalum	Tantalite	$Ta_2O_5 \bullet (Fe,Mn)O$
	Titanium	Ilmenite	$TiO_2 \bullet FeO$
	Tungsten	Scheelite	$WO_3 \bullet CaO$
		Wolframite	$WO_3 \bullet FeO$
Silicates			

Anhydrous	Beryllium	Beryl	$3BeO \bullet Al_2O_3 \bullet 6SiO_2$
	Lithium	Spodumene	$Li_2O \bullet Al_2O_3 \bullet 4SiO_2$
	Zirconium	Zircon	$ZrSiO_4$
Hydrated	Cesium	Pollucite	$2Cs_2O \bullet 2Al_2O_3 \bullet 4SiO_2 \bullet H_2O$
	Copper	Chrysocolla	$Cu_3(OH)_2 \bullet Si_4O_{10} \bullet nH_2O$
	Nickel	Garnierite	$(Ni,Mg)_3(OH)_4 \bullet Si_2O_5 \bullet nH_2O$
Sulfides	Antimony	Stibnite	Sb_2S_3
	Arsenic	Realgar	As_4S_4
		Orpiment	As_2S_3
		Arsenopyrite	FeAsS
	Cobalt	Linnæite	Co_3S_4
	Copper	Chalcocite	Cu_2S
		Covellite	CuS
		Digenite	Cu_9S_5
		Bornite	Cu_5FeS_4
		Chalcopyrite	$CuFeS_2$
		Cubanite	$CuFe_2S_3$
		Enargite	Cu_3AsS_4
	Iron	Pyrite	FeS_2
		Marcasite	FeS_2
		Pyrrhotite	FeS
	Lead	Galena	PbS
	Mercury	Cinnabar	HgS
	Molybdenum	Molybdenite	MoS_2
	Nickel	Pentlandite	(Fe,Ni)S
	Silver	Argentite	Ag_2S
	Zinc	Sphalerite	ZnS
Phosphate	Rare earths	Monazite	$LnPO_4$
		Xenotime	$LnPO_4$
Sulphate	Lead	Anglesite	$PbSO_4$
	Aluminium	Alunite	$KAl_3(SO_4)_2(OH)_6$
Telluride	Gold	Calaverite	$AuTe_2$
Arsenide	Cobalt	Smaltite	$CoAs_2$

Table 4 Classification of the most important metallic minerals according to chemical composition of no technical importance Ln stands for lanthanide.

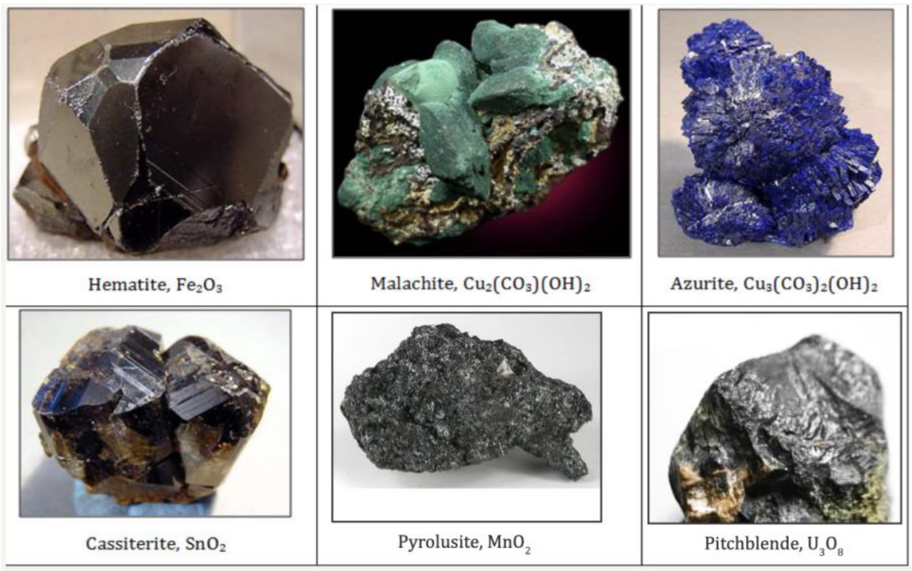


Figure 5: Museum samples of common oxide minerals.

Figure 6: Museum samples of common sulfide minerals.

Table 4: Gives a list of the most important metallic minerals classified according to chemical composition.

Group		Minerals	Composition
Native Metals		Gold	Au
		Silver	Ag
		Electrum	Au-Ag
		Platinum metals	Pt, Ir, Os, Ru, Rh, Pd
		Copper	Cu
		Awarite	$FeNi_2$
		Josephinite	$FeNi_3$
		Native mercury	Hg

There are thought to be well over 4,000 different minerals, many of which contain metallic elements.

There is a difference between the data of the ore and the metal content, (only a fraction of ore) as shown with bauxite and aluminium.

Here are all the metals and metal ores mined in 2019, according to the British Geological Survey:

Metal/Ore	Quantity Mined (tonnes)	% of Total
Iron Ore	3,040,000,000	93.57%
Industrial Metals	207,478,486	6.39%
Technology and Precious Metals	1,335,848	0.04%
Total	**3,248,814,334**	**100%**

An important factor is the rock to metal ratio, well studied by USGS in the 2022 Nassar et al paper: https://pubs.acs.org/doi/10.1021/acs.est.1c07875 Rock-to-Metal Ratio: A Foundational Metric for Understanding Mine Wastes Nedal T. Nassar; Graham W. Lederer; Jamie L. Brainard; Abraham J. Padilla; Joseph D. Lessard, USGS April 2022

Rock to metal ratio of analyzed commodities varies from low to high:

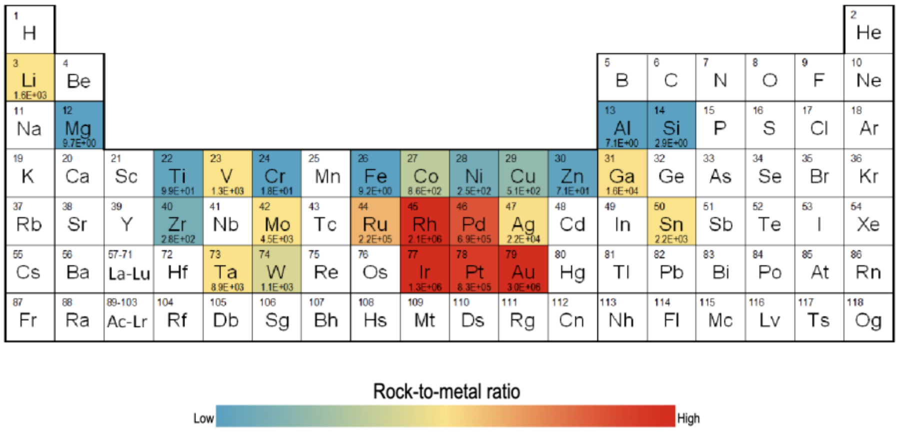


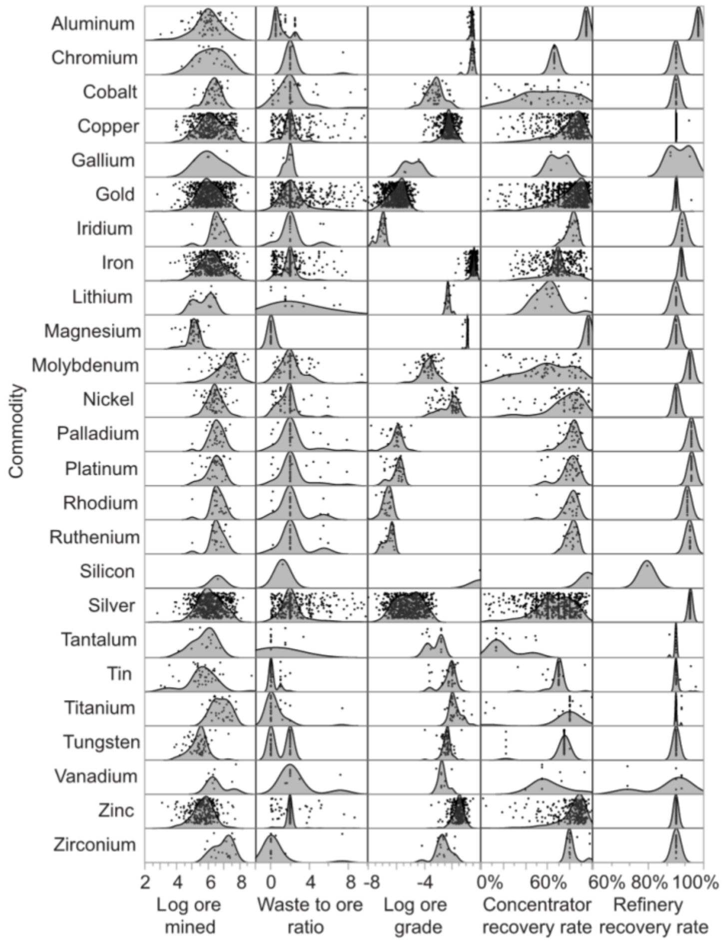
Figure S2. *Periodic table displaying the 2018 global RMR for the mineral commodities analyzed*

Percent contribution to rock to metal ratio

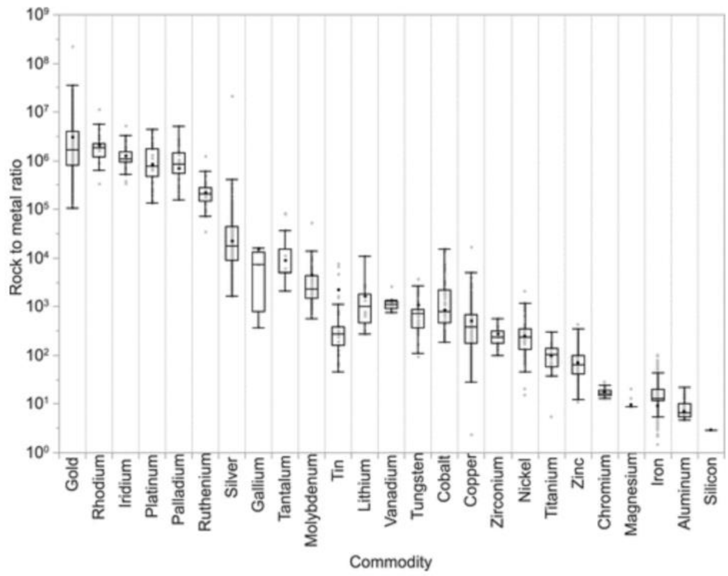
Commodity	Percent contribution to rock to metal ratio (RMR)				
	Concentrator recovery rate	Ore grade	Refinery recovery rate	Revenue share	Waste to ore ratio
Aluminum	0.0%	28.0%	0.0%	0.0%	72.0%
Chromium	0.0%	95.6%	0.0%	1.8%	2.6%
Cobalt	1.8%	56.4%	0.0%	39.7%	2.0%
Copper	19.5%	48.0%	0.0%	26.3%	6.2%
Gallium	2.0%	13.8%	1.0%	68.6%	14.6%
Gold	12.4%	64.3%	0.0%	15.2%	8.1%
Iridium	48.6%	16.4%	0.0%	18.8%	16.3%
Iron	14.2%	42.3%	0.0%	0.2%	43.3%
Lithium	1.1%	47.3%	0.0%	1.2%	50.4%
Magnesium	0.0%	100.0%	0.0%	0.0%	0.0%
Molybdenum	33.6%	18.2%	0.0%	45.7%	2.4%
Nickel	14.5%	21.5%	0.0%	14.1%	49.9%
Palladium	33.3%	8.4%	0.0%	3.8%	54.5%
Platinum	11.5%	10.9%	0.0%	66.4%	11.2%
Rhodium	4.4%	6.0%	0.0%	7.9%	81.7%
Ruthenium	10.5%	20.2%	0.0%	6.6%	62.7%
Silicon	-	-	-	-	-
Silver	17.9%	13.8%	0.0%	68.1%	0.2%
Tantalum	1.0%	18.1%	0.1%	66.7%	14.1%
Tin	0.1%	97.8%	1.2%	0.2%	0.8%
Titanium	3.9%	34.5%	3.4%	20.8%	37.4%
Tungsten	4.4%	74.8%	0.0%	0.2%	20.6%
Vanadium	11.1%	23.9%	2.1%	58.8%	4.2%
Zinc	6.3%	52.1%	0.0%	30.9%	10.7%
Zirconium	3.2%	29.3%	0.0%	62.2%	5.3%
All	**4.0%**	**68.9%**	**4.9%**	**16.9%**	**5.4%**

Details of percent of ore mined, waste rock removed, ore grade, concentrator recovery rate:

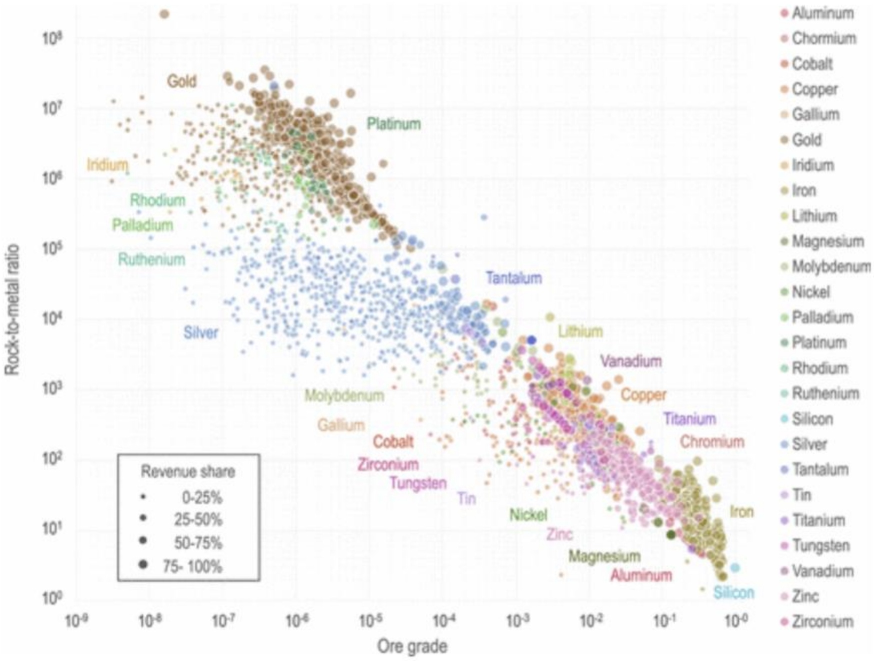
Ore grade, waste to ore ratio, ore grade, concentrator recovery rate, refinery recovery rate



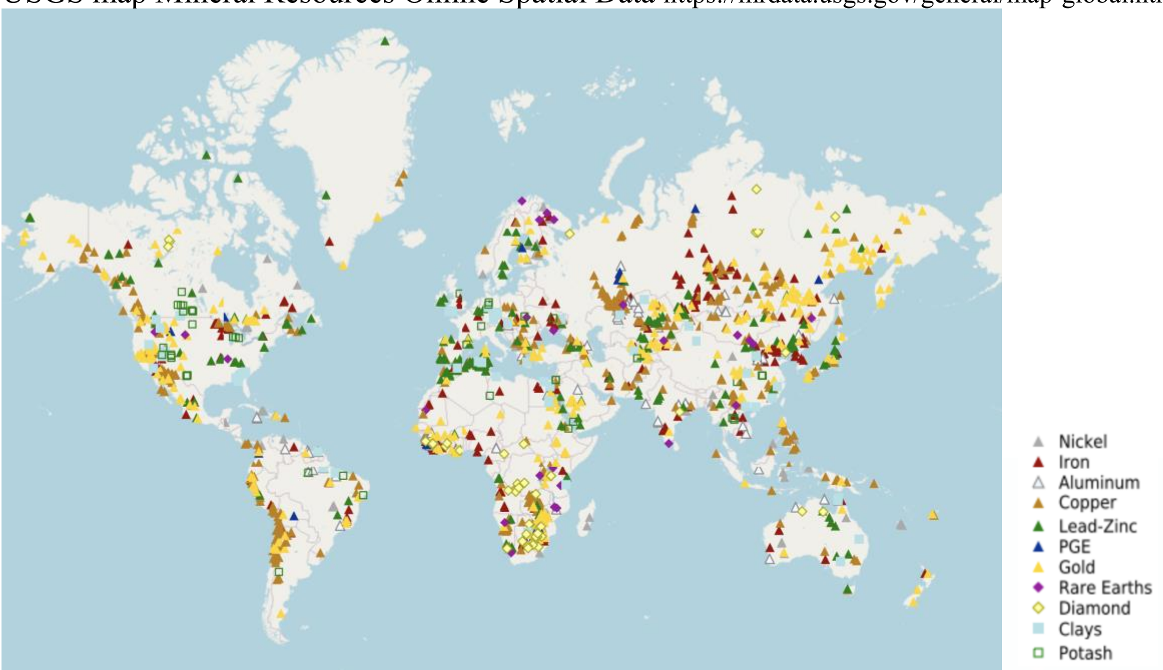
Range of rock to metal ratio from one to one million:



Rock to metal ratio versus ore grade



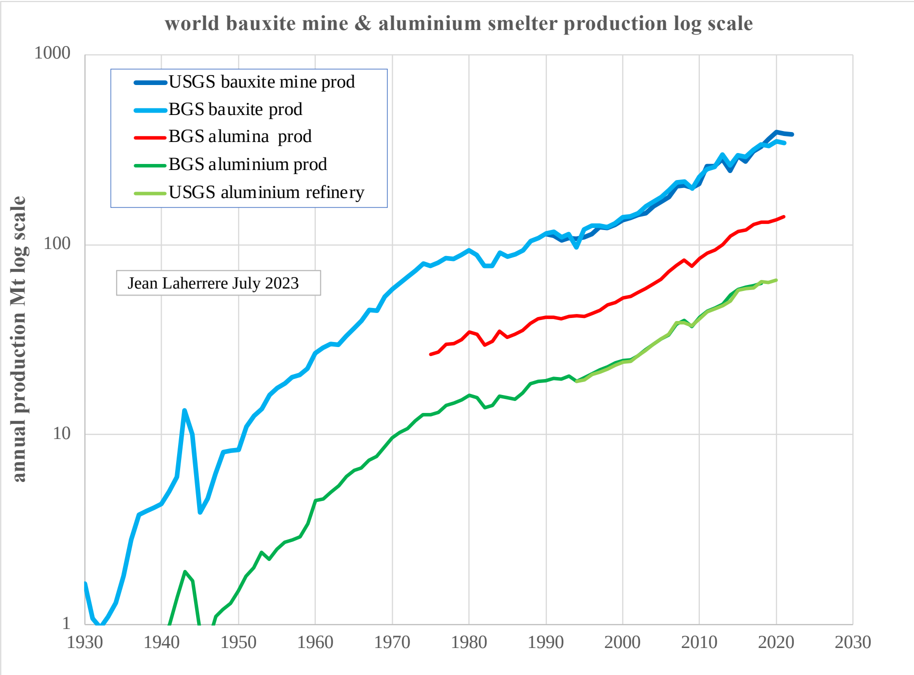
USGS map Mineral Resources Online Spatial Data https://mrdata.usgs.gov/general/map-global.html



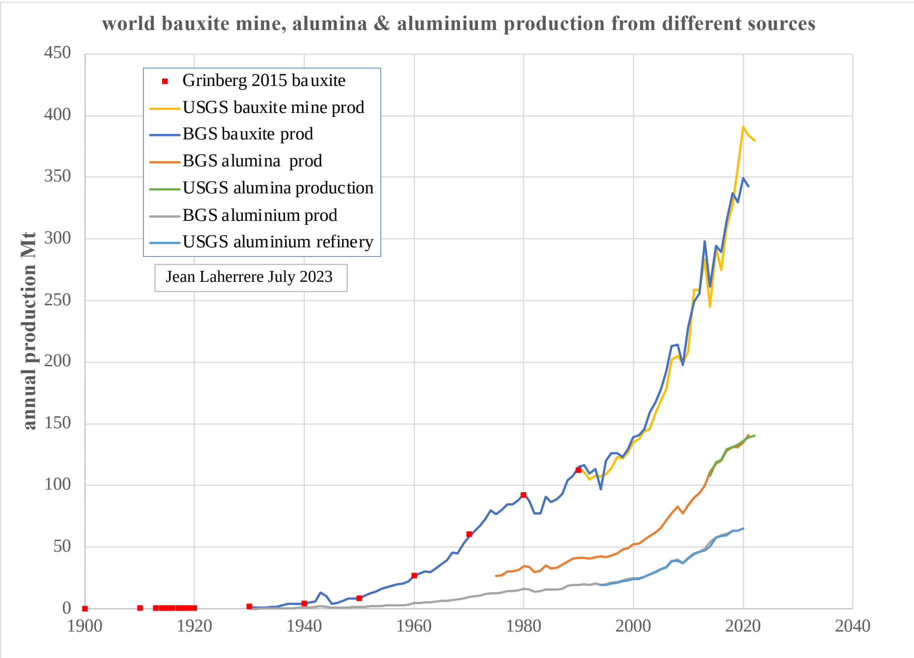
-bauxite, aluminium Al

Bauxite = $Al_2O_3.2H_2O$, alumina = Al_2O_3

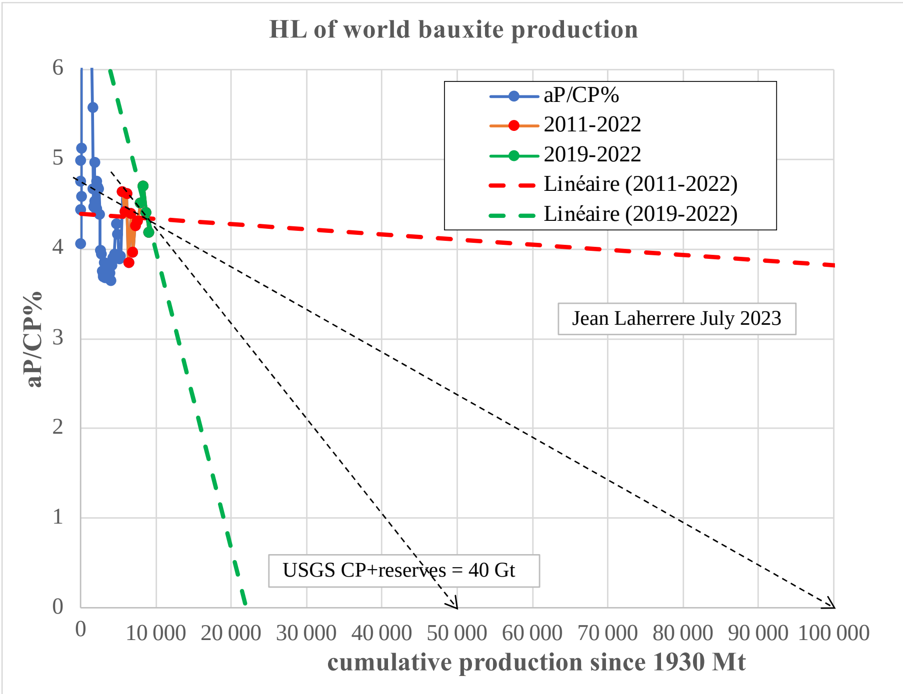
Production plot in log scale of bauxite, alumina and aluminium



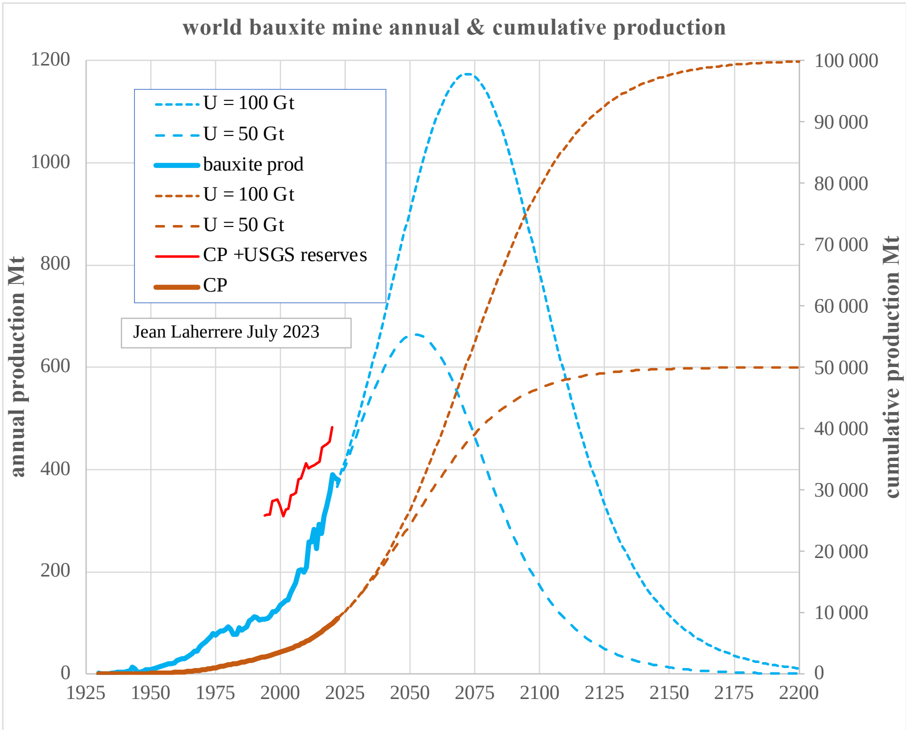
Production data from different sources:



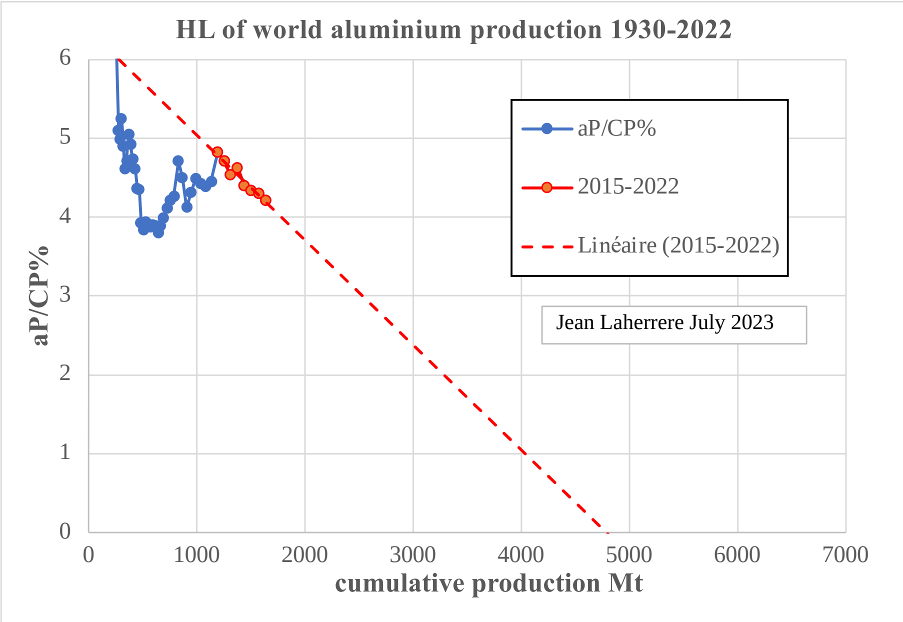
HL of world bauxite production is useless, when USGS CP+reserves is about 40 Gt!
An ultimate of 50 & 100 Gt is plotted



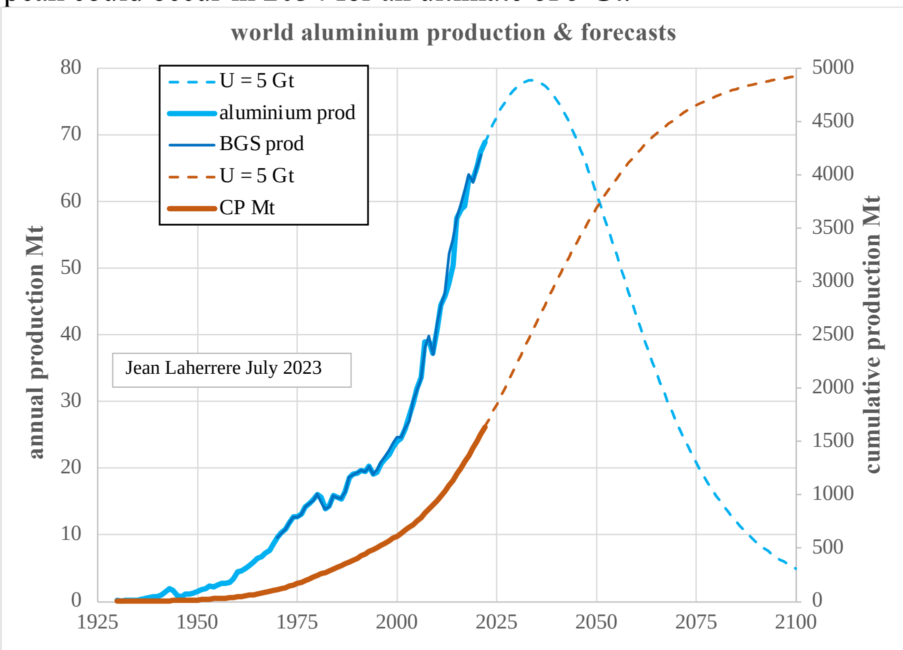
Bauxite peak could occur from 2050 to 2075!



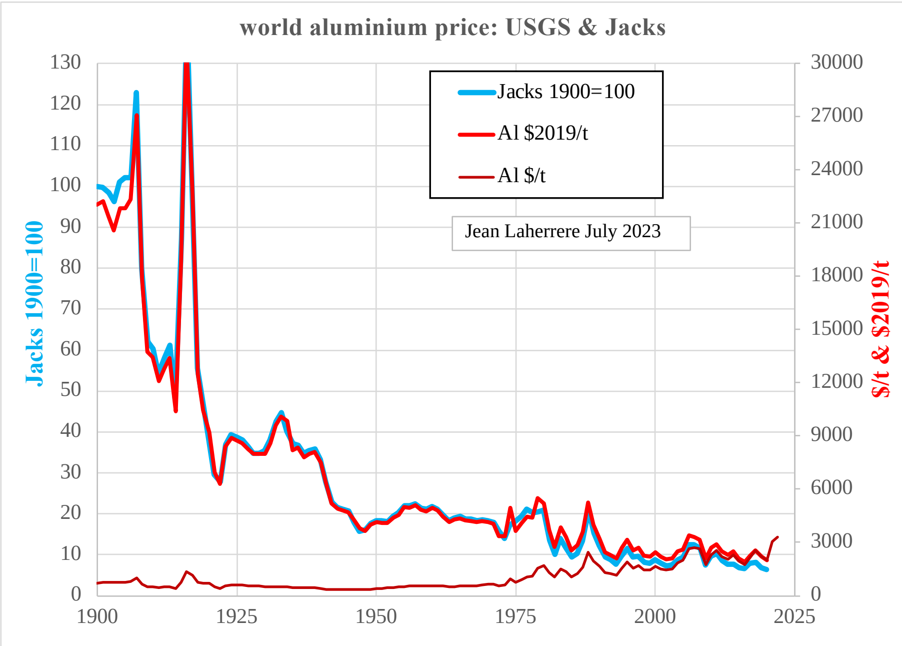
HL of world aluminium production trends for 2015-20211 towards 5 Gt:



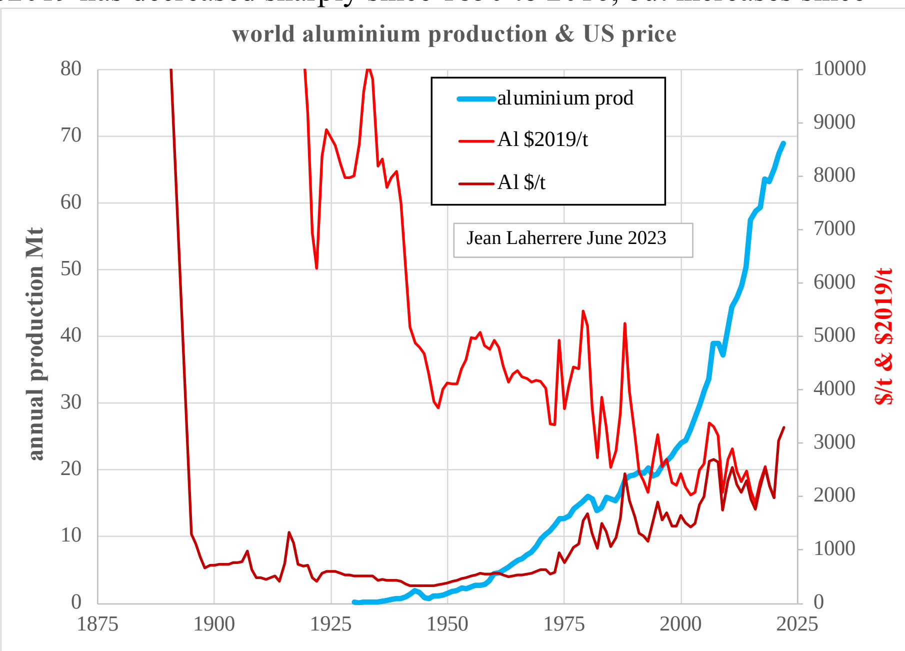
Aluminium peak could occur in 2034 for an ultimate of 5 Gt:



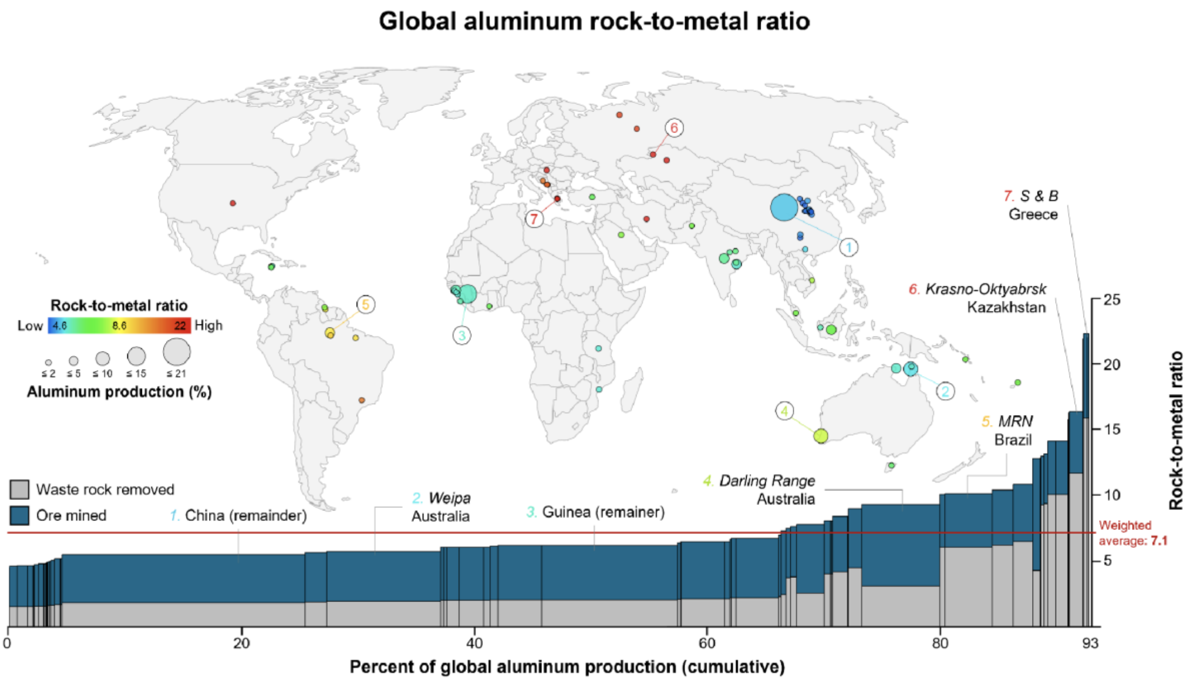
Aluminium price from USGS and Jacks



Al price in $2019 has decreased sharply since 1850 to 2016, but increases since

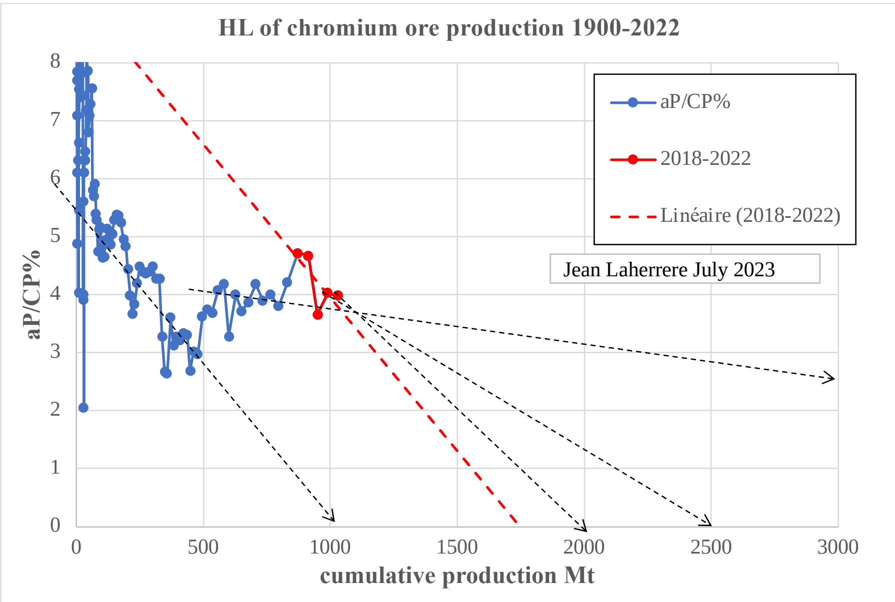


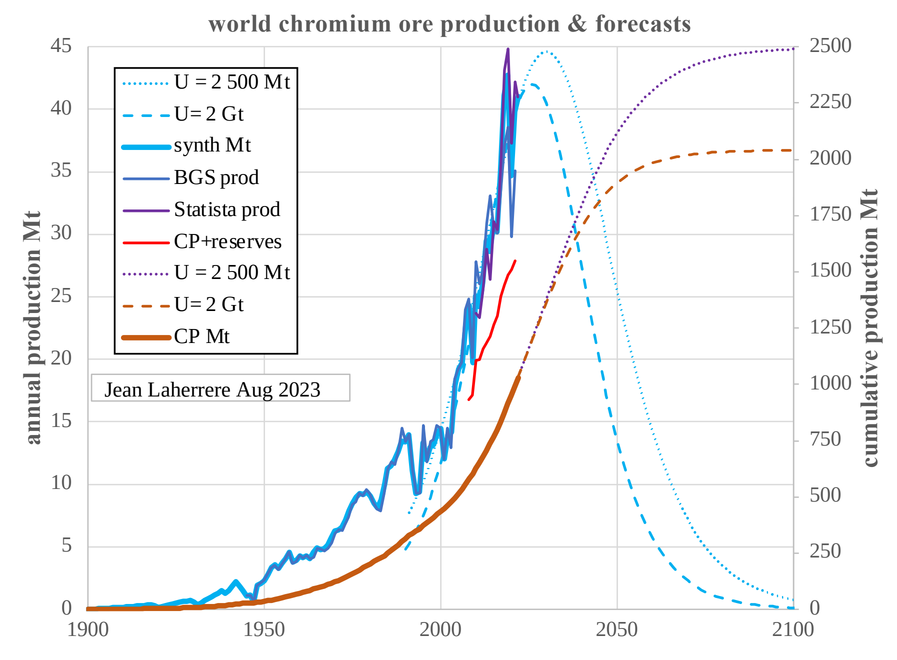
USGS Nassar et al 2022 paper displays the rock to metal ratio with a map and a graph versus percent of production with a weighted average of 7



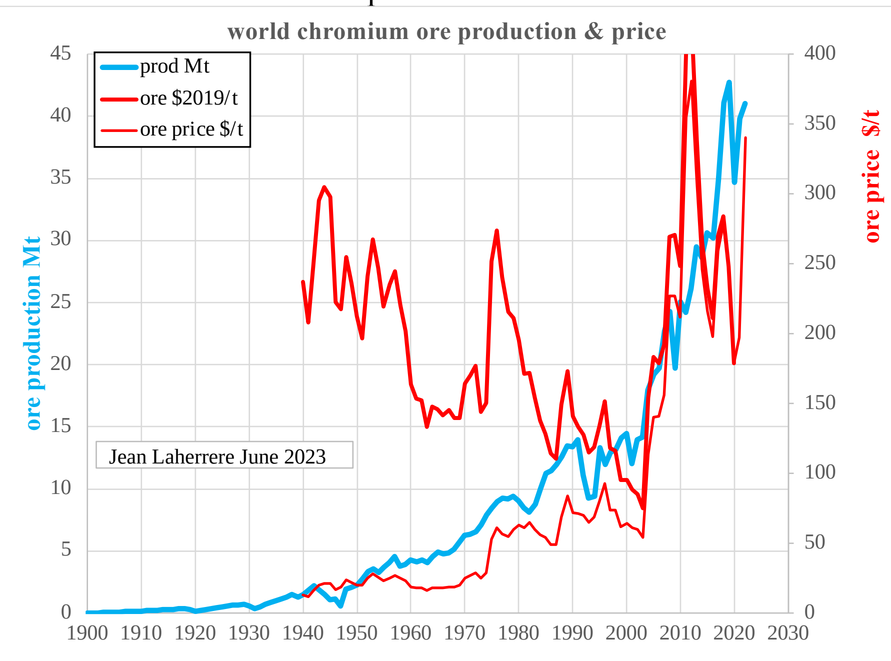
-Chromium

HL of world chromium ore production trends poorly towards1750 Mt for 2018-2022 but before the trend was much higher an ultimate of 2.5 and 2 Gt is taken, giving a past peak in 2019

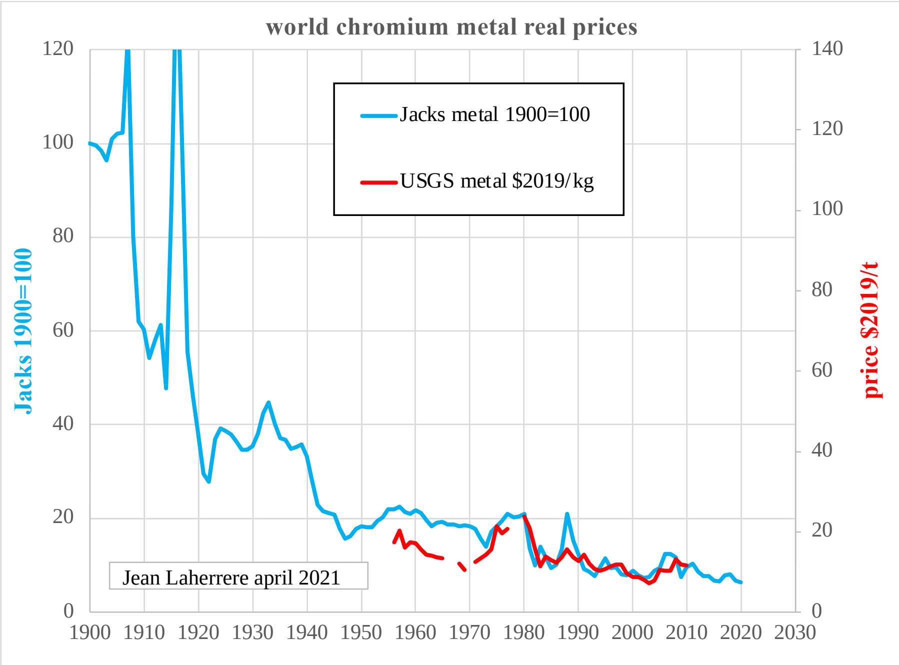




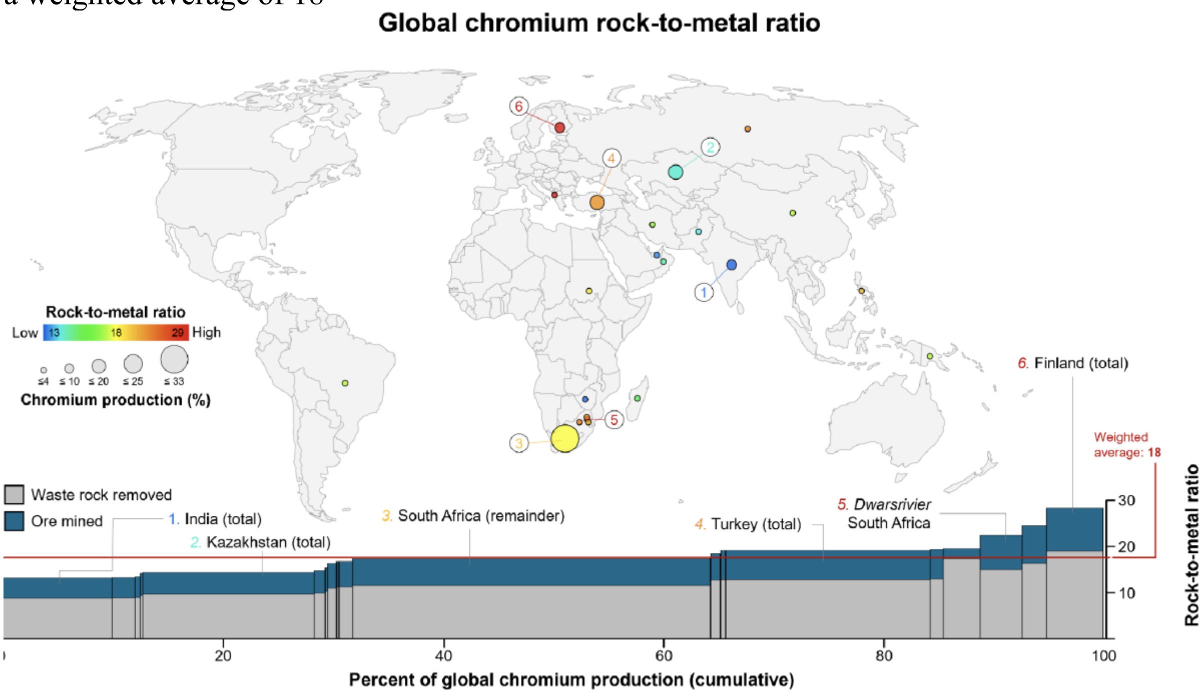
Chromium production sharp increase in 2005 d correlates with a sharp increase in price and the peak of 2019 correlates with a lower price.



But chromium price in 2020 is 10 times lower than the price in 1900

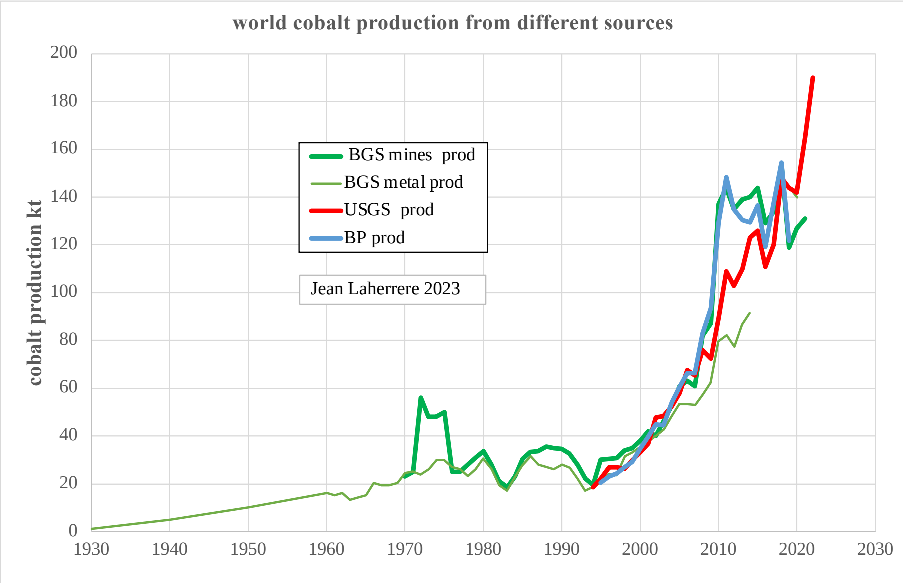


Nassar et al 2022 displays the map and rock to metal ratio versus cumulative production with a weighted average of 18

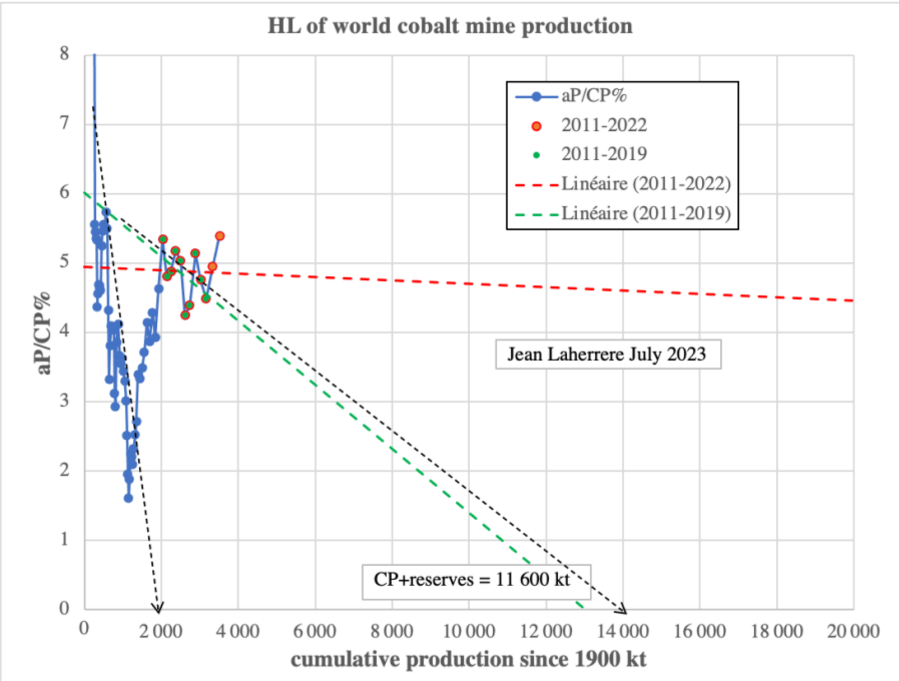


-cobalt

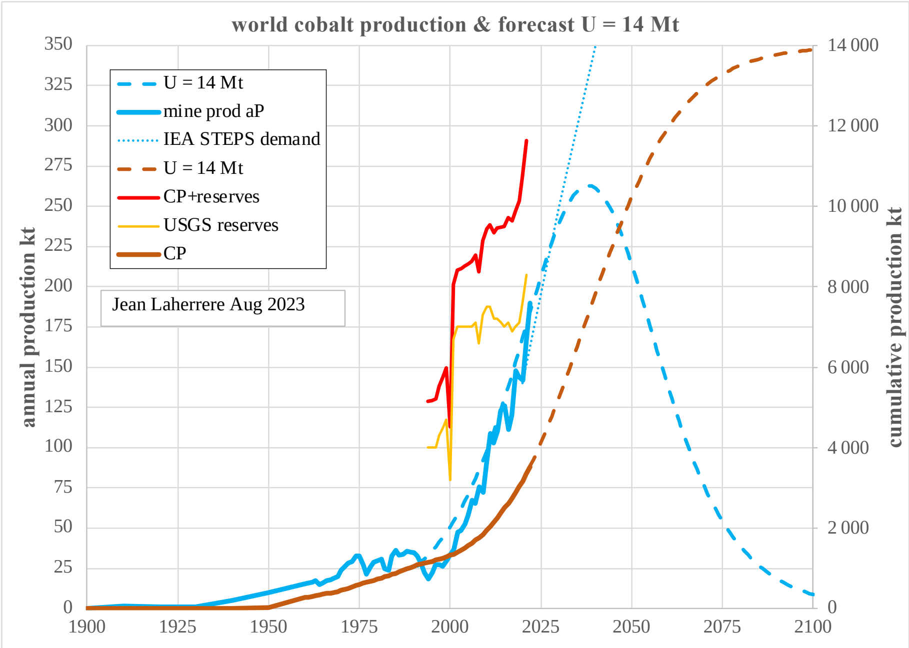
Cobalt production data varies with sources



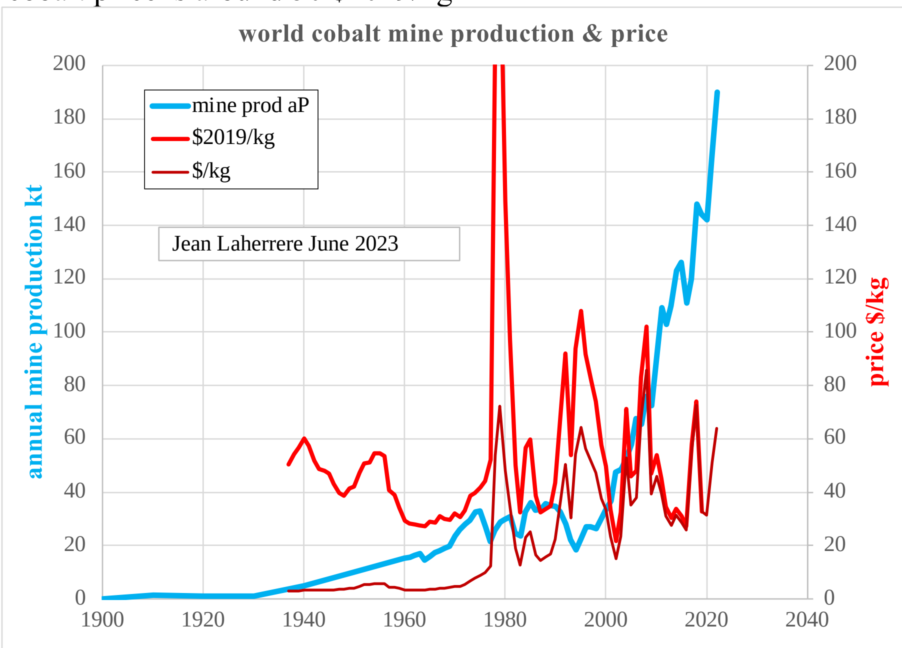
HL of world chromium production for 2011-2019 trends towards 13 Mt but for 2011-2022 towards almost infinite, when CP+reserves is over 11.6 Mt. An ultimate of 14 Mt is taken.



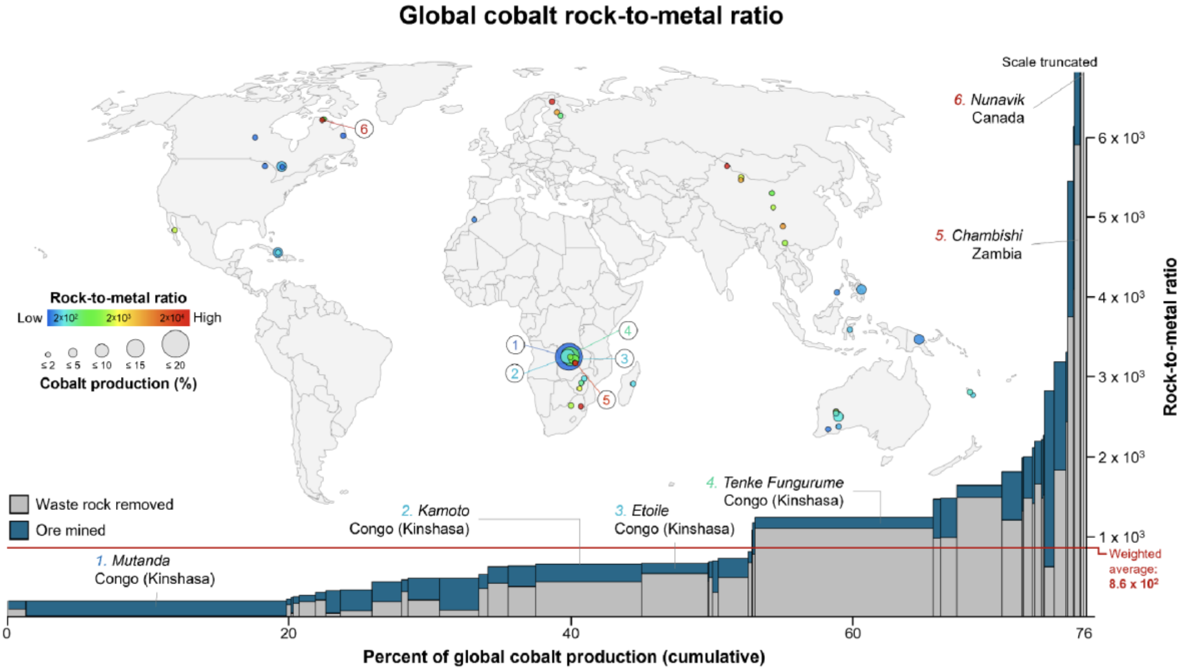
An ultimate of 14 Gt gives a peak in 2038 at 260 kt, but IEA STEPS reports the demand at 350 kt in 2040, meaning that the demand will not be fulfilled.



Since 1940, cobalt price is around 50 $2019/kg

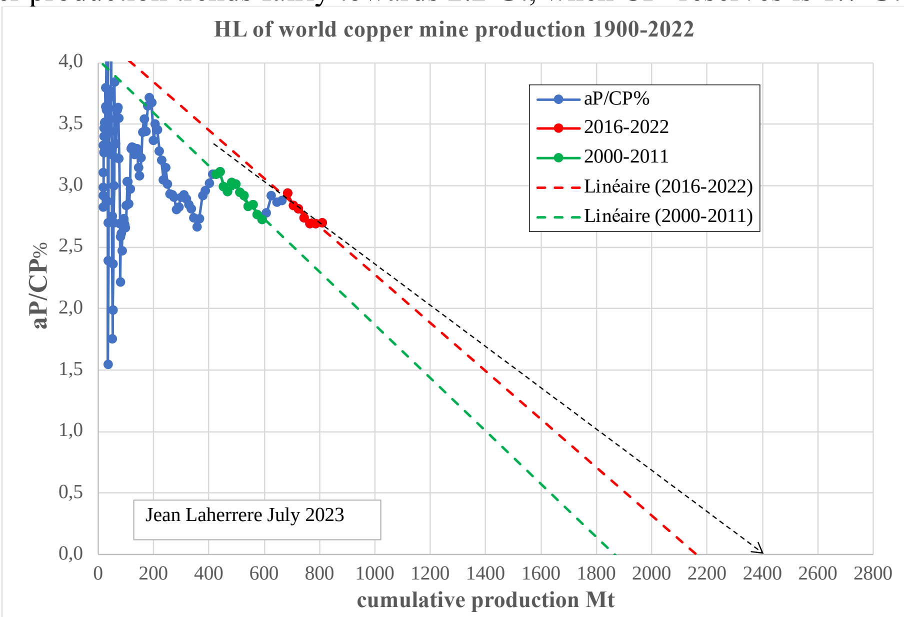


Nassar et al 2022 displays map and rock to metal ratio, with high value in Zambia & Canada. And a weighted average of 860i

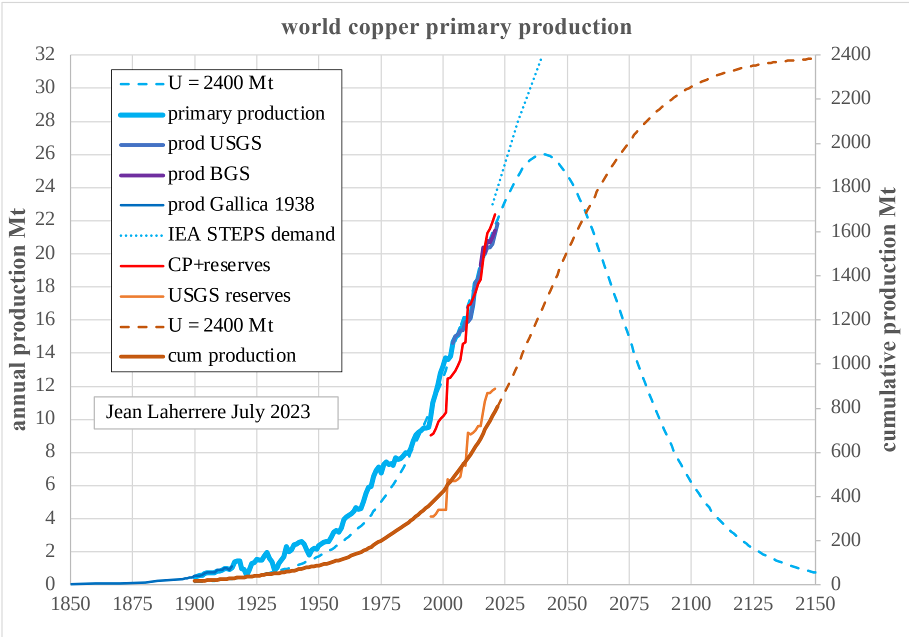


-copper

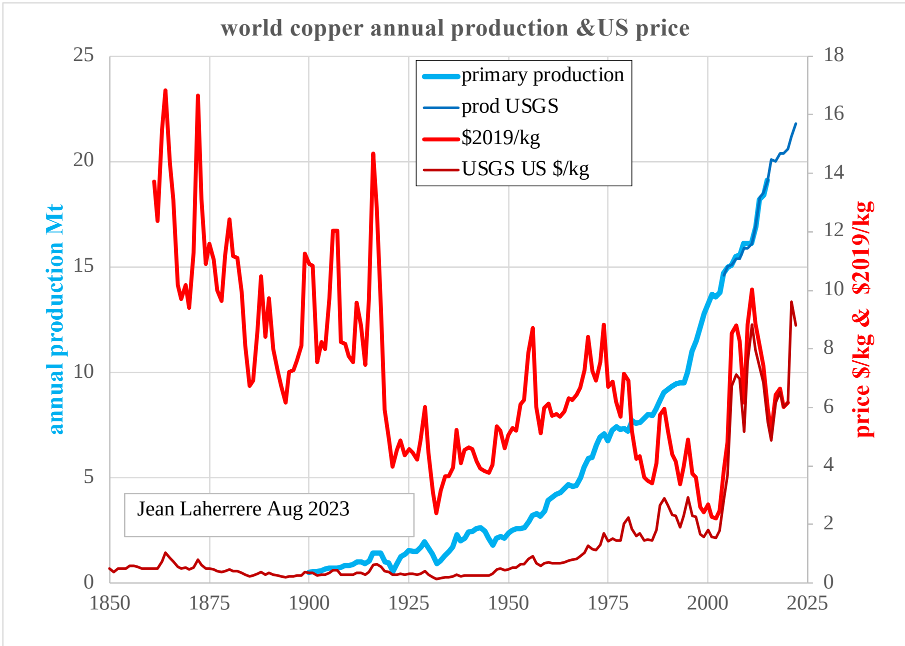
HL of copper production trends fairly towards 2.2 Gt, when CP+reserves is 1.7 Gt



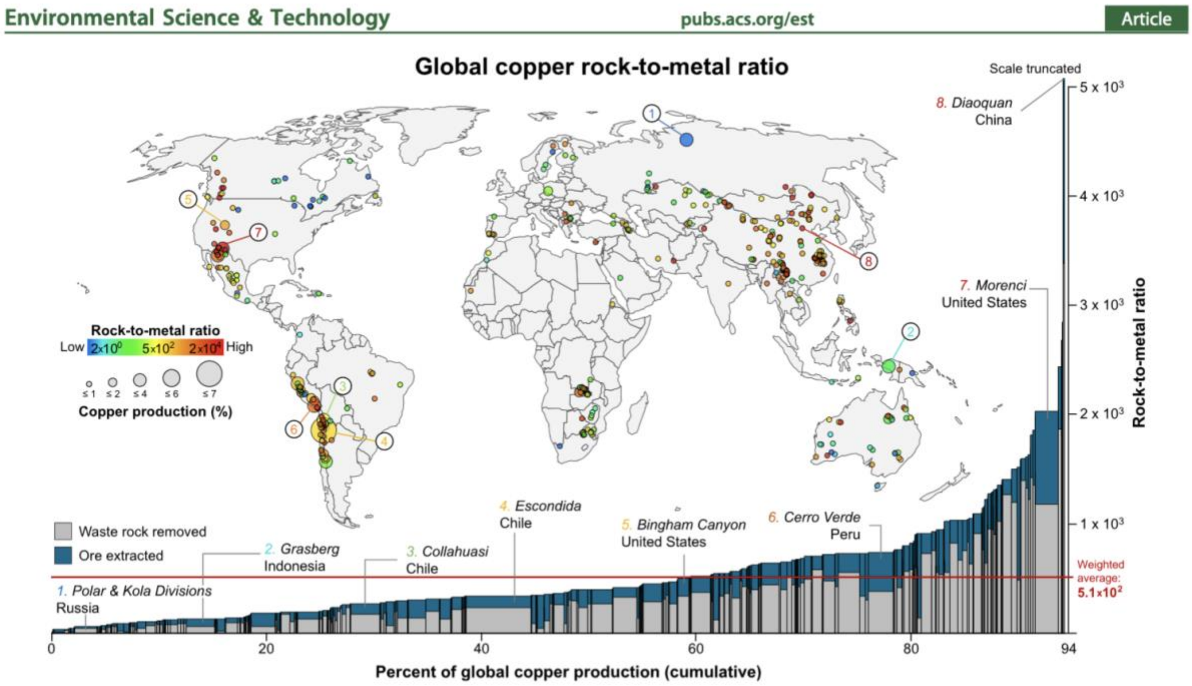
An ultimate of 2.4 Gt gives a peak in 2040 at 26 Mt/a, with a good fit since 1990, but the IEA STEPS scenario reports the demand at 35 Mt in 2040, meaning that copper demand will not be fulfilled!



Copper price in $2019 was high from 1860 to 1918, low in 1920, peak in 1974, 2011 and 2021.

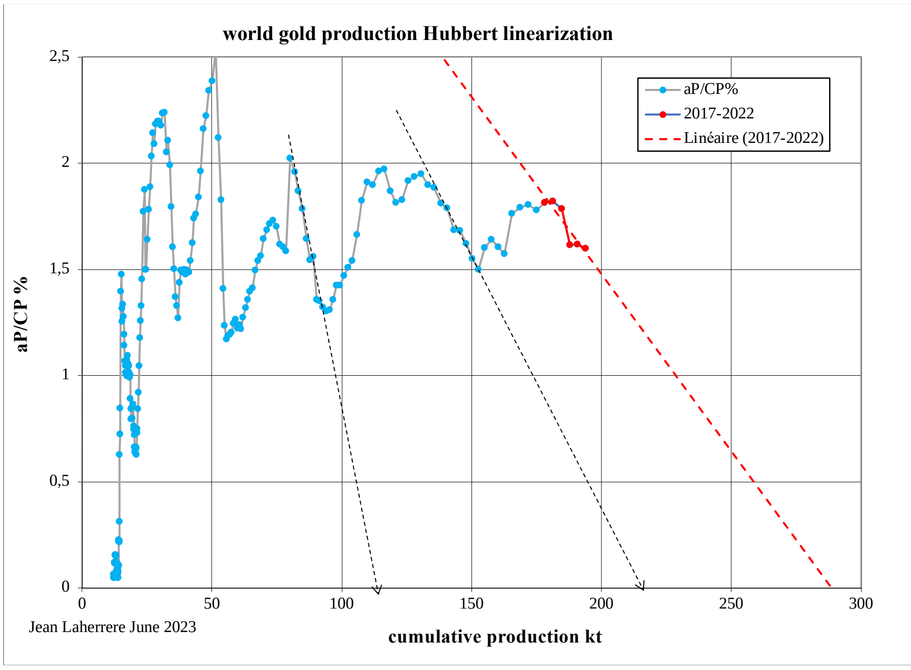


Nasser et al 2022 displays a copper map and the rock to metal ratio versus cumulative production with a weighted average of 500!

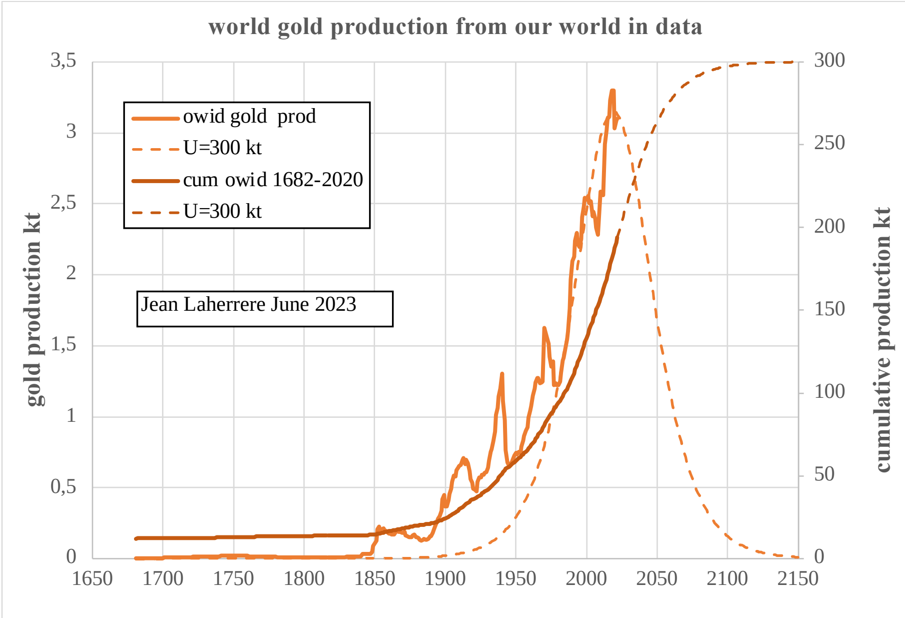


-gold

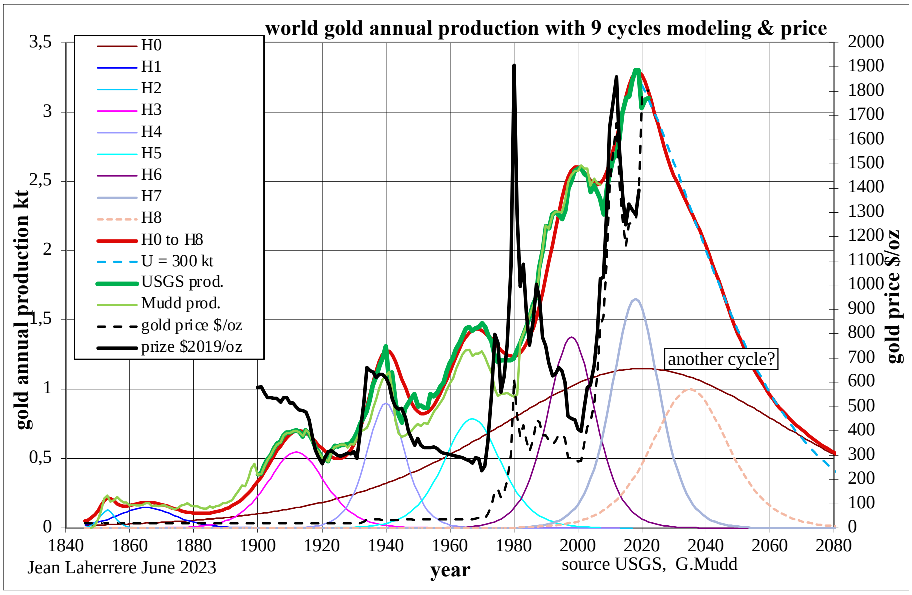
HL of world gold production displays in the past several linear trends and the last one trends towards 300 kt.



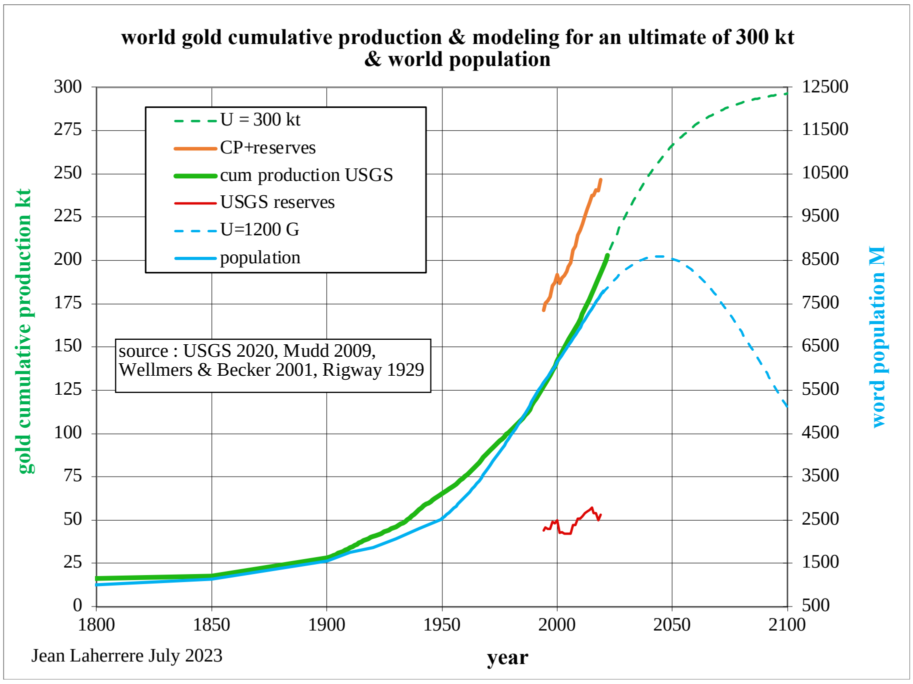
With a 300 kt ultimate, gold peak is in 2019.



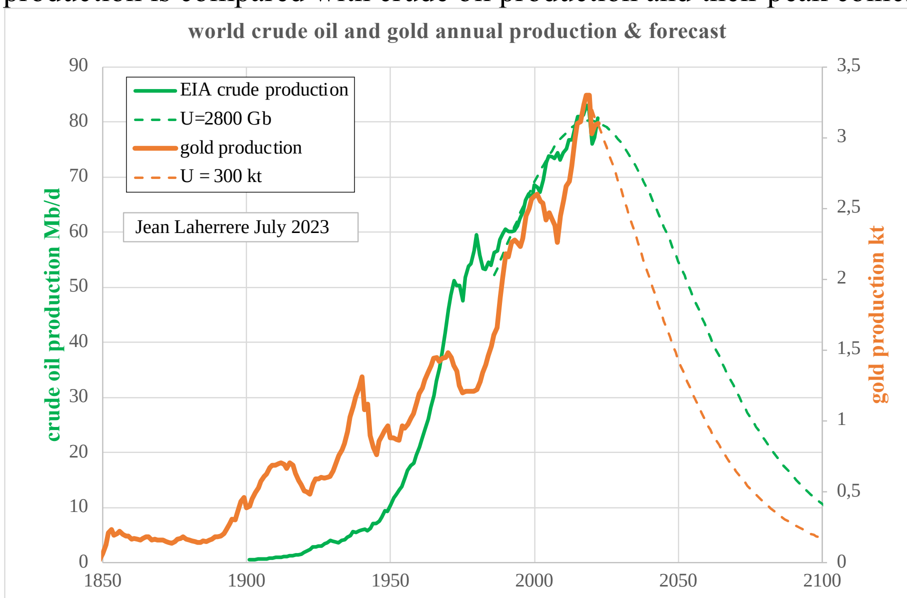
World gold production since 1840 can be modelled with 8 cycles (last one being future) and the total is similar with a 300 kt ultimate.



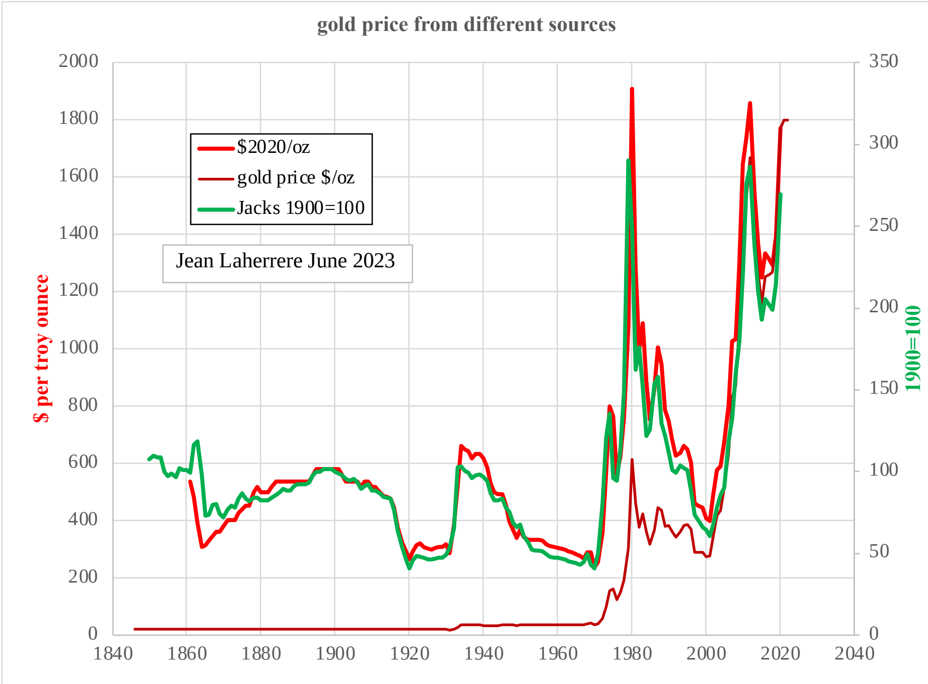
World gold cumulative production is compared with CP+reserves and with world population.



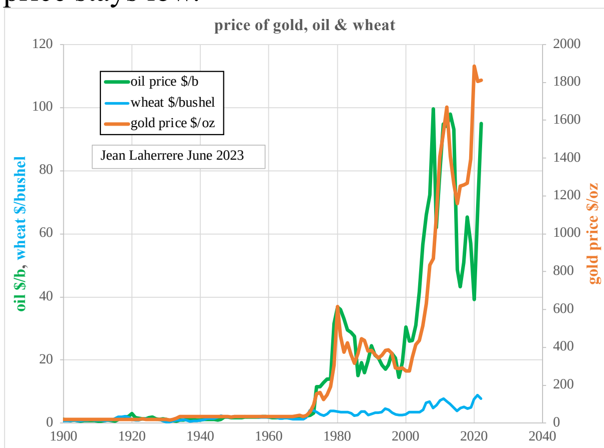
World gold production is compared with crude oil production and their peak coincide!

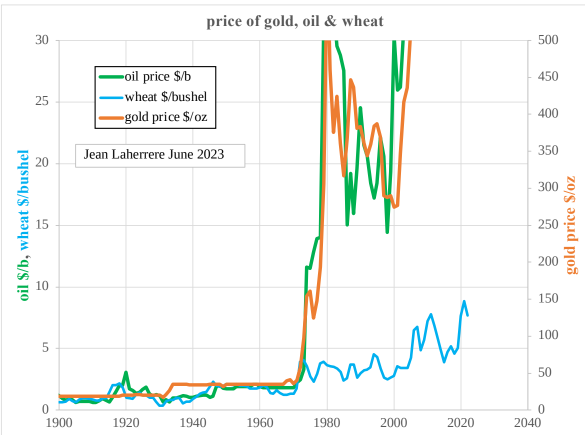


Gold price is displayed in nominal money and in constant money $2020/oz

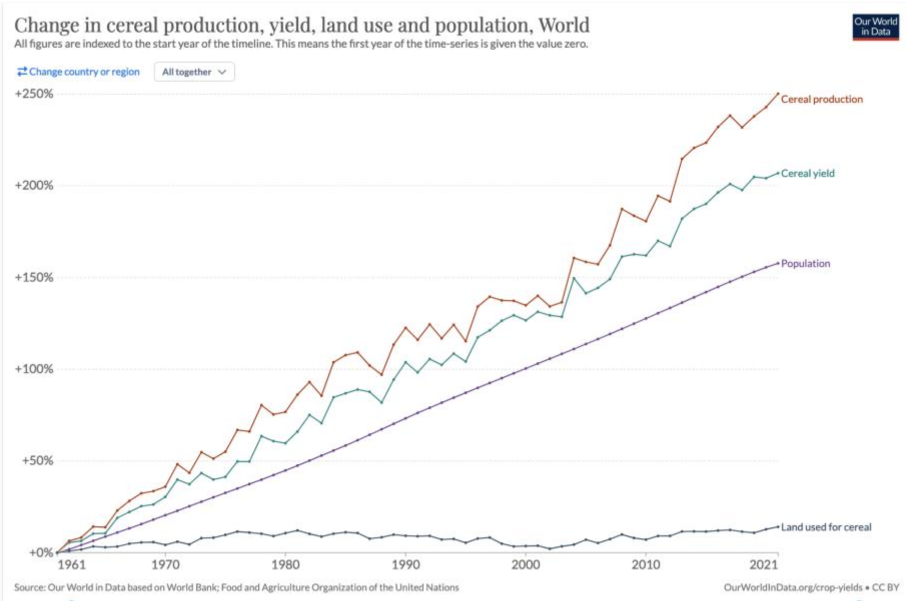


Prices of gold, oil and wheat are compared: from 1900 to 1973 (first oil shock) their evolution was similar: But after 1973 oil and gold price stay together in a sharp increase when wheat price stays low.

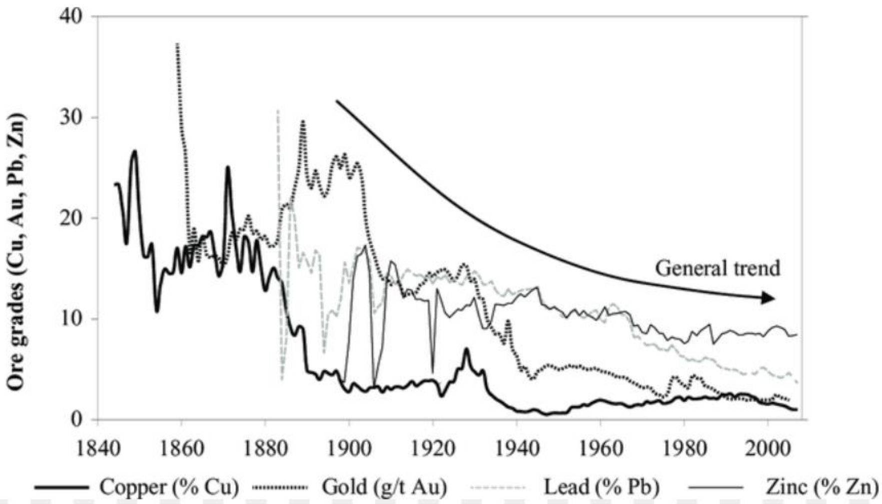




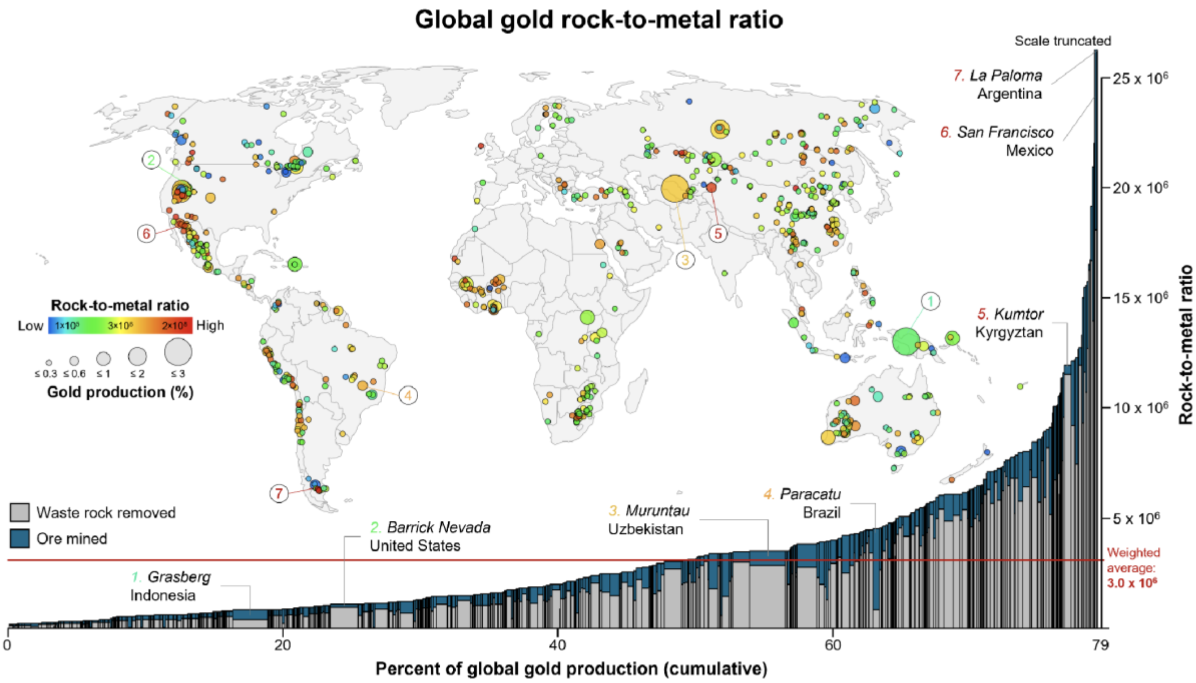
Wheat price stays low because the yield increases very much since 1961 = 200 % thanks to technology, fertilizer and increase in CO_2
https://ourworldindata.org/grapher/index-of-cereal-production-yield-and-land-use



In contrary gold price increases because a sharp decrease in ore grade for copper, gold, lead and zinc:

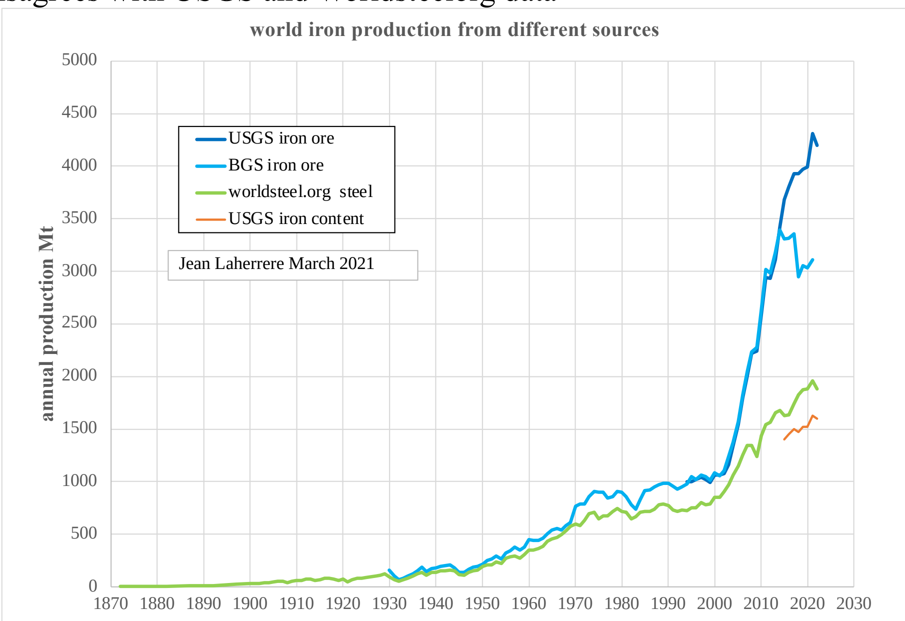


Nassar et al 2022 displays a gold map with the rock to metal ratio versus cumulative production with a weighted average of 3 000 000 = 3 ore tonne for 1 gold g!

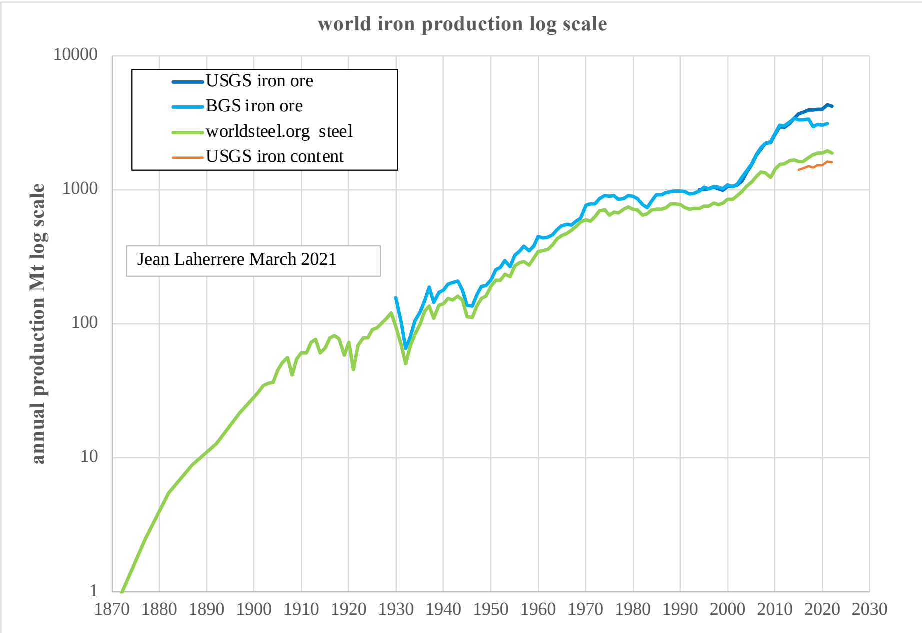


-iron

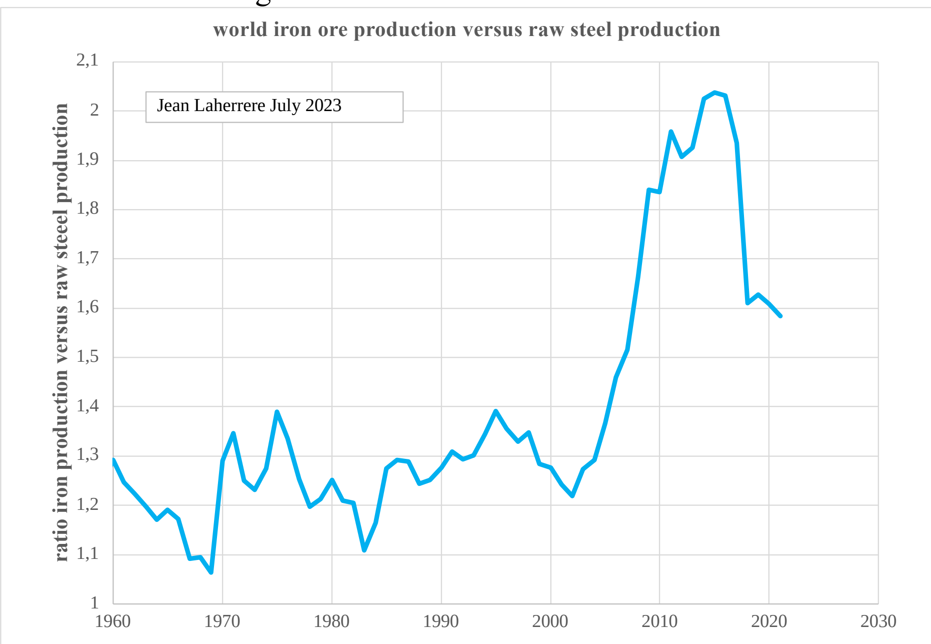
BGS data disagrees with USGS and Worldsteelorg data



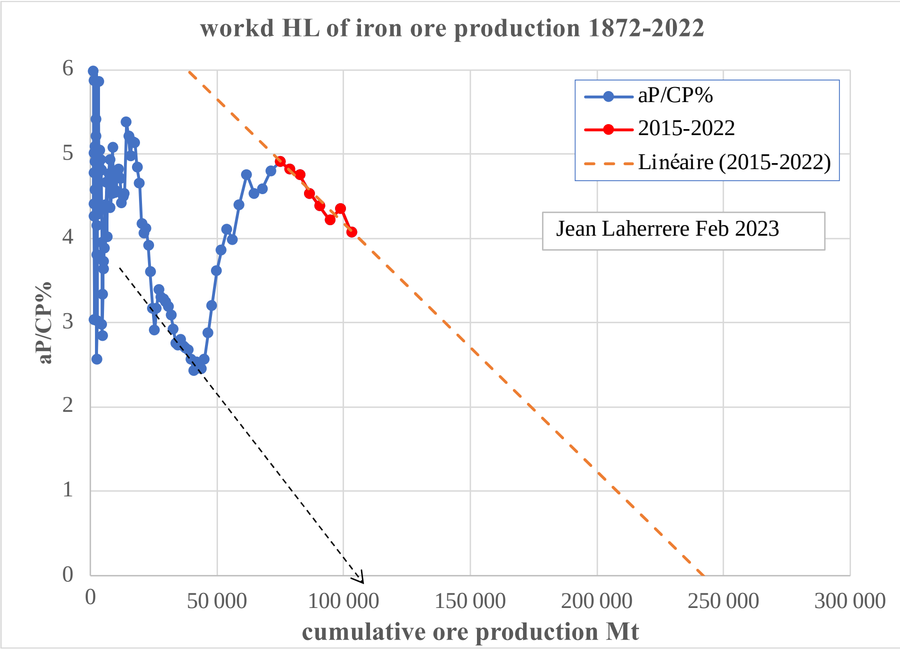
A display of the same graph in log scale is better, showing that growth in the 1880s is similar that growth in the 2000s



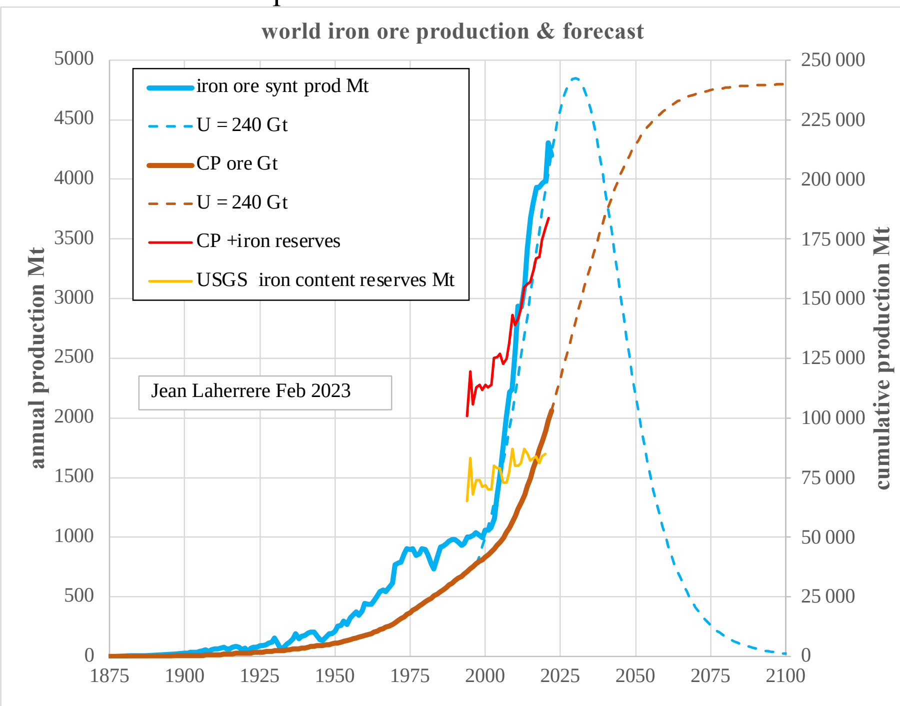
Iron ore production shows a range of 1.1 to 2 times raw steel.



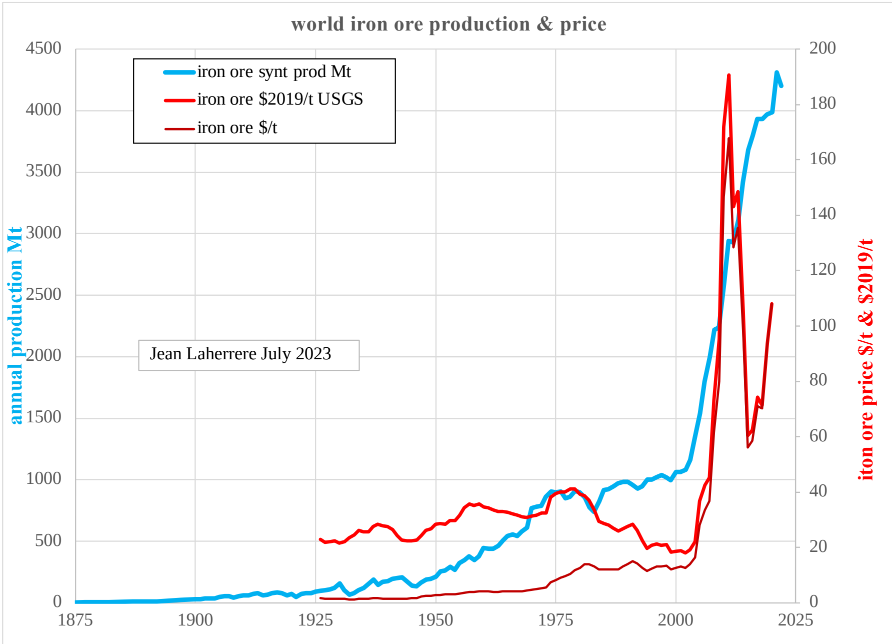
HL of world iron ore production trends (2015-2022) fairly towards 240 Gt, when CP+reserves equal 180 Gt.



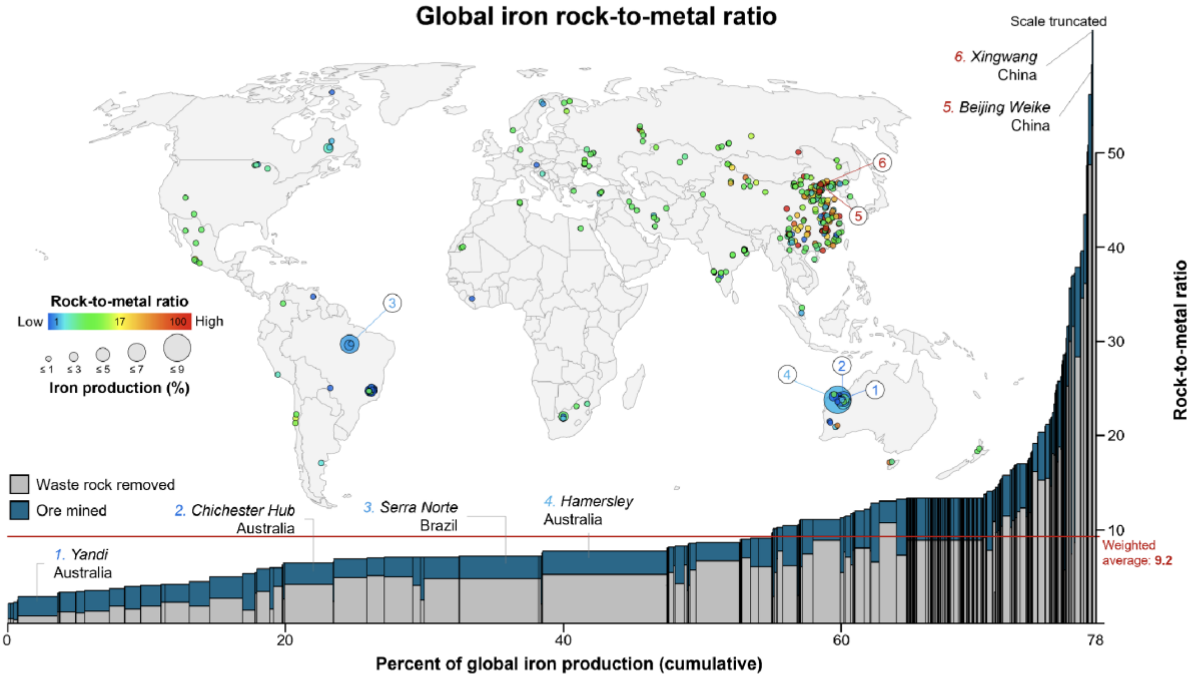
A 240 Gt ultimate means an iron peak in 2030.



The sharp iron ore production increase since 2001 correlates with a sharp increase in price, this price increase ends in 2011 followed by a decrease in iron production in 2021

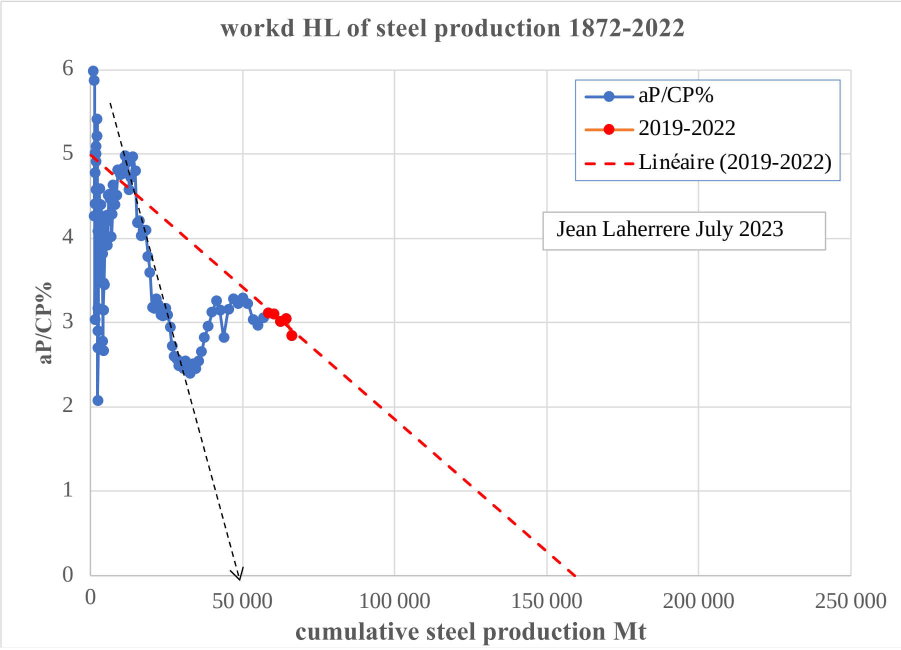


Nassar et al 2022 displays a map and rock to metal ratio with a weighted average of 5

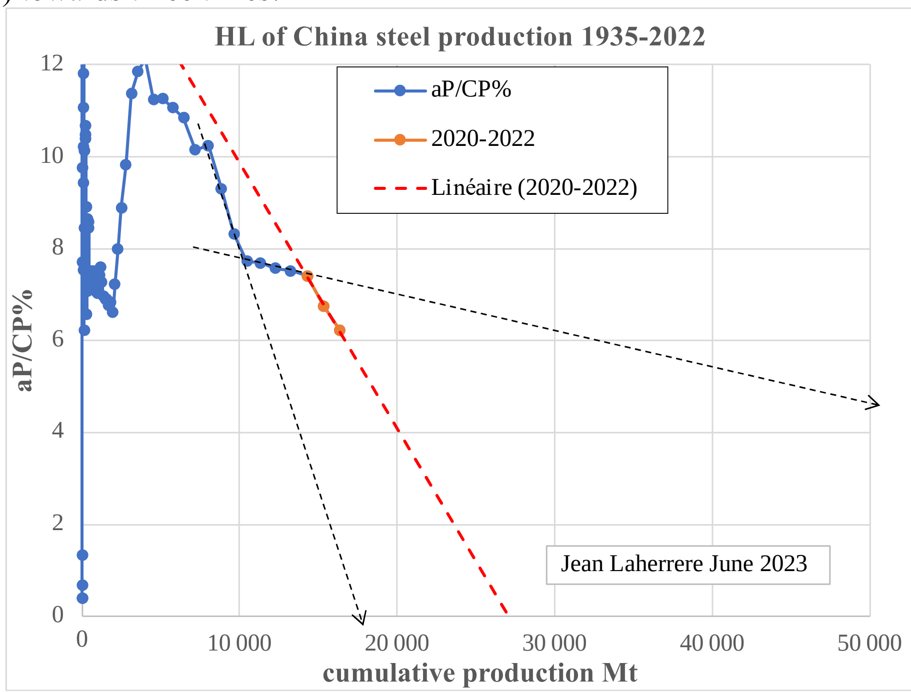


-steel

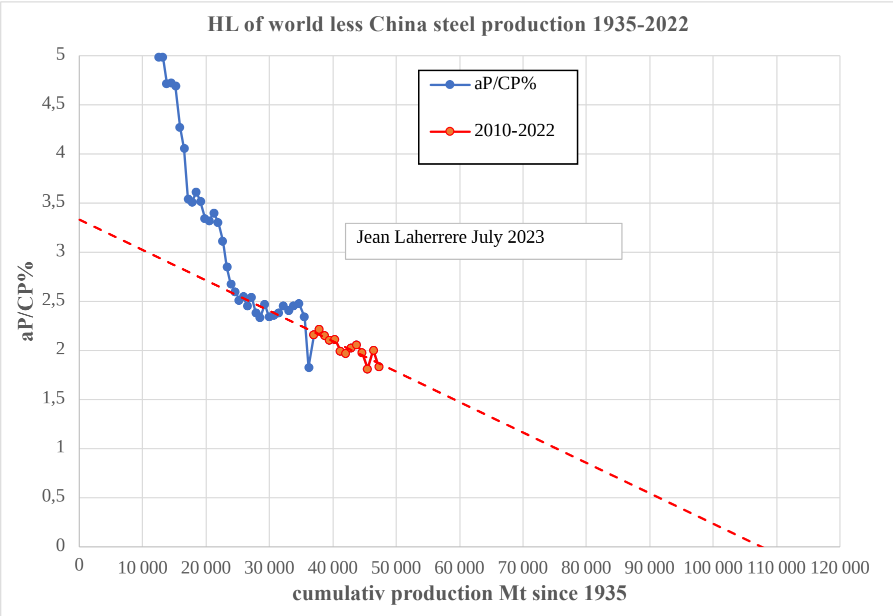
HL of world steel production (2019-2022) trends poorly towards 160 Gt:



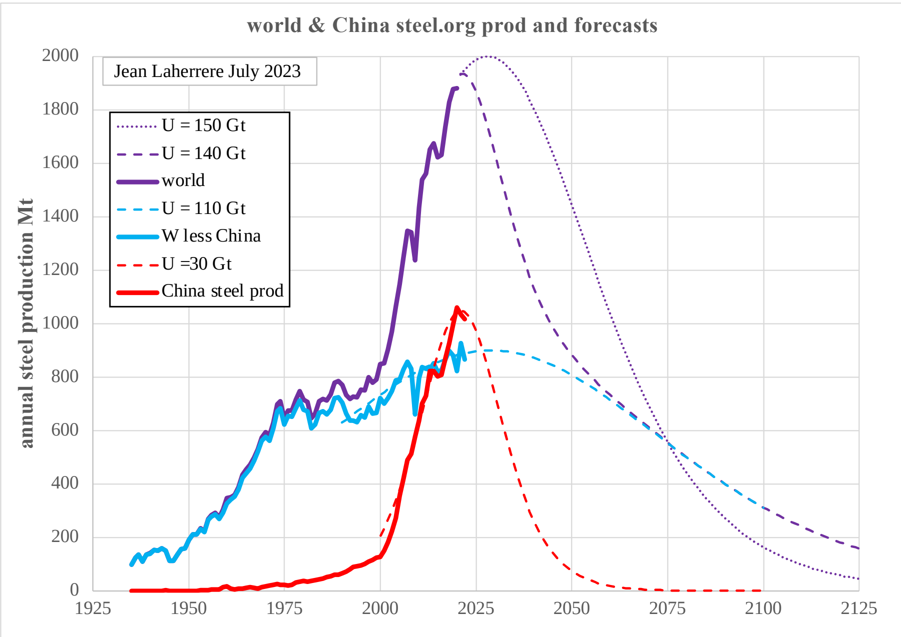
HL of China steel production is erratic, but trending (2020-2022) towards 28 Gt when before (2016-2019) towards three times!



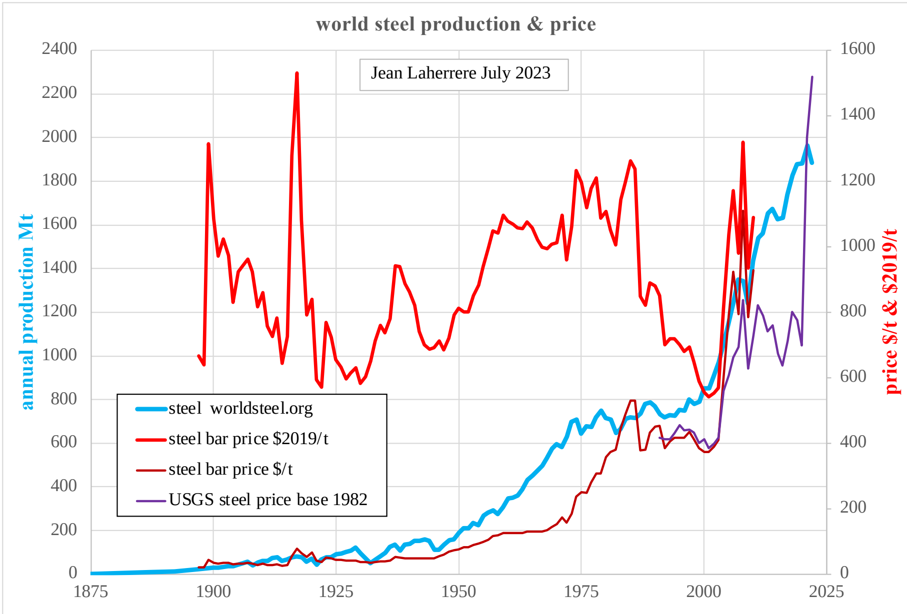
HL of world less China iron production trends towards 110 Gt



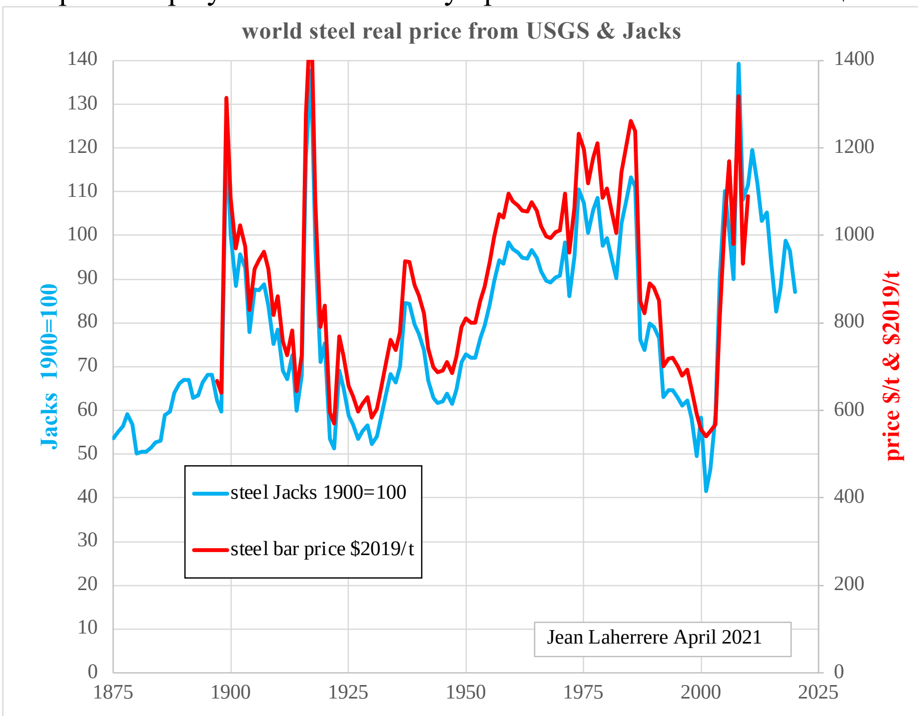
For these ultimates, steel production will peak in 2021 for China, in 2029 for world less China and about 2023-2028 for the world



World steel production correlates with steel price from 1947 to 2011.

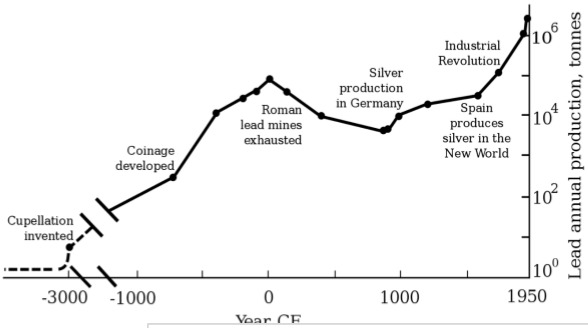


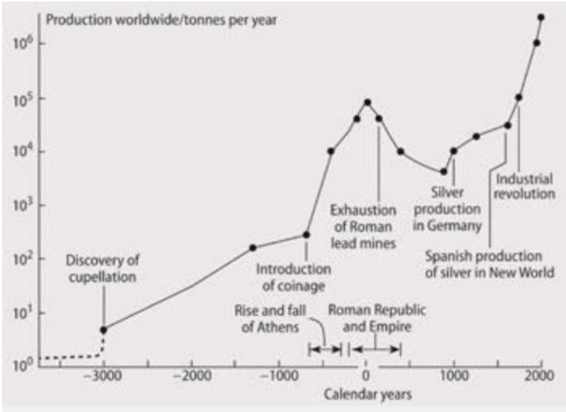
World steel real price displays since 1875 many ups and downs around 1000 $/t

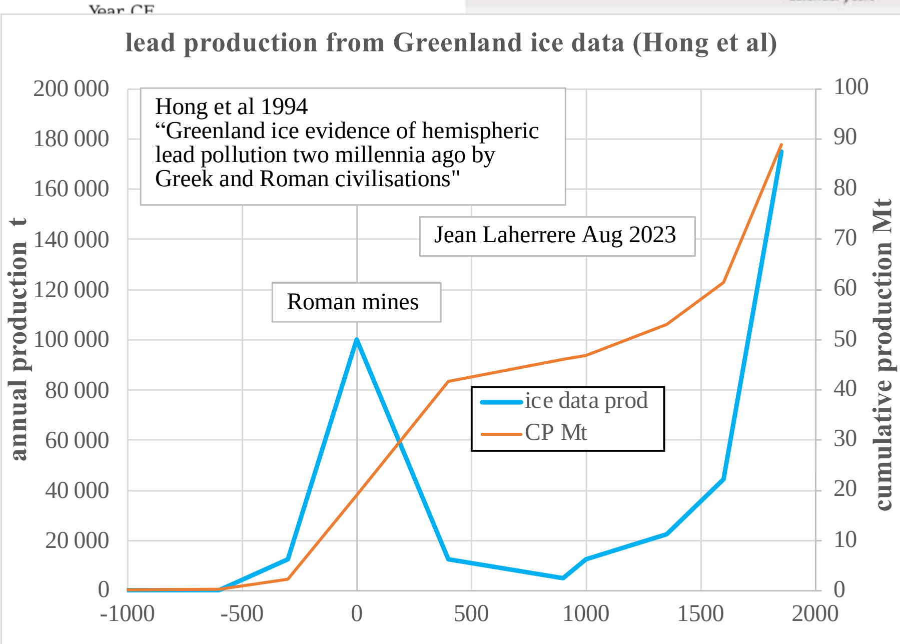


-lead

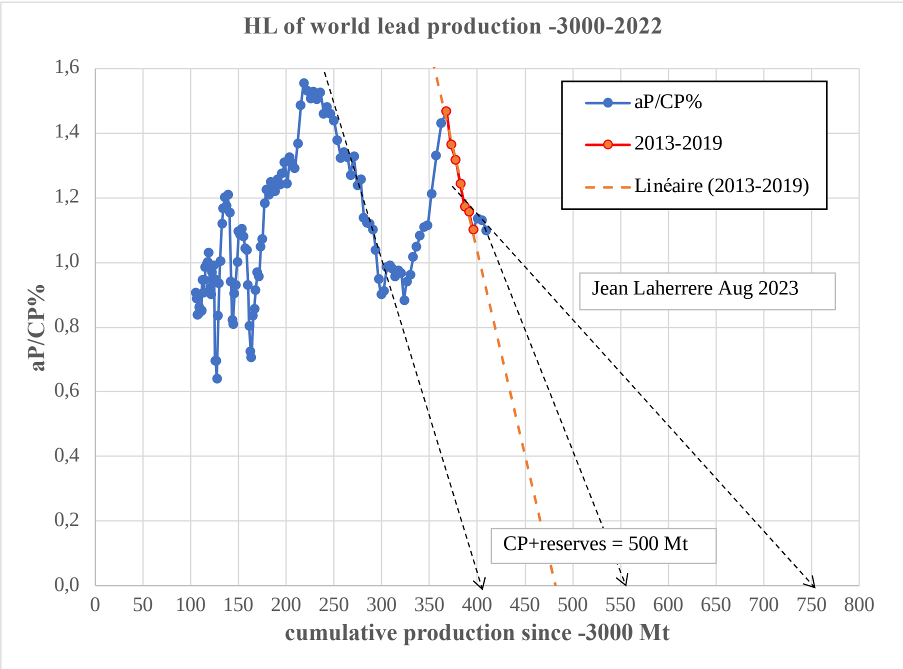
Lead is mined since a long time, as shown by “Greenland ice evidence of hemispheric lead pollution two millennia ago by Greek and Roman civilisations” S Hong, JP Candelone, C C. Paterson, C B. Boutron 1994



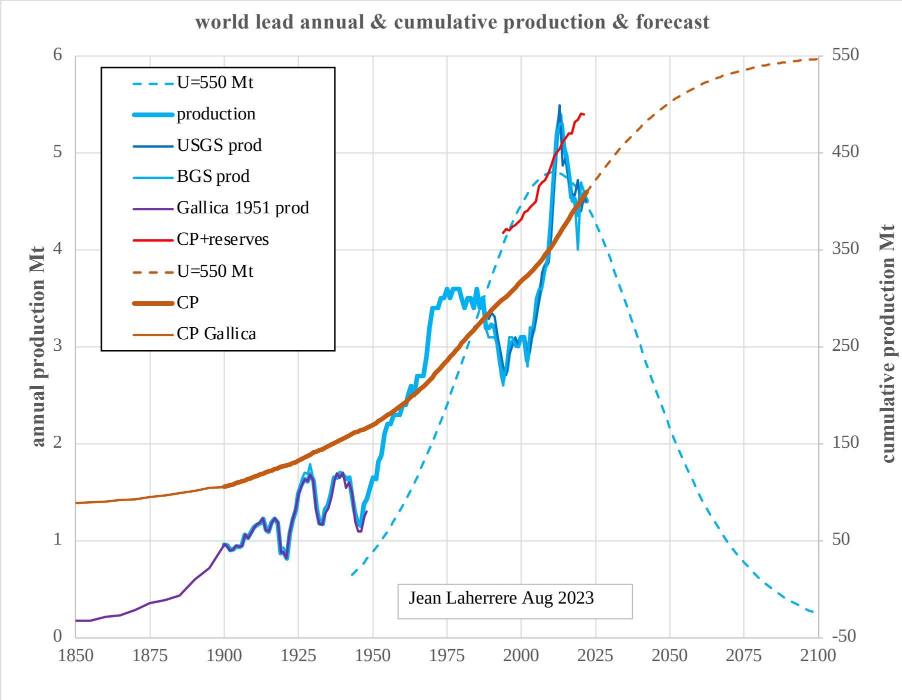




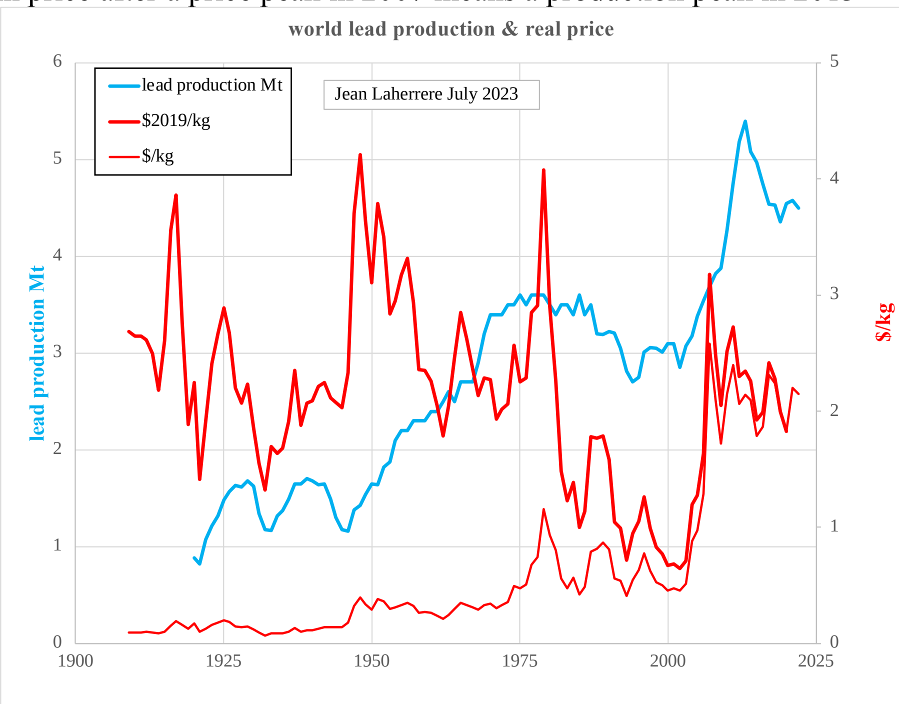
HL of world lead production is erratic and an ultimate of 550 Mt is taken in line with CP+reserves of 500 Mt



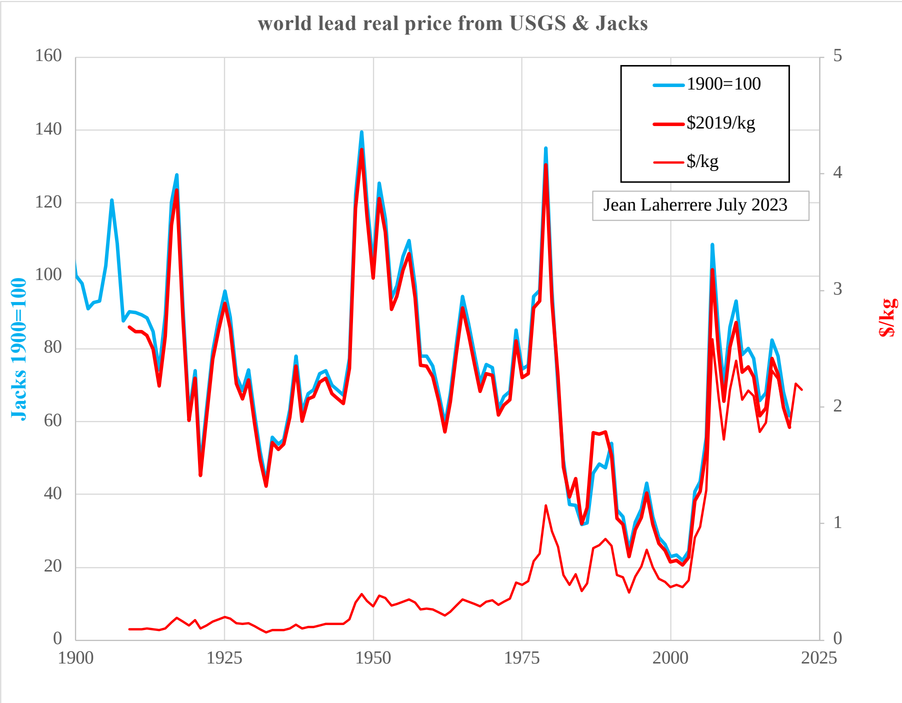
550 Mt ultimate means a peak in 2013



The sharp increase in lead price from 2004 is followed by a sharp increase in production, but the decline in price after a price peak in 2007 means a production peak in 2013

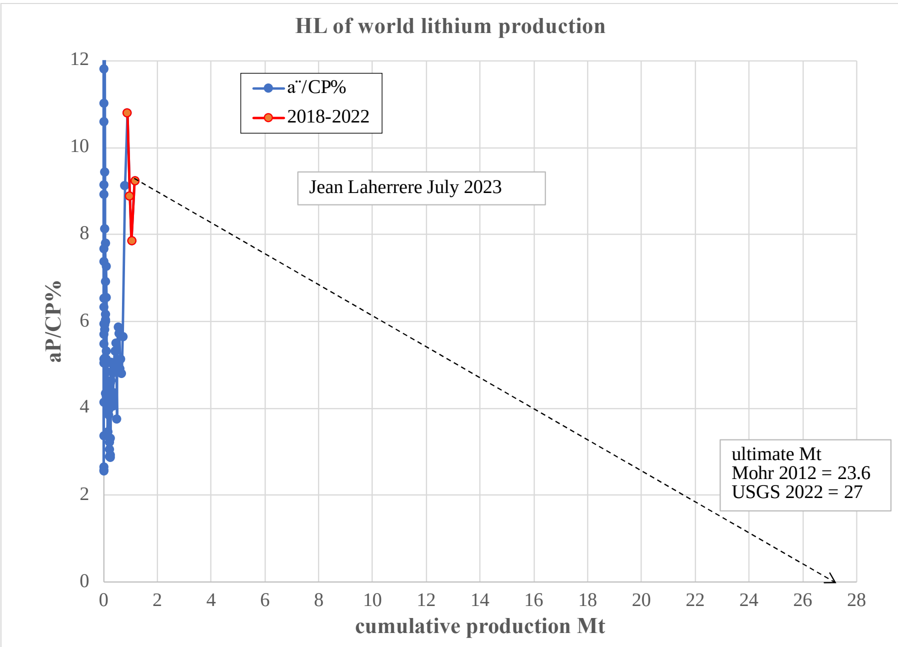


Lead $2019/kg price is compared with Jacks 1900=100

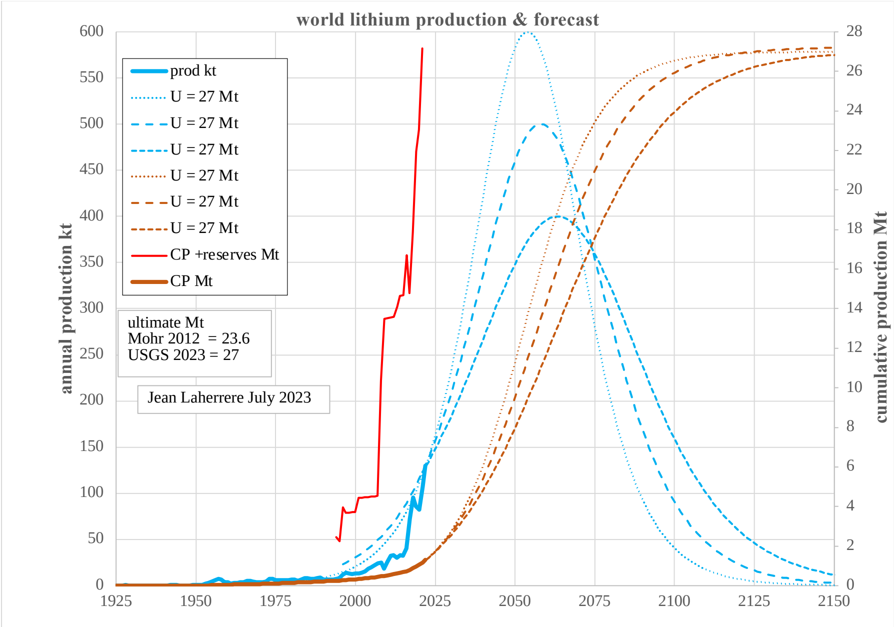


-lithium

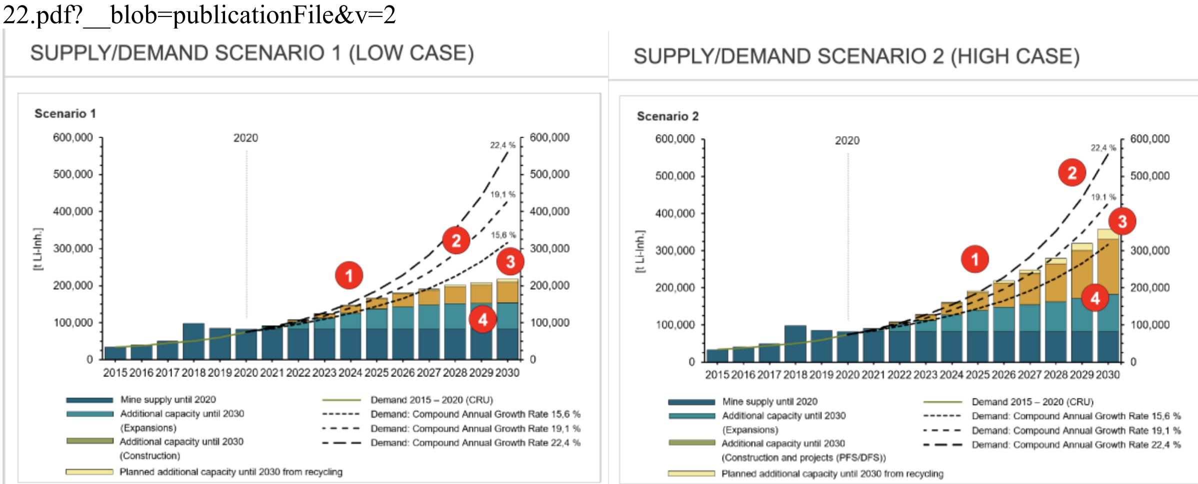
HL is useless and USGS CP+reserves = 27 Mt is used as ultimate



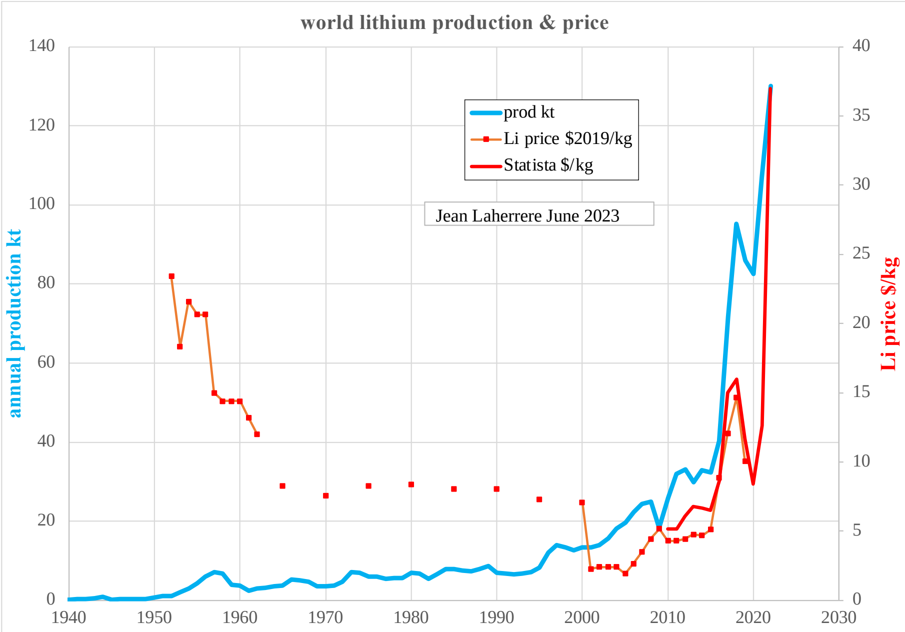
27Mt ultimate, taking as peak 400 kt, 500 kt and 600 kt: the middle one looks the most likely with a peak in 2058 at 500 kt



BGR's forecast for 2030 is for low case 0.22 kt and for high case 0.33 kt: Michael Smith 2022
https://www.deutsche-rohstoffagentur.de/DERA/DE/Downloads/vortrag-lithium-schmidt-22.pdf?__blob=publicationFile&v=2

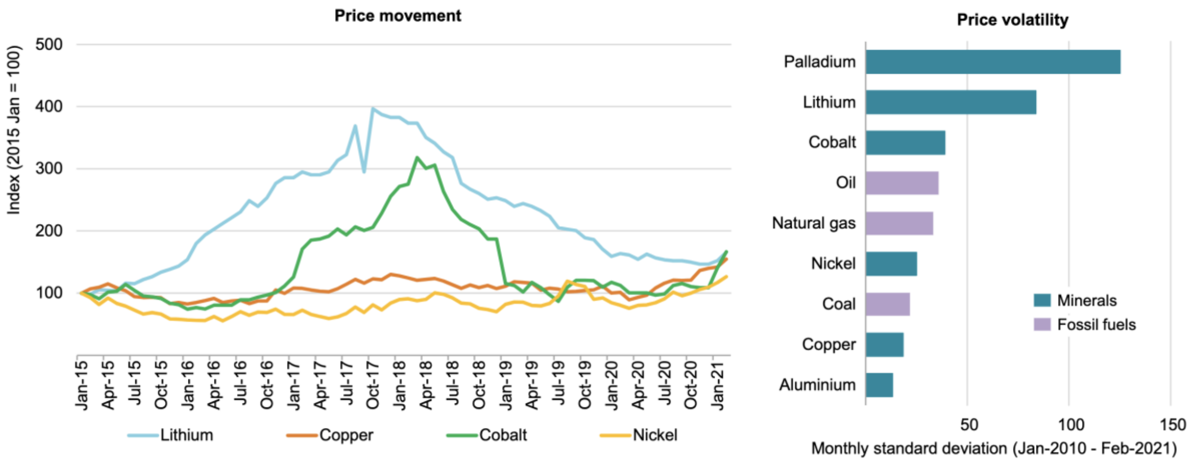


Lithium production correlates well with lithium price, with sharp increase since 2006, a peak in 2018 and a low in 2020:



Lithium price is very volatile from IEA 2021

Price movement and volatility of selected minerals



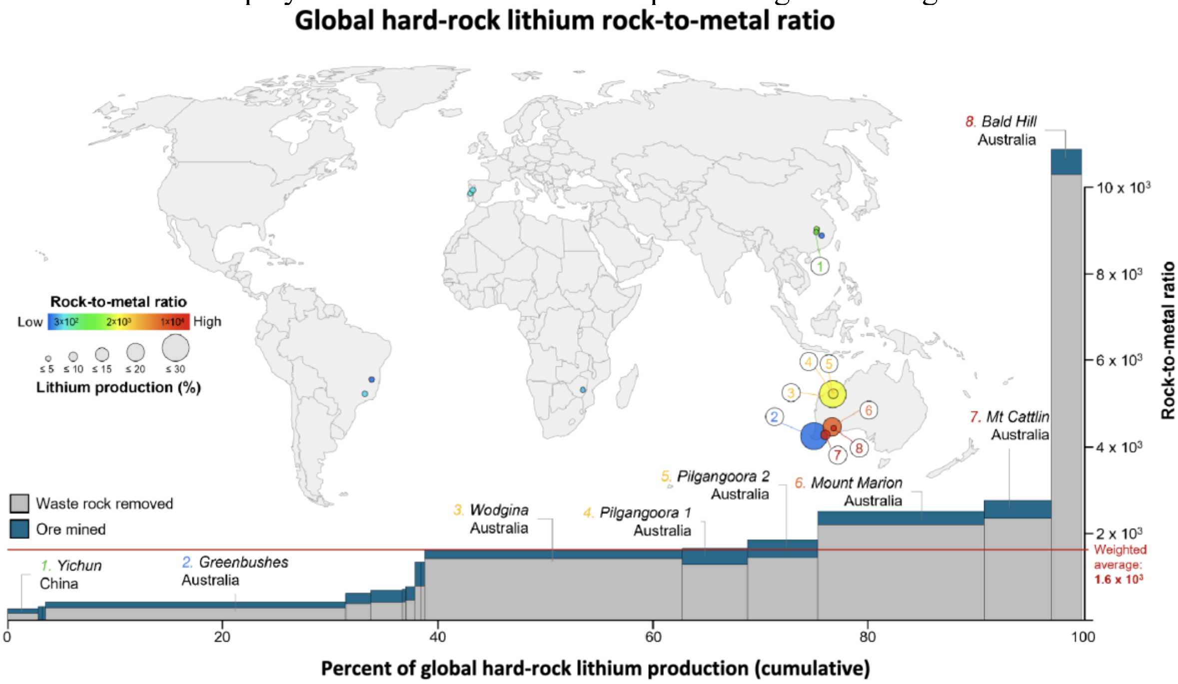
Lithium production is related with lithium batteries in electric cars, but the problem of Li batteries is that they may explode:
Institute for energy research July 2023
So far this year, there have been 108 lithium-ion battery fires in New York City, which have injured 66 people and killed 13, up from 98 fires that had injured 40 and killed two at this time last year. The most recent was a fire at an e-bike shop that killed four people near midnight on the morning of June 21 and left two individuals in critical condition and one firefighter with minor injuries. According to Fire Commissioner Laura Kavanagh, it was "very clear" that the fire was linked to lithium-ion batteries, and she warned New Yorkers that such devices could be very dangerous and typically exploded in such a way that rendered escape impossible, as opposed to slowly catching on fire.

Burning Questions: Unraveling the Truth Behind Electric Vehicle Fires in Maritime Shipping
Mike Schuler August 11, 2023

The Fremantle Highway, a pure car and truck carrier (PCTC) chartered by "K" Line, caught fire off the coast of the Netherlands last month while transporting some 3,800 new cars, including nearly 500 were EVs. While the cause of the fire is under investigation, there is speculation that it may have started from an EV battery.

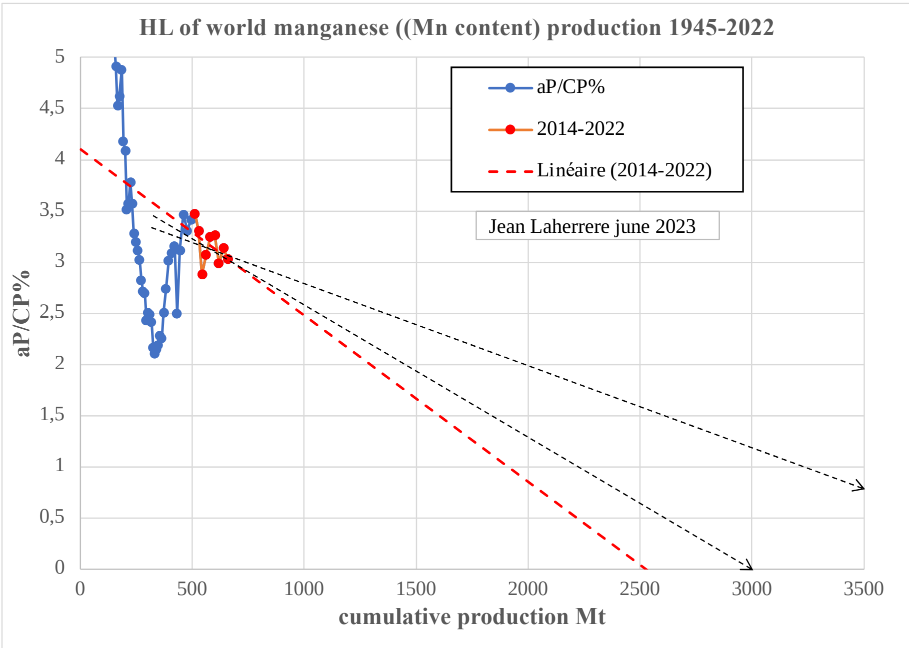
The security of LI batteries could be a serious problem for insurance.

Nassar et al 2022 displays the rock to metal ratio map and weighted average of 1600

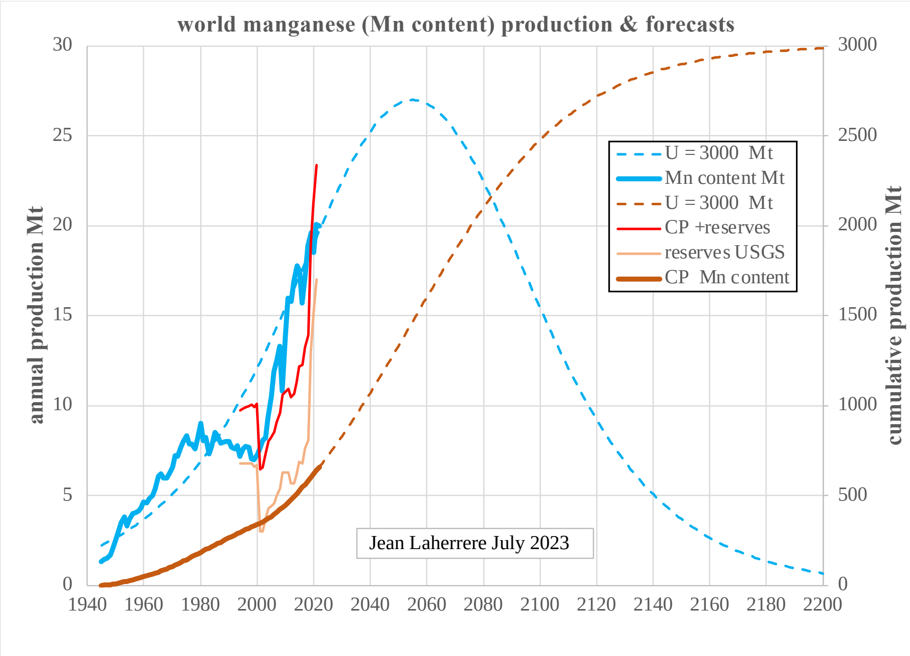


-manganese Mn

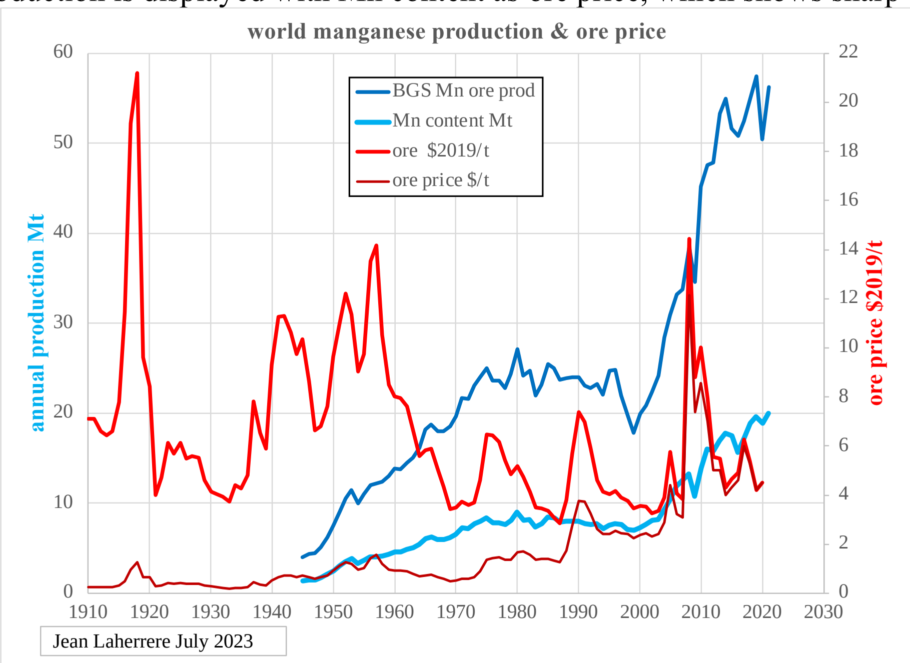
HL of Mn production trends (2014-2022) poorly towards 2500 Mt when CP+reserves = 2350 Mt. A 3000 Mt is taken.



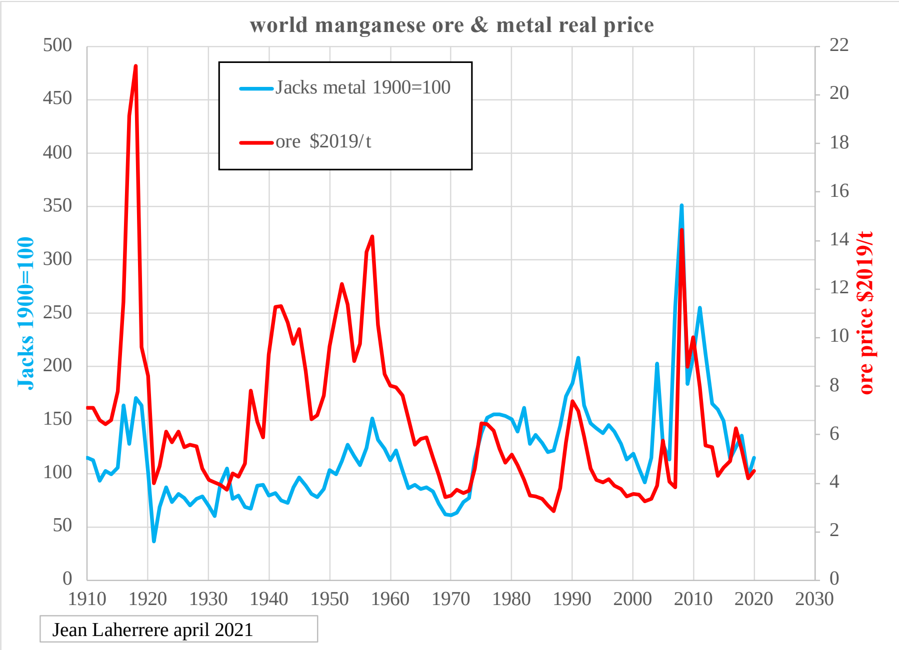
A 3 Gt ultimate means a peak in 2055



BGS ore production is displayed with Mn content as ore price, which shows sharp bursts:



Jacks metal 1900=100 is compared with real ore price $2019/kg



South Africa is the largest producer 37%

USGS	2021	Mn prod Mt	%	reserves Mt	%
	world	20,1	100	1700	100
	South Africa	7,2	37	640	38
	Gabon	4,3	22	61	4
	Australia	3,3	17	270	16
	China	1,0	5	280	16
	Ghana	0,9	5	13	1
	Brazil	0,5	3	270	16

-mercury Hg

Mercury production is reported beginning in 1500 associated with silver mining in Spanish America, but Romans operated a mercury mine in Spain.

https://mercurypolicy.scripts.mit.edu/blog/?p=367

History Of Mercury Use in Products and Processes

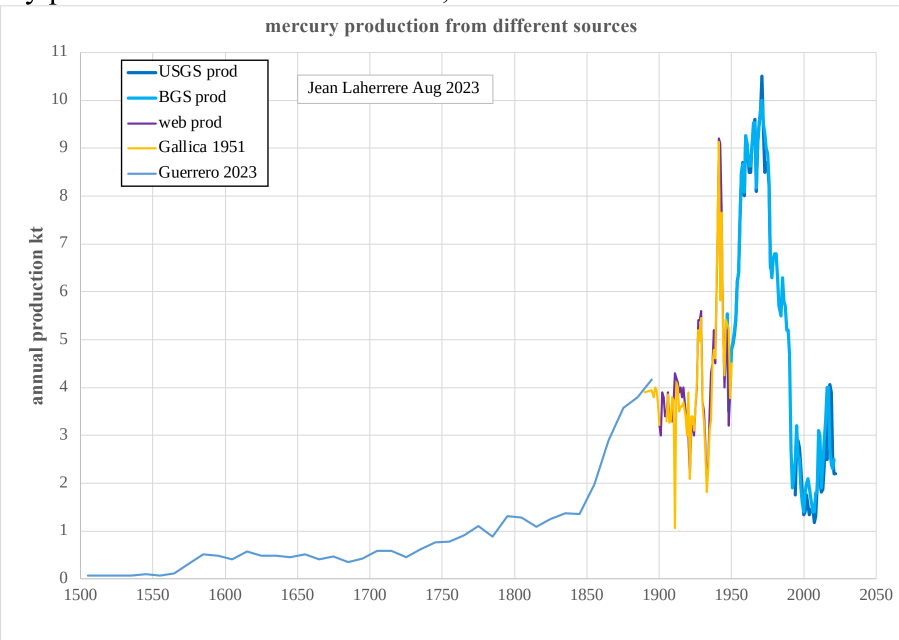
Aristotle is credited with the oldest known written record of mercury (in an academic text dating back to sometime during the 4th century BCE), in which he referred to it as "fluid silver" and "quicksilver.

Chinese women are reported to have consumed mercury as a contraceptive 4,000 years ago. By 1000 CE, mercury was used to extract gold by amalgamation.

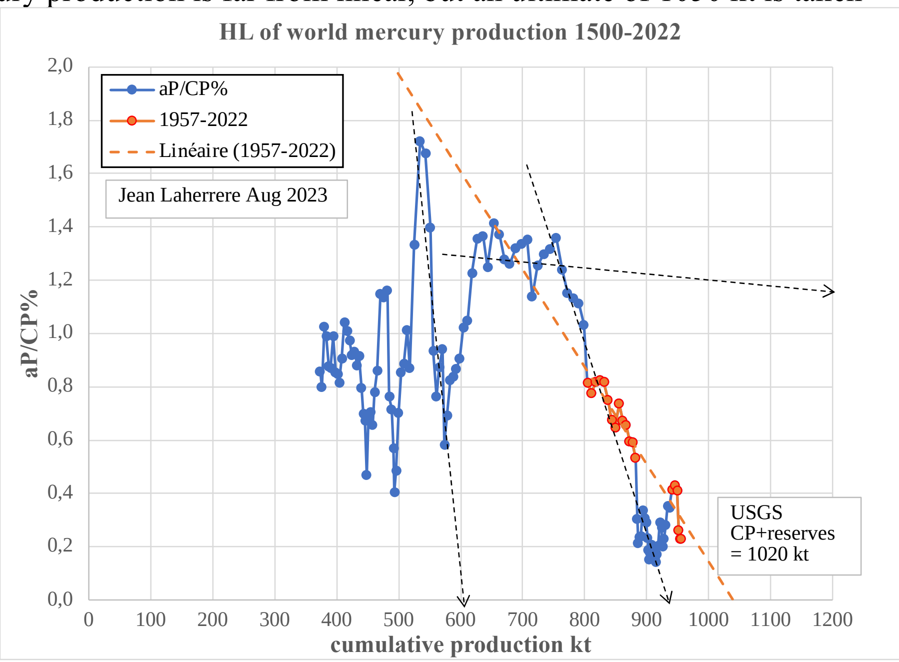
Mercury was used in scientific research largely as a result of Torricelli's 1643 invention of the barometer and Fahrenheit's 1720 invention of the mercury thermometer

Archaeologists found mercury in an Egyptian tomb dating from 1500 BC.

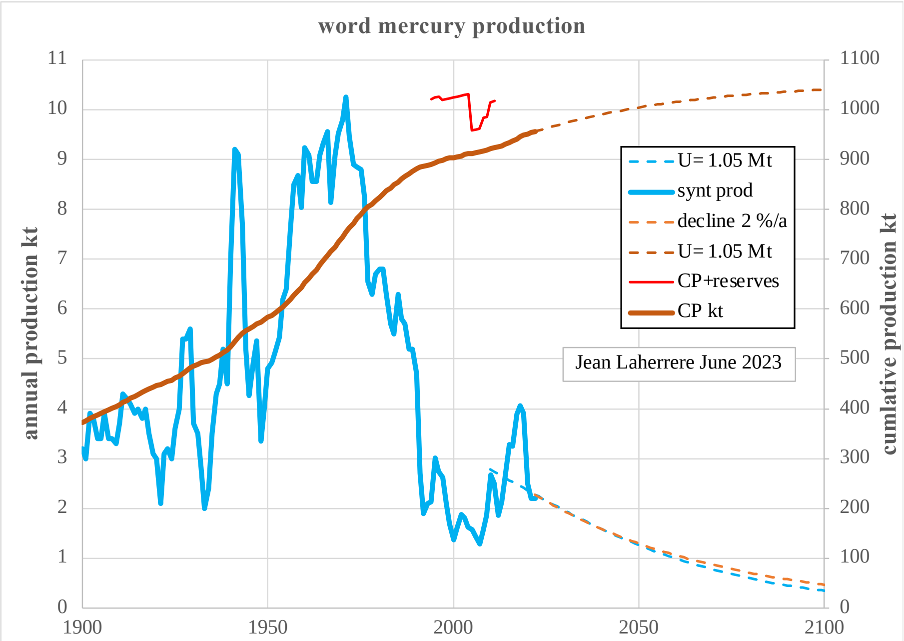
World mercury production varies with sources, when data starts in 1500.



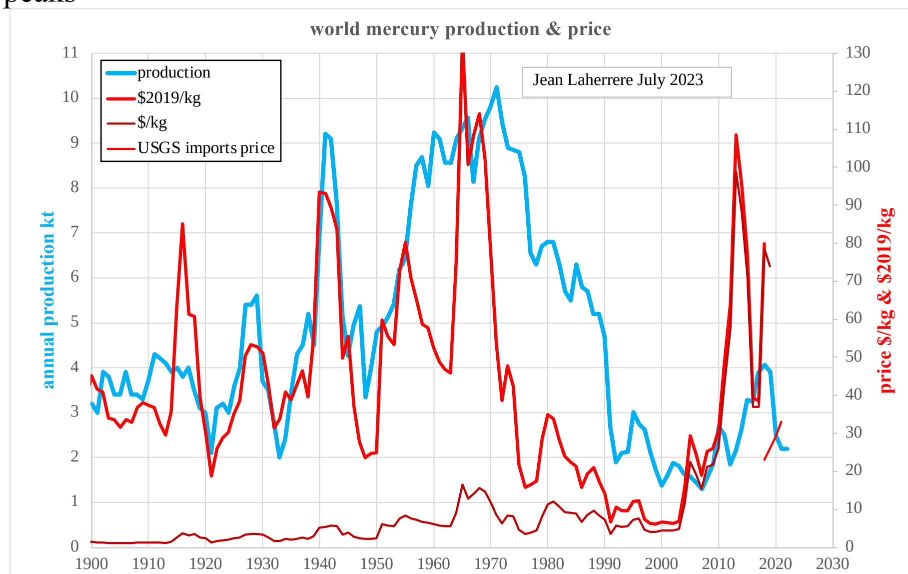
HL of mercury production is far from linear, but an ultimate of 1050 kt is taken



With an ultimate of 1.02 Mt, Hg production will decline with a rate of 2%/a

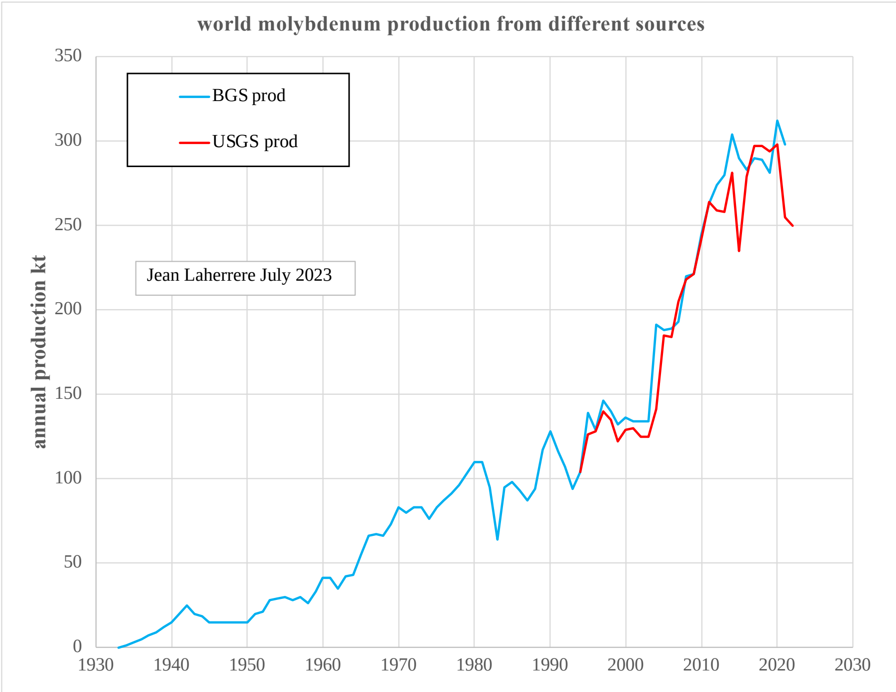


Mercury real price ($2019/kg) displays several sharp peaks, correlating sometimes with production peaks

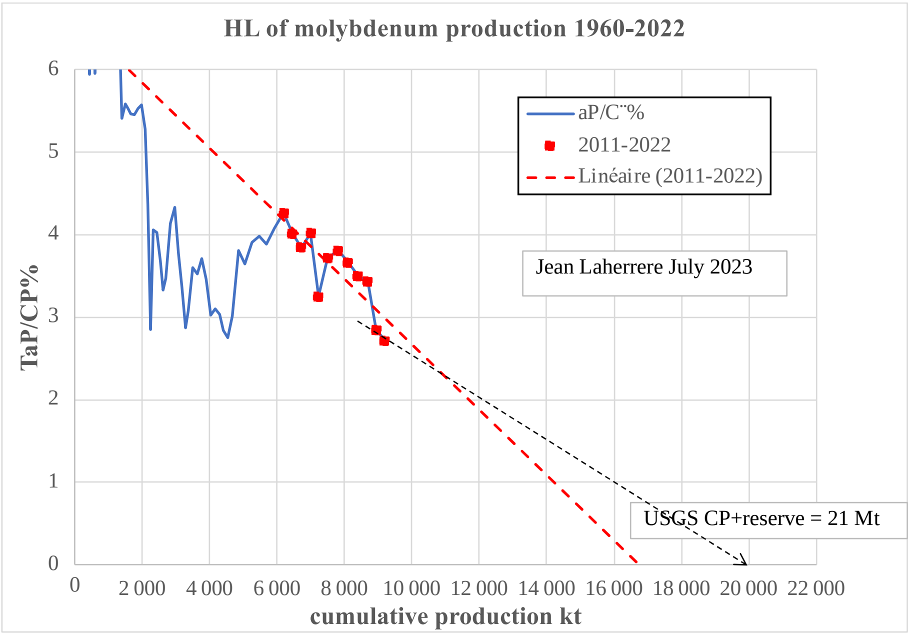


-molybdenum Mo

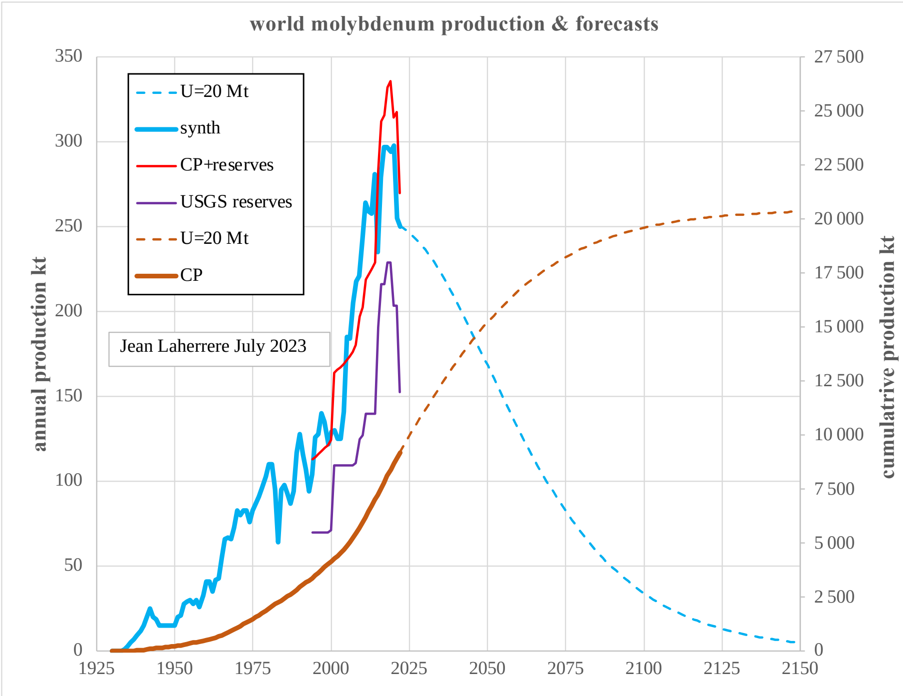
BGS production data is more complete than USGS data



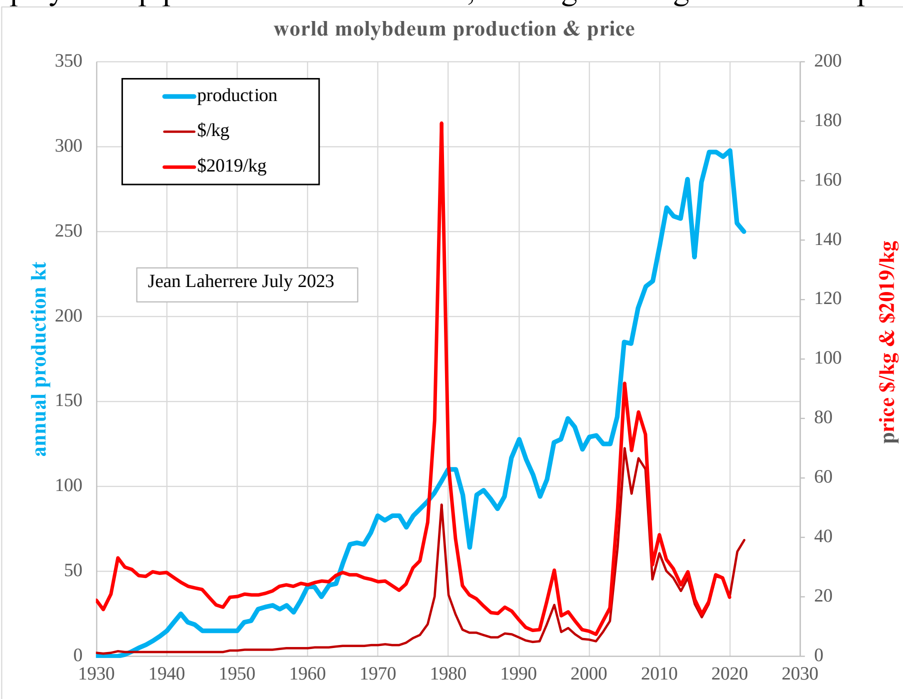
Hl of Mo production trends (2011-2022) poorly towards 17 Mt, when CP+reserves (declining) is 21 Mt: a 20 Mt ultimate is taken



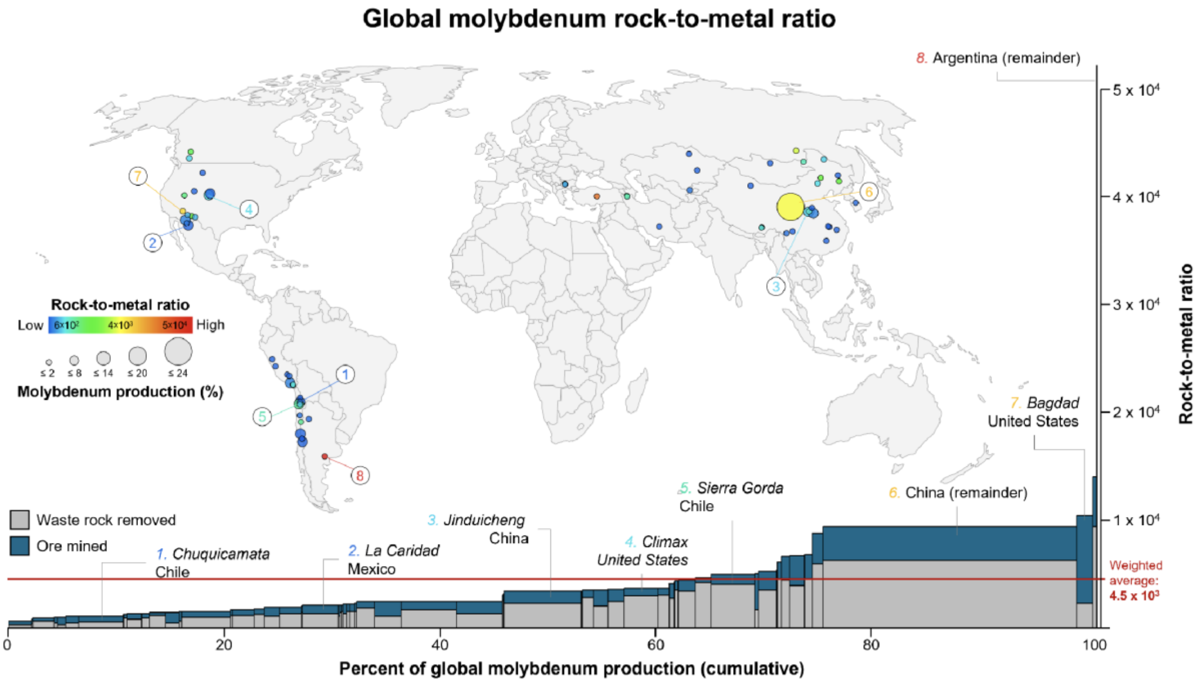
With a 20 Mt ultimate Mo peak is 2020.



Mo price displays sharp peaks in 1979 and 2004, leading to a large increase in production.

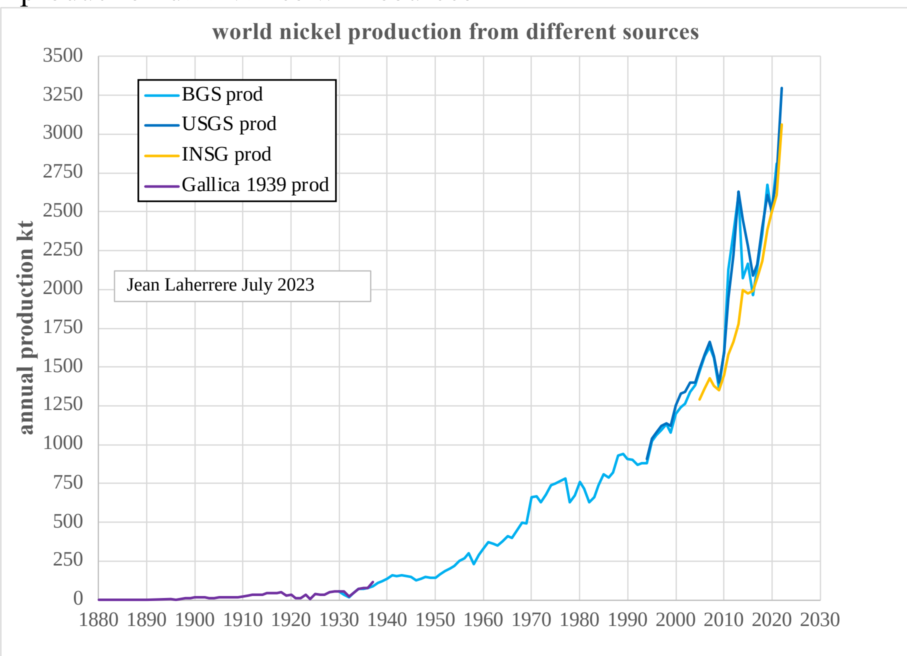


Nassar et al 2022 displays rock to metal ratio map and weighted average of 4500

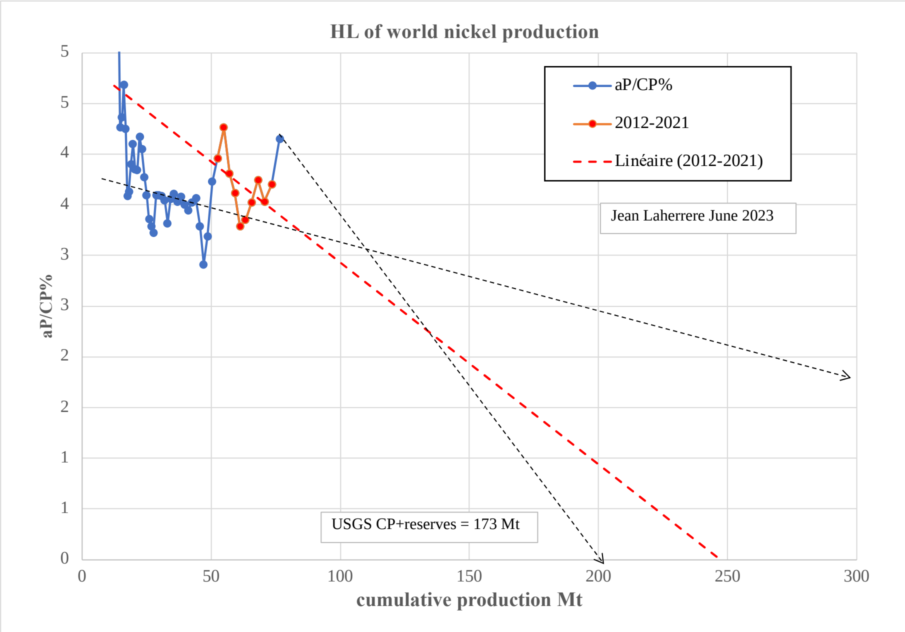


-nickel = Ni

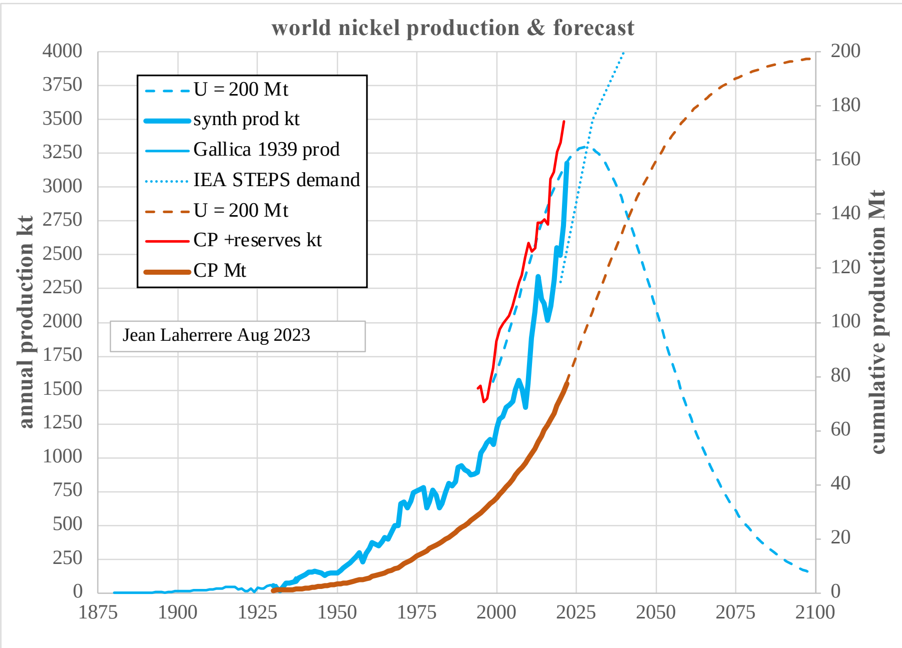
World nickel production data varies with sources



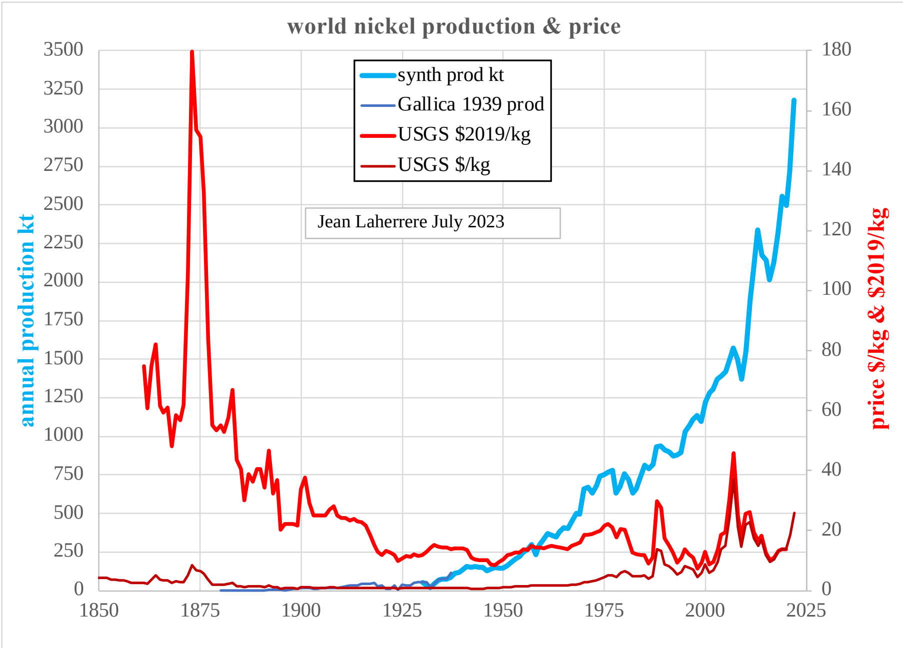
HL of Ni production trends very poorly towards 250 MT when CP+reserves = 180 Mt



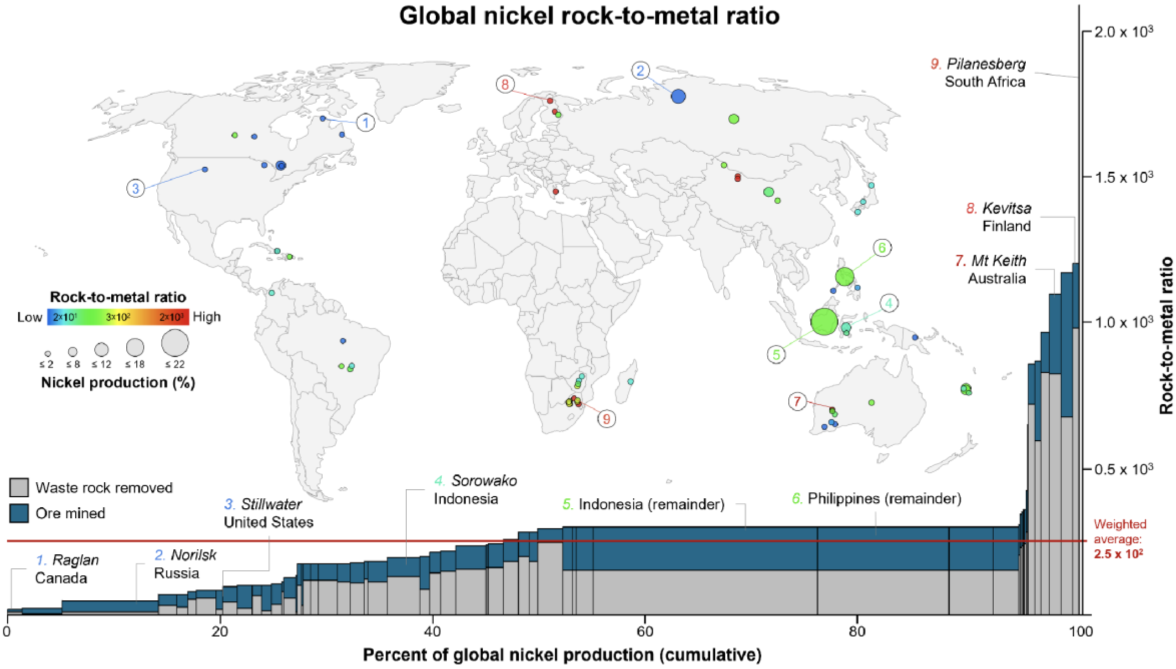
A 200 Mt ultimate is taken, giving a peak in 2028 at 3300 kt when IEA forecasts the demand in 2040 at 4000 kt.



The real price of Ni was very high in 1875 and in 2007 compared with today

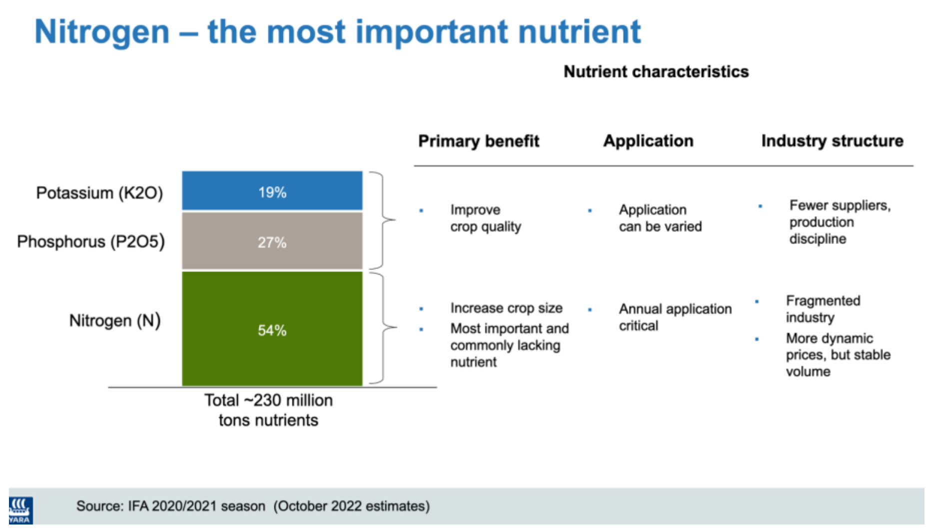


Nassar et al 2022 displays the rock to metal ratio map and the weighted average of 250

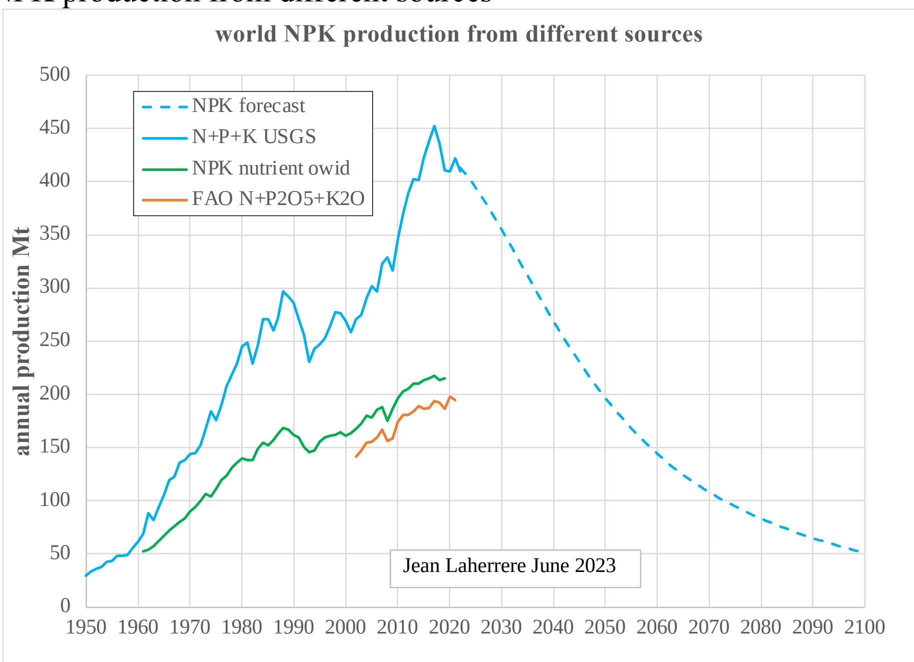


-nitrogen = N

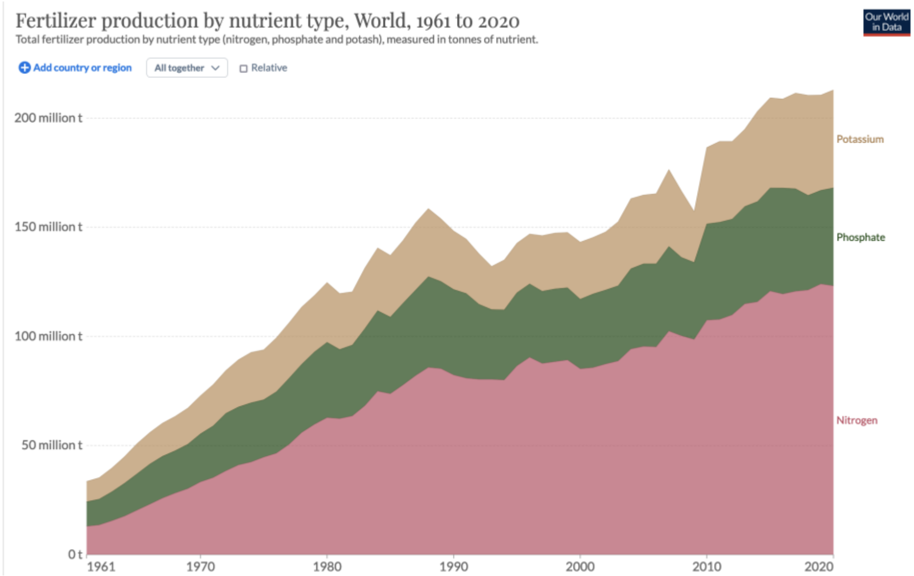
Nitrogen is the most important of the 3 nutrients NPK: IFA 2022



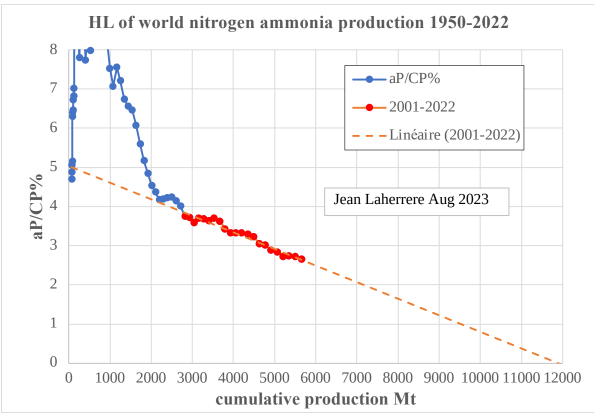
The world NPK production from different sources

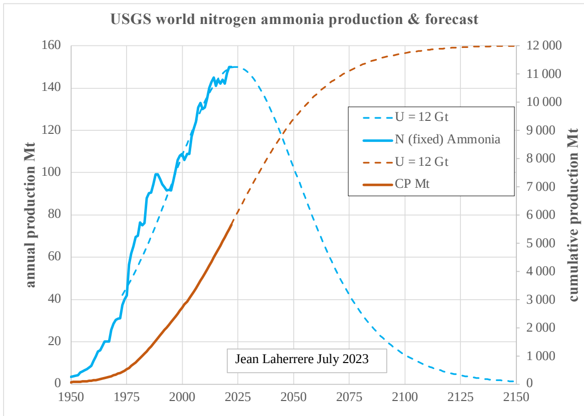


OWID fertilizer production graph 1961-2020

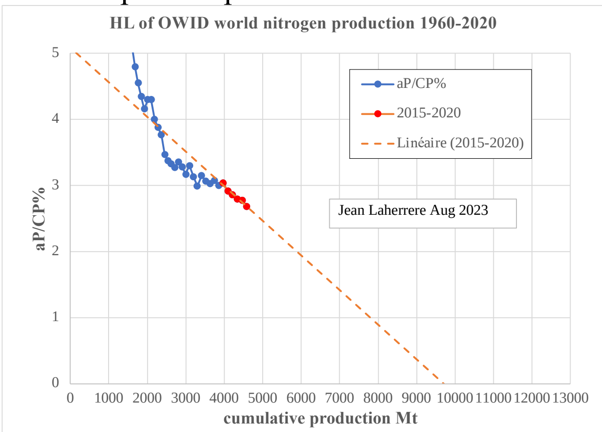


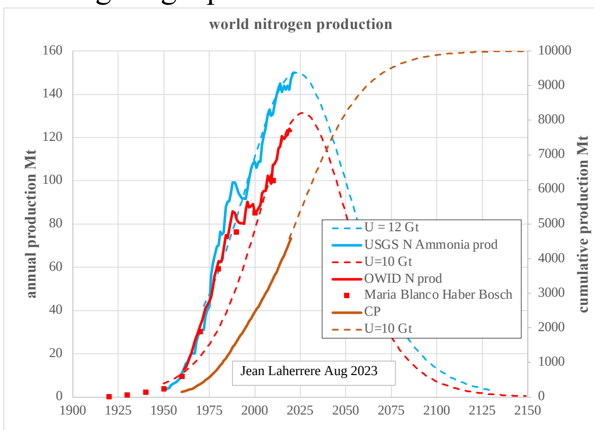
USGS reports nitrogen ammonia
HL of nitrogen ammonia production trends (1995-2022) fairly towards 12 Gt
With a 12 Gt ultimate, N peak has occurred in 2025:



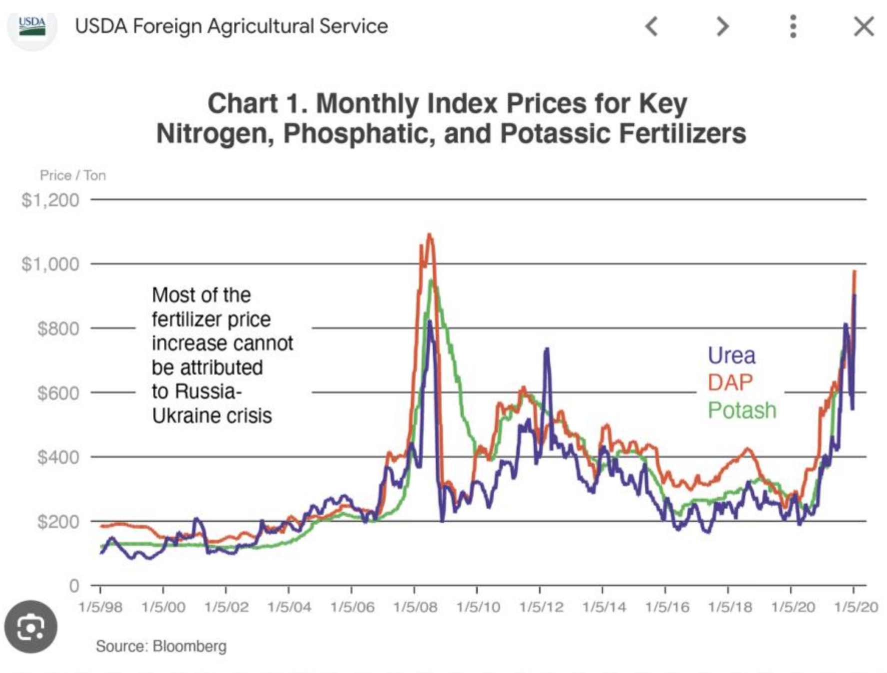


OWID reports N production: HL trends towards 10 Gt giving a peak in 2027



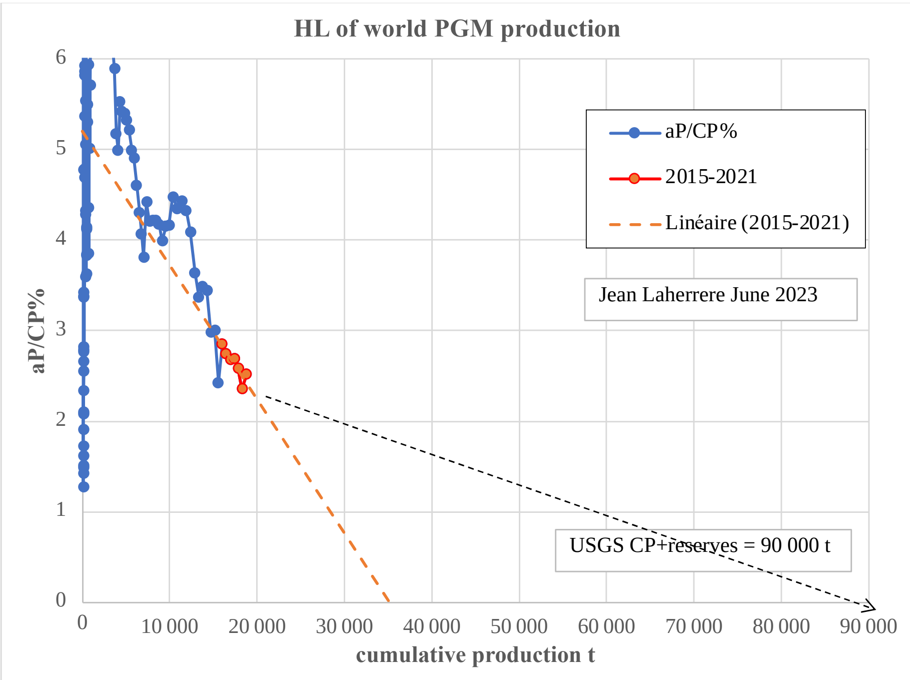


NPK price: fertilizers prices vary together with a good correlation.

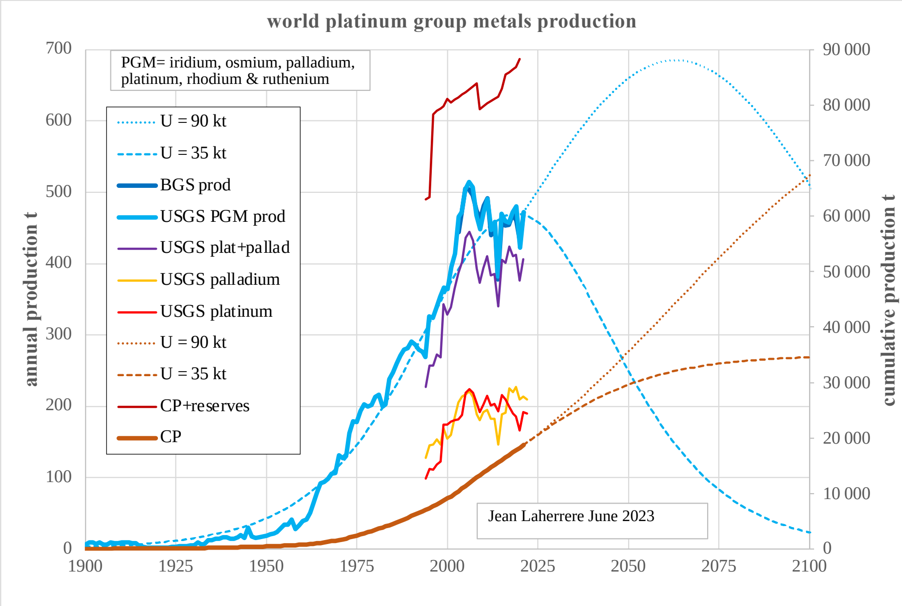


-platinum group metal = PGM

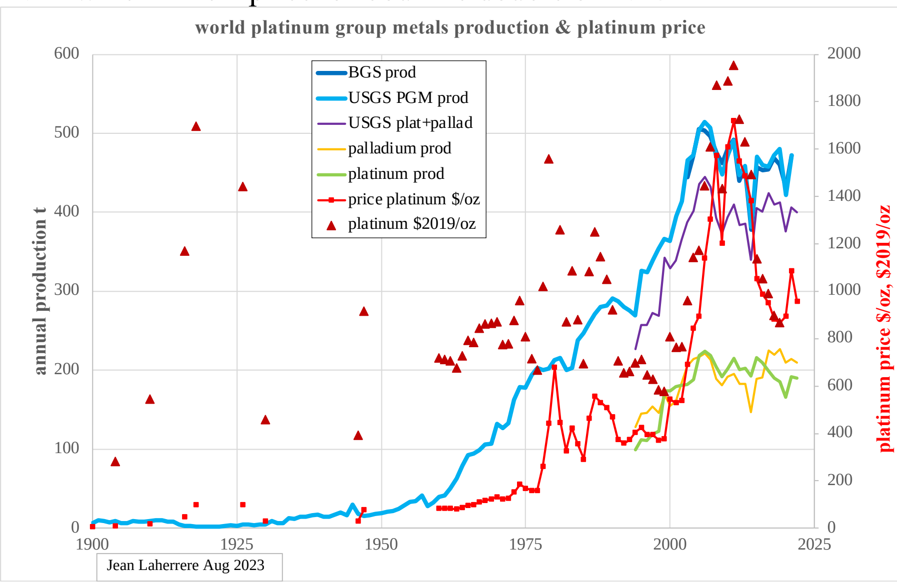
Platinum group metal gathers ruthenium, rhodium, palladium, osmium, iridium, and platinum.
HL of world PGM trends poorly towards 35 kt, but USGS CP+reserves is 90kt.
PGM ultimate is then taken as 35 kt or 90 kt



With 35 kt ultimate PGL production has peaked in 2011 at 0.5 kt, bit with 90 kt ultimate peak will occur in 2060.



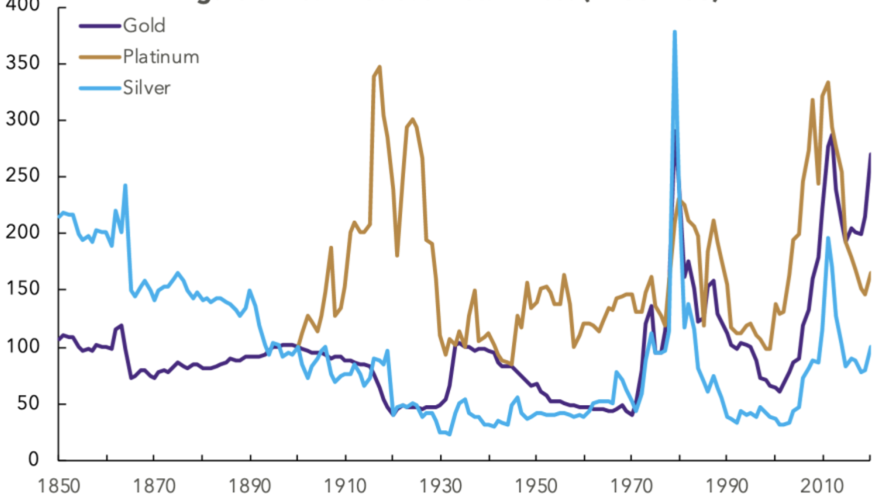
PGM production is compared with platinum price, which displays a sharp increase from 2000 to a peak in 2011 which in real price is about the double of 2023



Platinum price is compared to gold & silver prices

https://www.sfu.ca/~djacks/data/boombust/Chartbook for Boom to Bust 2102.pdf

Figure 6: Real Precious Metal Prices (1900=100)



Share of automotive PGM demand by metal 2012-2023: palladium is the most used PGM in vehicles, followed by platinum and rhodium.

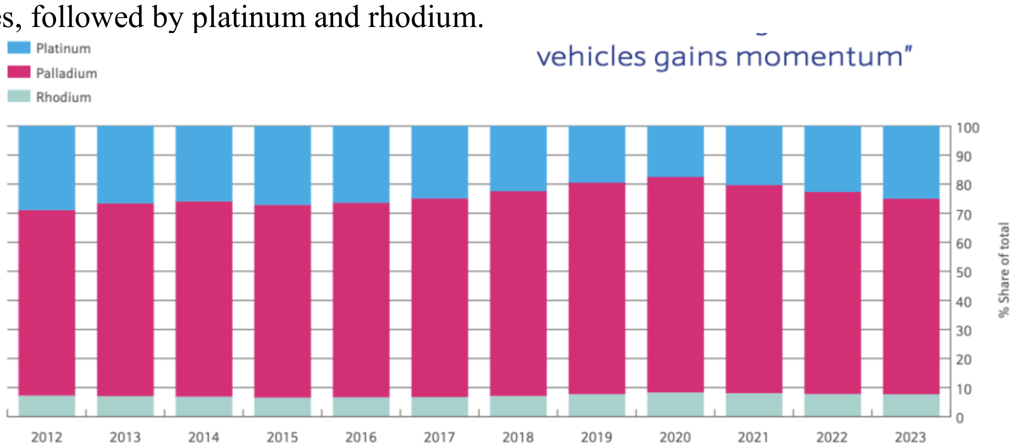


Figure 17 Share of automotive PGM demand by metal

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PGM supply share in 2021 per region

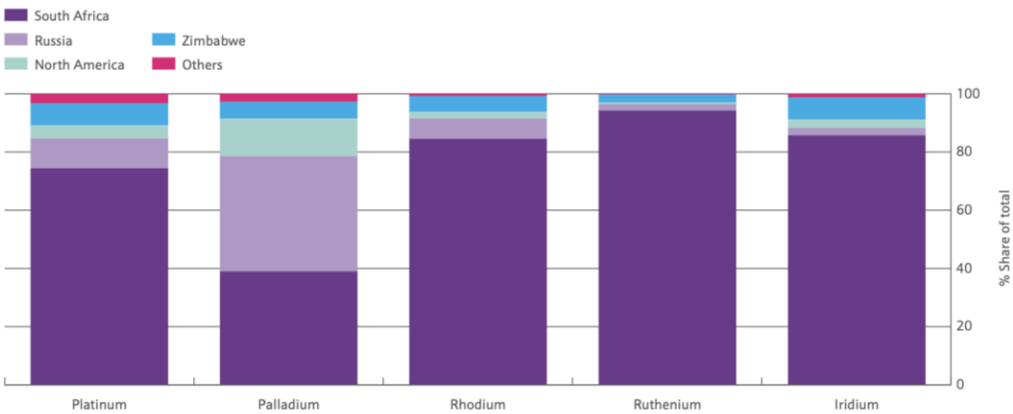


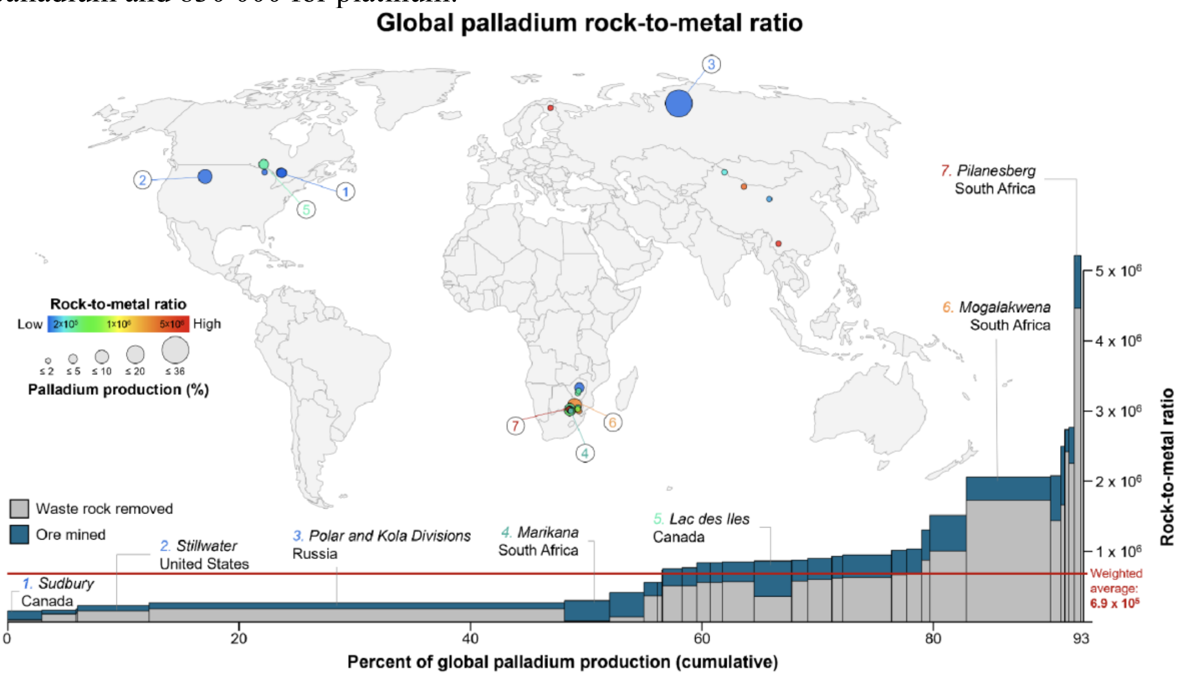
Figure 3 Primary supply share by region, 2021

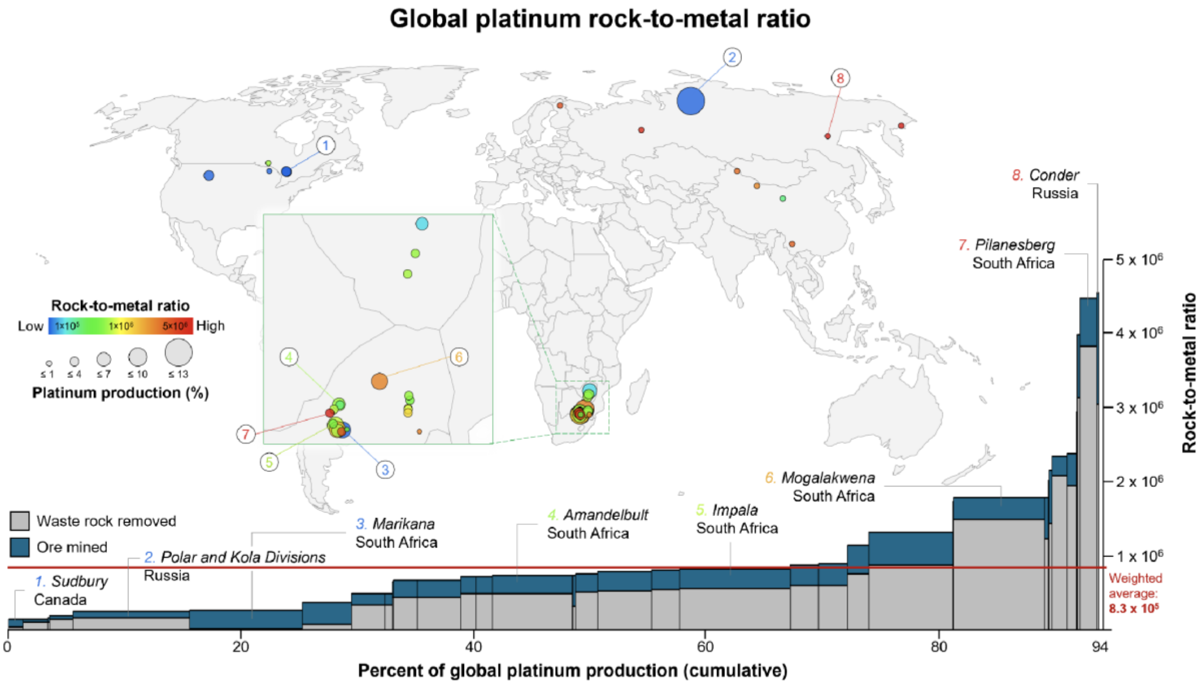
6 **Johnson Matthey** PGM market report May 2022

International PGM association
https://ipa-news.de/index/platinum-group-metals/mining-und-production/primary-production.html

According to the U.S. Geological Survey, 95 per cent of the known world reserves of PGMs are located in South Africa. 58 per cent of world primary PGM production takes place in South Africa and Russia accounts for a further 26 per cent, most of this as a co-product of nickel mining. Nearly all of the rest comes from Zimbabwe, Canada, and the United States. Deposits in Russia and North America have high palladium contents while deposits in South Africa and Zimbabwe are richer in platinum.

Nassar et al 2022 displays the rock to metal ratio map, as the weighted average of 690 000 for palladium and 830 000 for platinum:

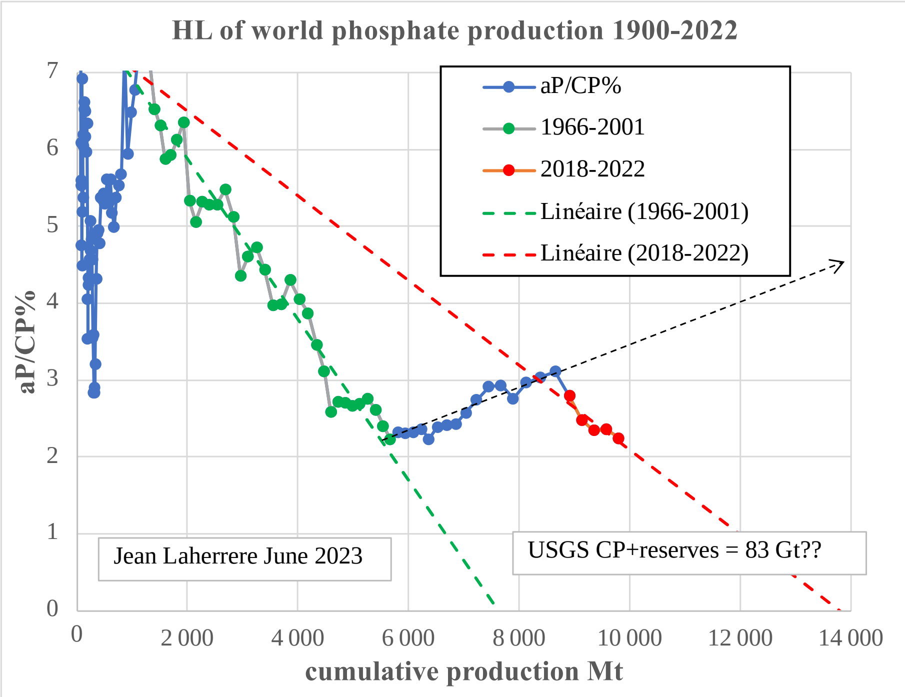




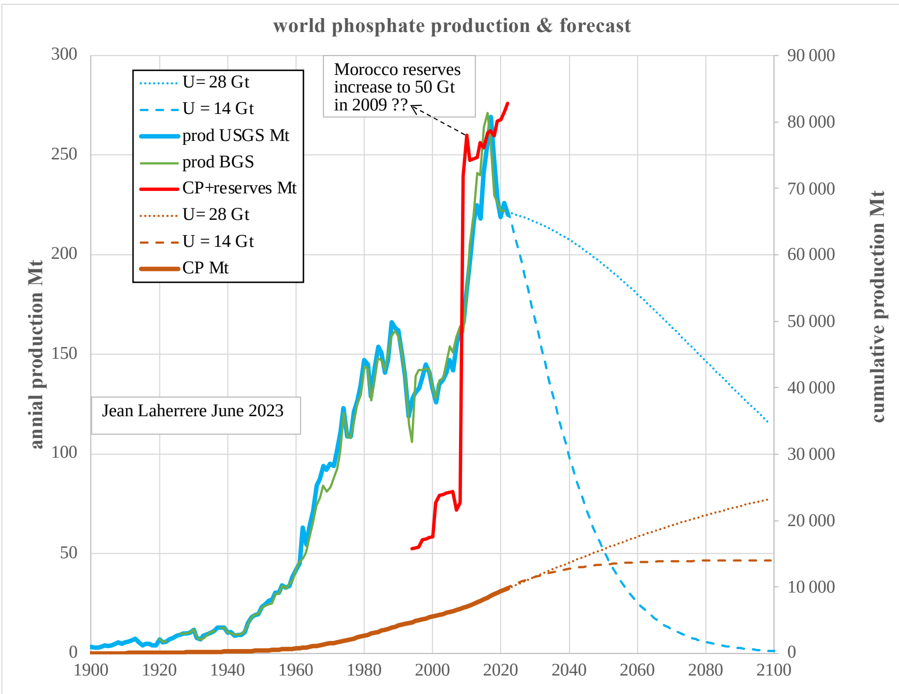
-phosphate = PO4

HL of phosphate production trends 2018-2022 poorly towards 14 Gt, when USGS CP+reserves is 83 Gt with a sudden 50 Gt increase in 2009. This huge increase looks

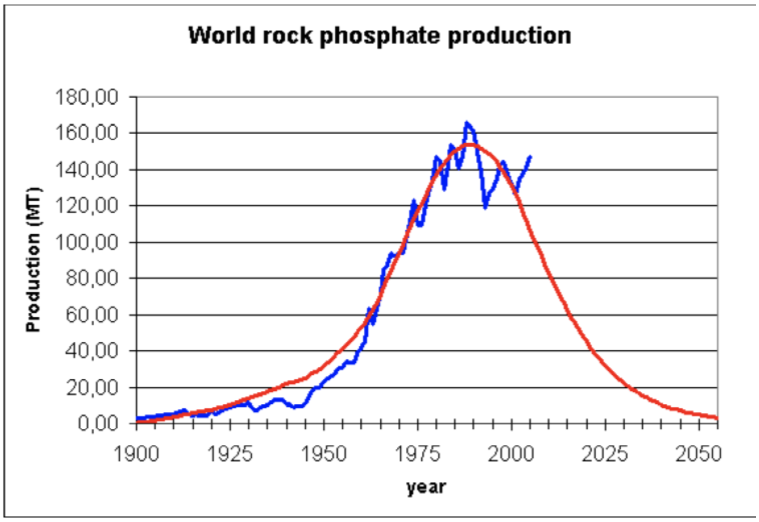
unreliable and it is challenged by Norway: https://www.atalayar.com/en/articulo/economy-and-business/norway-challenges-moroccos-position-top-phosphate-supplier/20230703181130187642.html.
In 2021 Morocco has produced only 18 % of the world production when having 70 % of the reported reserves!



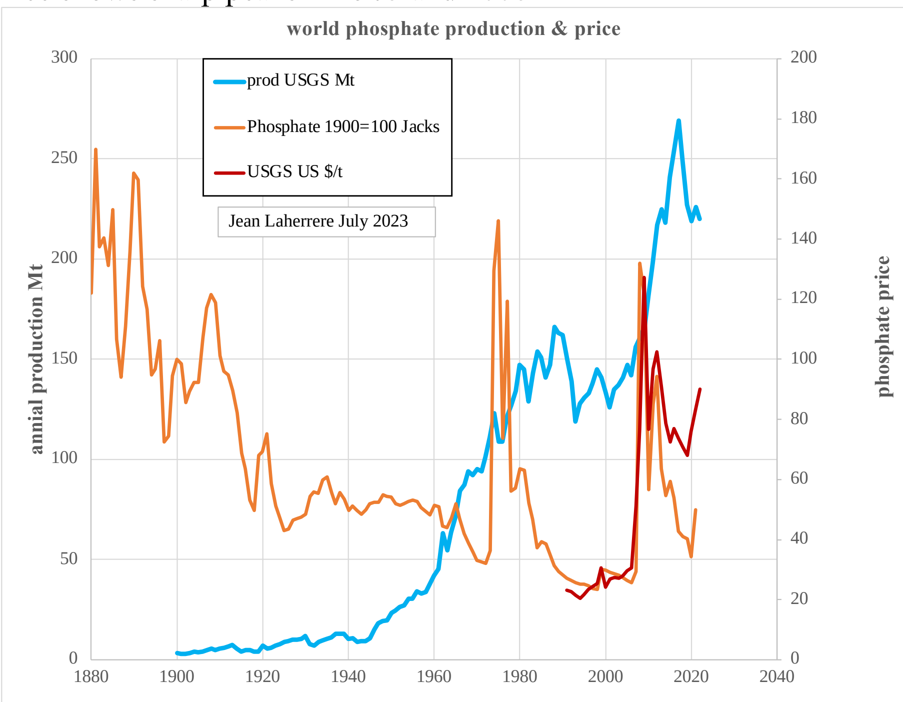
Phosphate ultimate is taken as 14 Gt from HL, giving a decline symmetrical to the increase, with a peak in 2017.
A double ultimate of 28 Gt leads to a slow decline.



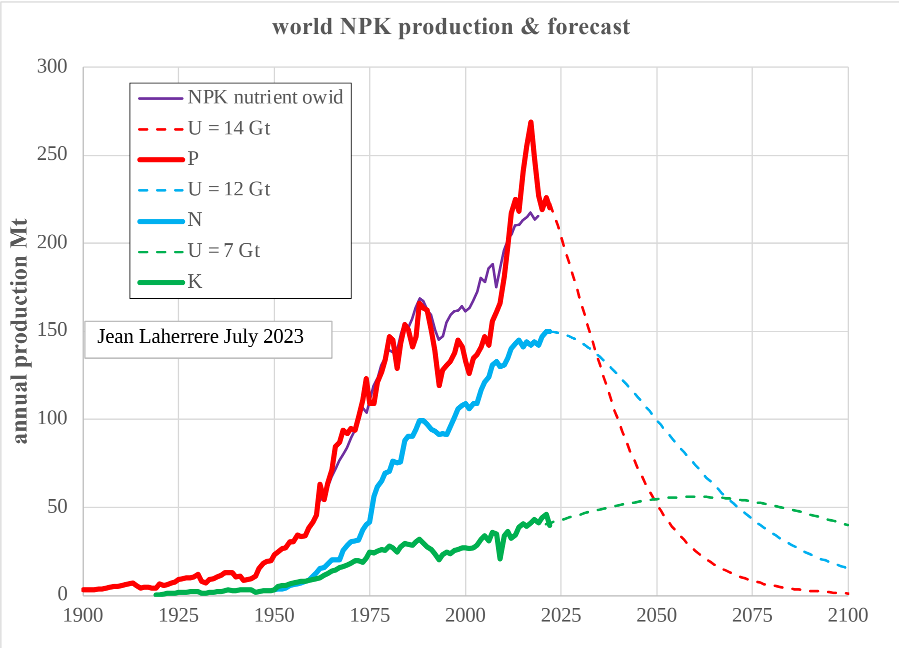
World phosphate production displays a first peak in 1988 at 166 Mt and in Aug 2007 Patrick Dhéry in Energy bulletin "Peak Phosphorus" estimated with HL the ultimate at 8 Gt: he was wrong missing the phosphate increase starting in 2010



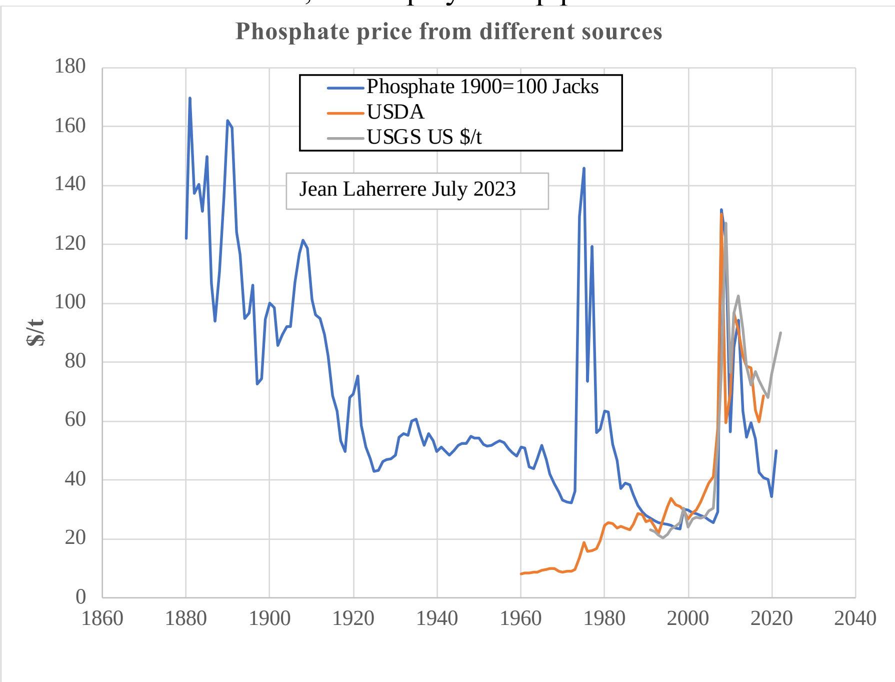
Phosphate price shows sharp peaks in 1975 and 2008



The next graph gathers the past and future production of NPK.
Owid reports NPK data which agrees with USGS phosphate production data from 1960 to 1990 and beyond disagrees!

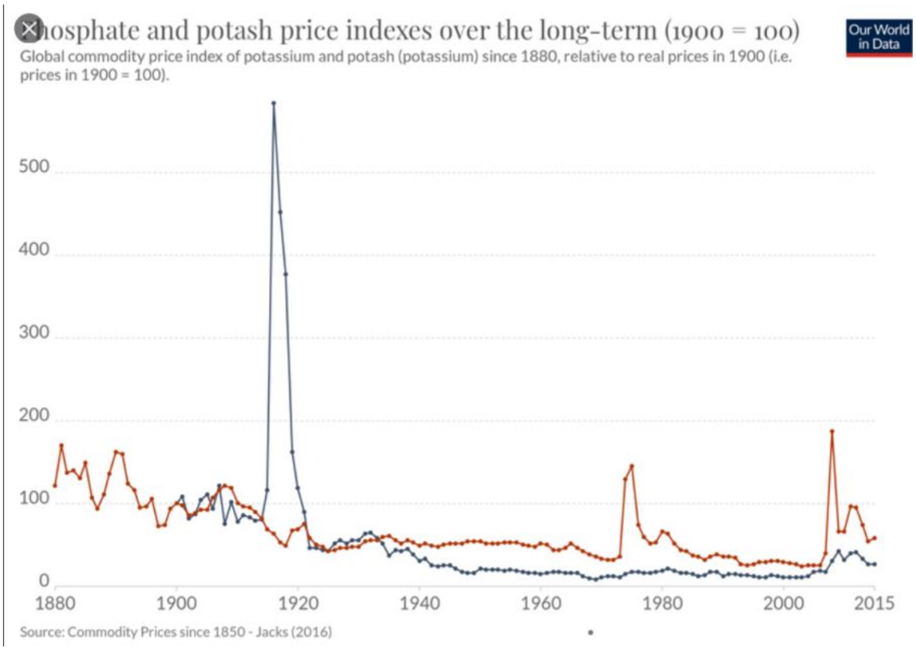


Phosphate price varies with sources, but displays sharp peaks: the last one is 2009

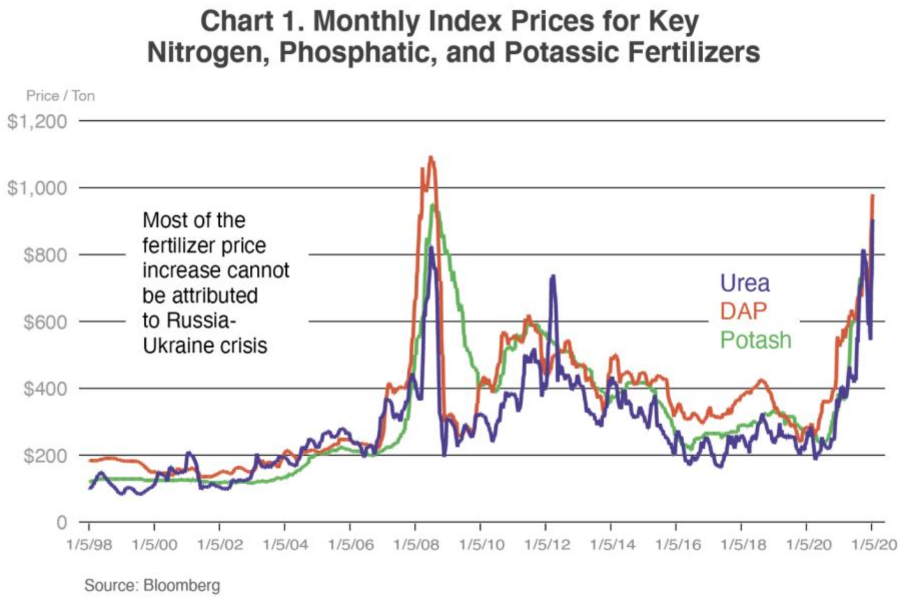


Owid reports phosphate and potash price since 1880 to 2015 from David Jacks https://en.macromicro.me/charts/78681/david-jacks-real-commodity-prices-index-minerals, but forgets to define which is the blue curve = potash; the red curve is phosphate

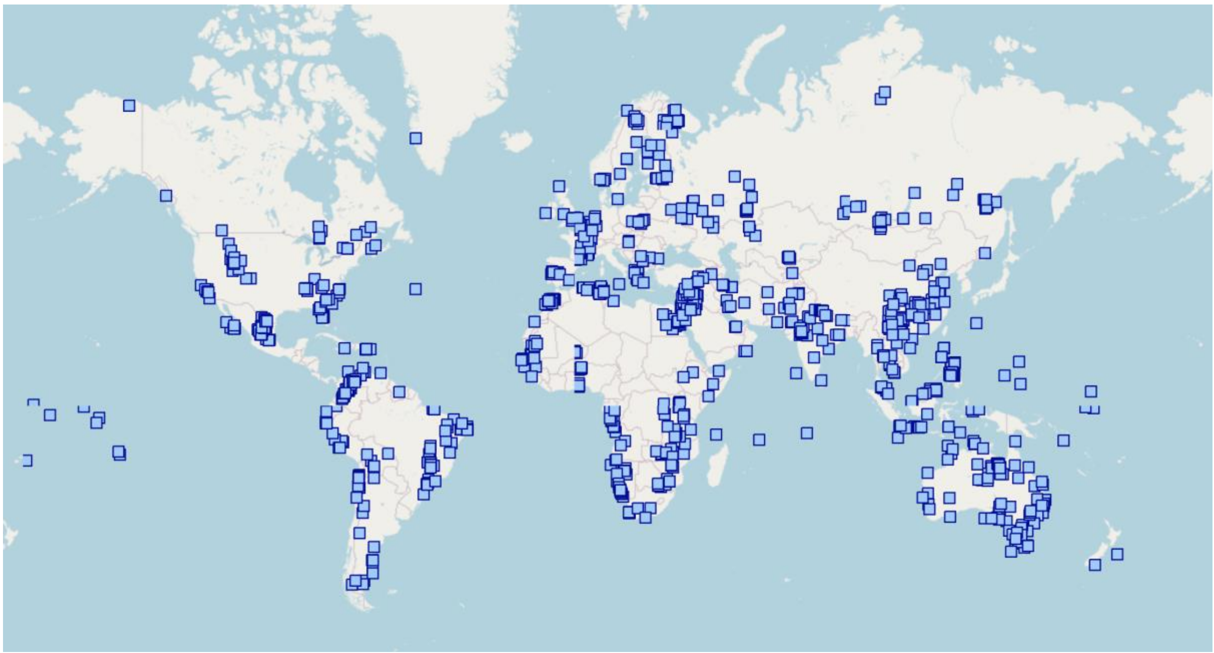
Both blue and red curves display short and sharp peaks.



NPK prices from 1998 to 2020

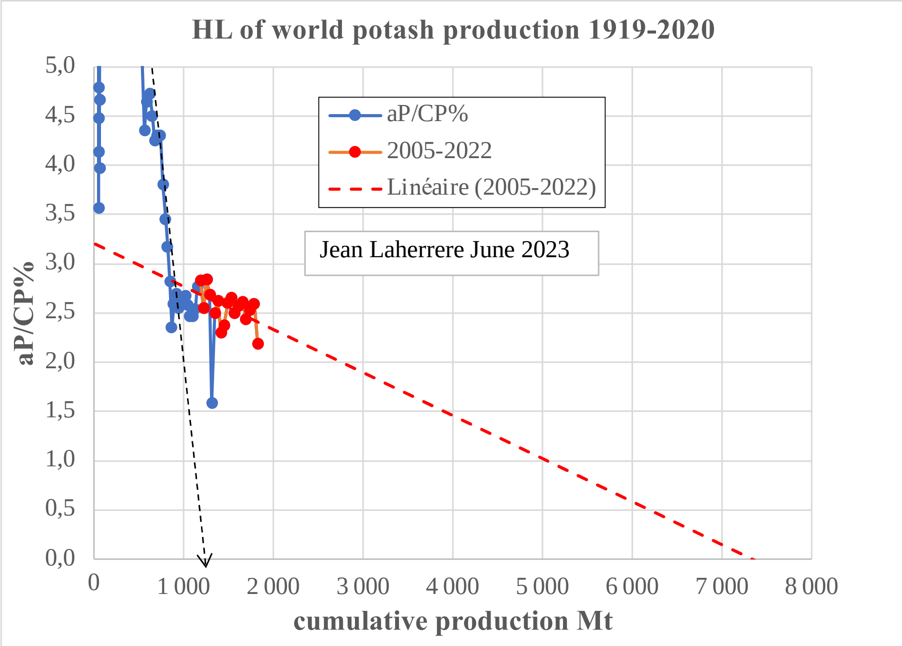


USGS phosphate map

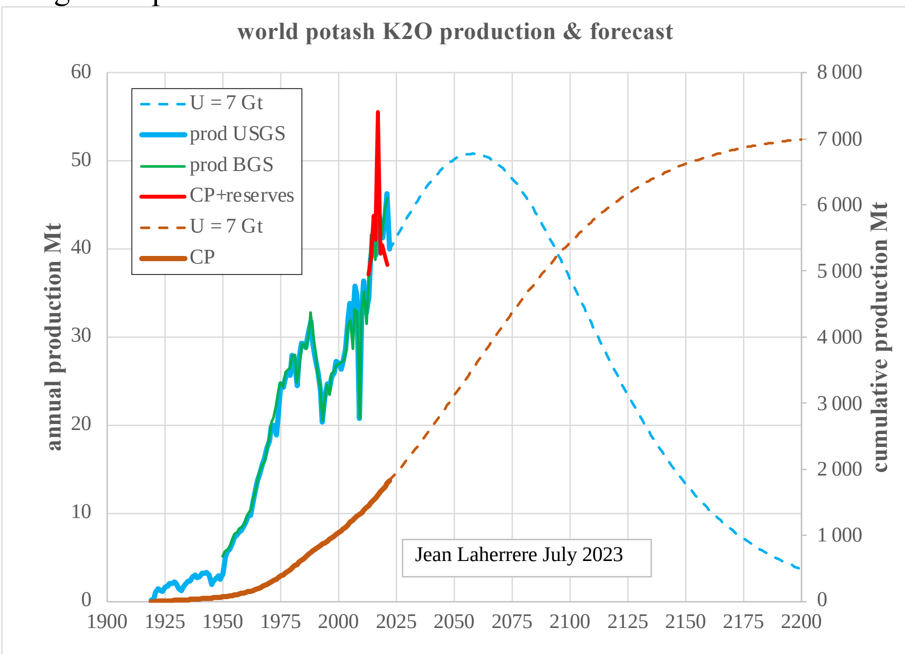


-Potash
Wikipedia:
Potash refers to potassium compounds and potassium-bearing materials, most commonly potassium carbonate. The word "potash" originates from the Middle Dutch "potaschen", denoting "pot ashes" in 1477. The old method of making potassium carbonate (K2CO3) was by collecting or producing wood ash (the occupation of ash burners), leaching the ashes, and then evaporating the resulting solution in large iron pots, which left a white residue denominated "pot ash". Approximately 10% by weight of common wood ash can be recovered as potash.
Potash fertilizer: potassium carbonate (K2CO3); any one or more of potassium chloride (KCl), potassium sulfate (K2SO4) or potassium nitrate (KNO3). Does not contain potassium oxide (K2O), which plants do not take up. The amount of potassium is often reported as K2O equivalent (that is, how much it would be if in K2O form), however, to allow apples-to-apples comparison between different fertilizers using different types of potash
Beginning in the 14th century potash was mined in Ethiopia, Potash became an important international trade commodity in Europe from at least the early 14th century. It is estimated that European imports of potash required 6 or more million cubic metres each year from the early 17th century.
Potash (especially potassium carbonate) has been used in bleaching textiles, making glass, ceramic, and making soap, since the Bronze Age.
Beginning in the 14th century potash was mined in Ethiopia. One of the world's largest deposits, 140 to 150 million tons, is located in the Dallol area of the Afar Region.
But good data starts in 1919 for mined production.

HL of world potash production 2005-2022 trends fairly towards 7 Gt, when USGS CP+reserves decline from 7.4 to 5.1 Gt

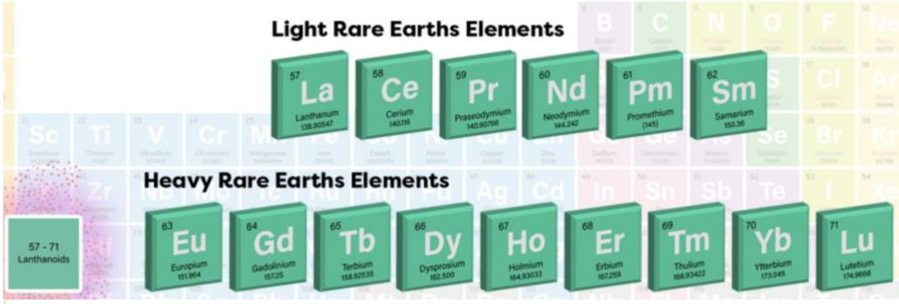


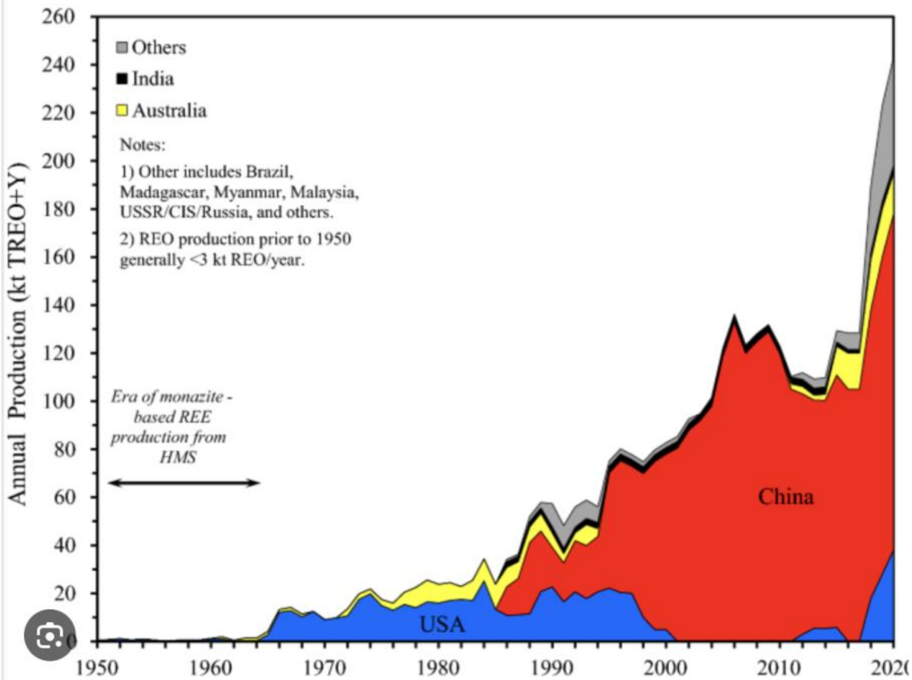
A 7 Gt ultimate gives a peak in 2060 at 50 Mt:



-rare earths

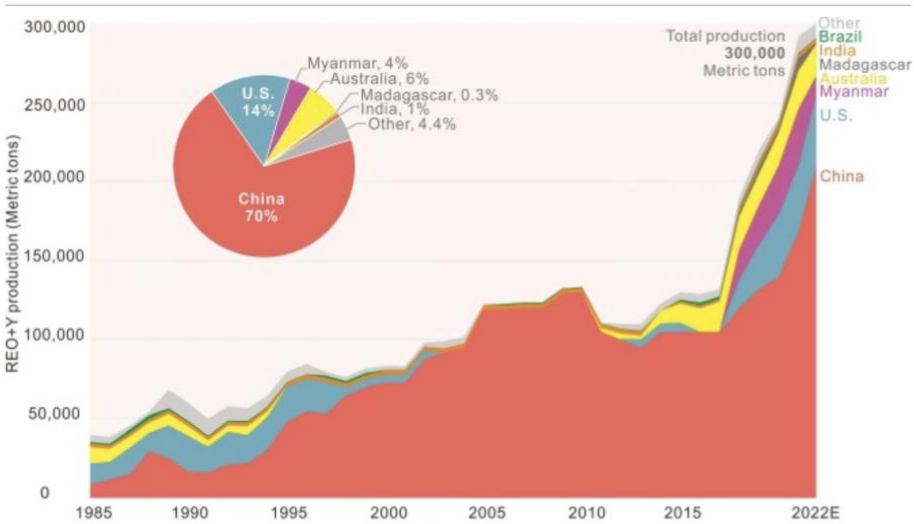
Rare earths are not rare and represent 17 minerals (cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, praseodymium, promethium, samarium, scandium, terbium, thulium, ytterbium, yttrium), but their production pollutes, and their production varies within country depending their policy on pollution: in 1980 China was not producing rare earths, when in 2010 China was almost the only producer





Mineral economics of the rare-earth elements | SpringerLink

Consulter

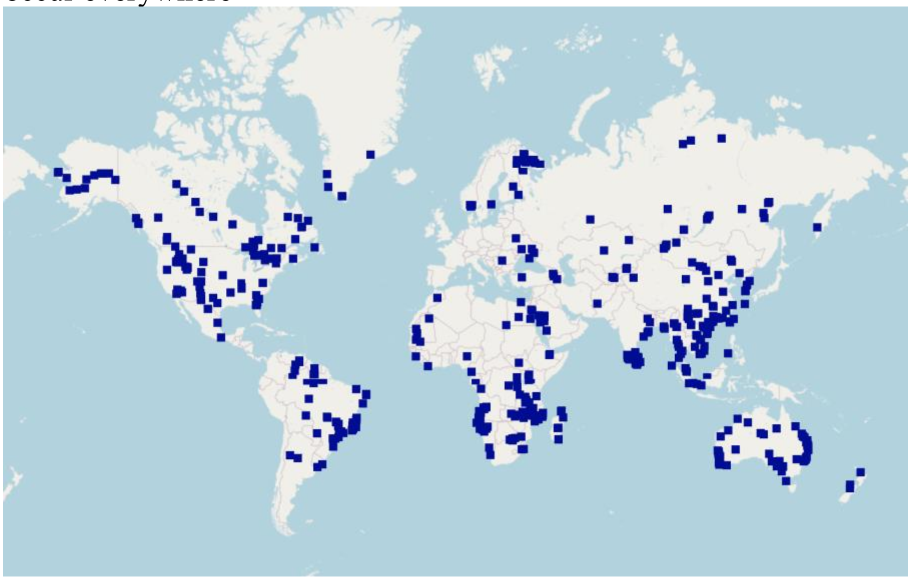


Rare Earth Industry Association
https://www.global-reia.org/wp-content/uploads/2022/11/REIA-Input-for-EU-RawMaterials-Act.pdf

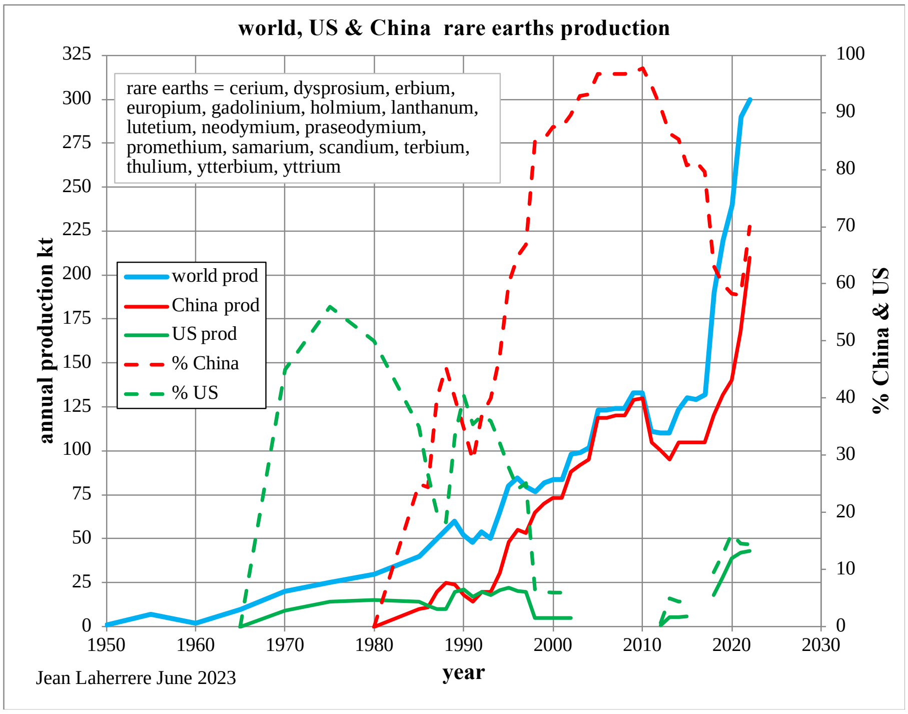
For the average passenger Electric Vehicle to be competitive enough in terms of performance to average passenger Internal Combustion Engine Vehicle, it would require 2 kilograms of rare-earth permanent magnets used in its drivetrain motor. Of this 2 kilogram amount of rare-earth permanent magnets needed for use in the average Electric Vehicle, this is the breakdown of the most used rare earths:

- 21% Neodymium
- 7% Praseodymium
- 2% Dysprosium
- 1.5% Terbium
- Total ~31.5% Rare Earths used per kg of magnet

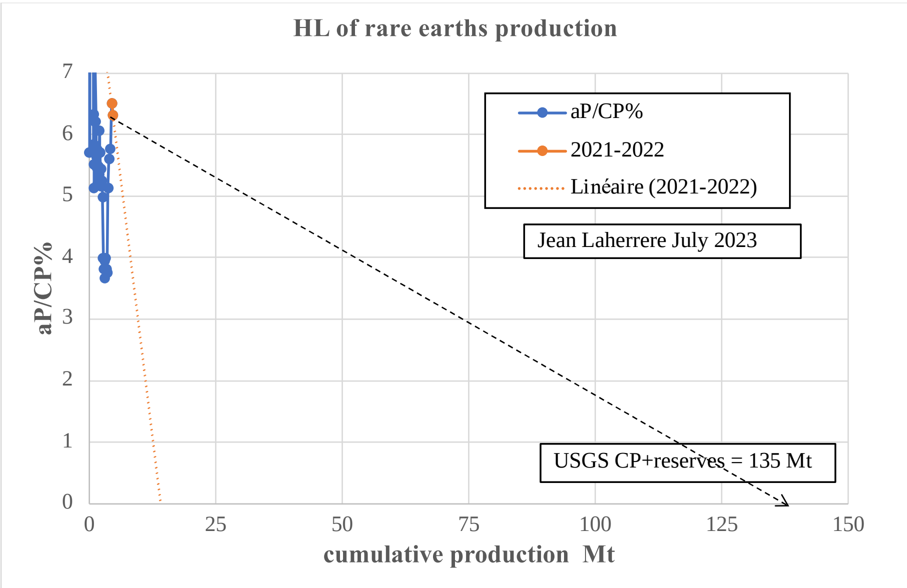
USGS rare earths map https://mrdata.usgs.gov/general/map-global.html
Rare earths occur everywhere



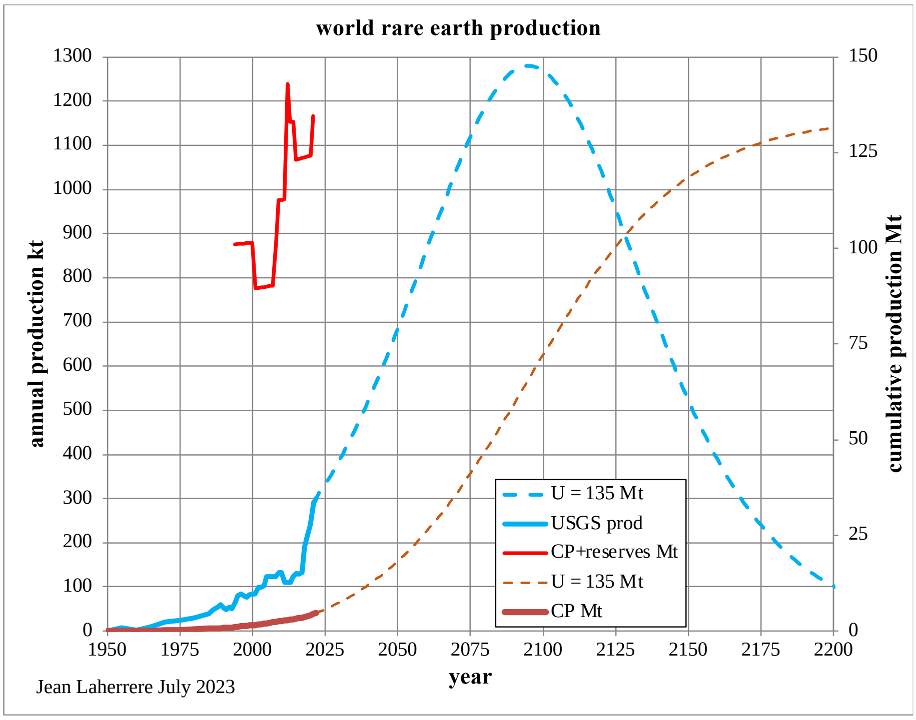
World, US and China production as their world percentage



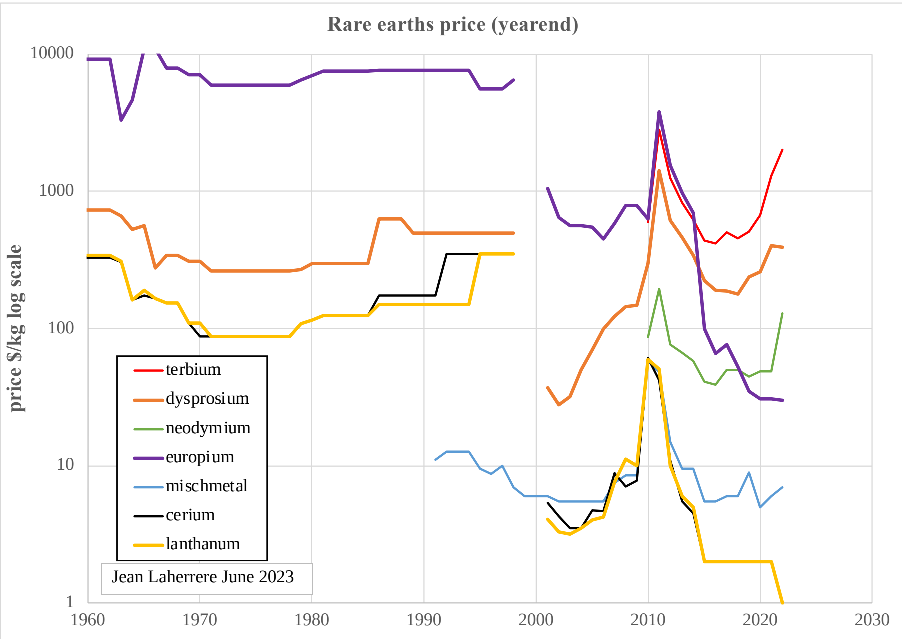
HL of rare earths is useless and USGS CP+reserves = 135 Mt is taken as ultimate



A 135 Mt ultimate gives a peak about 2100: the limit is not the resources.

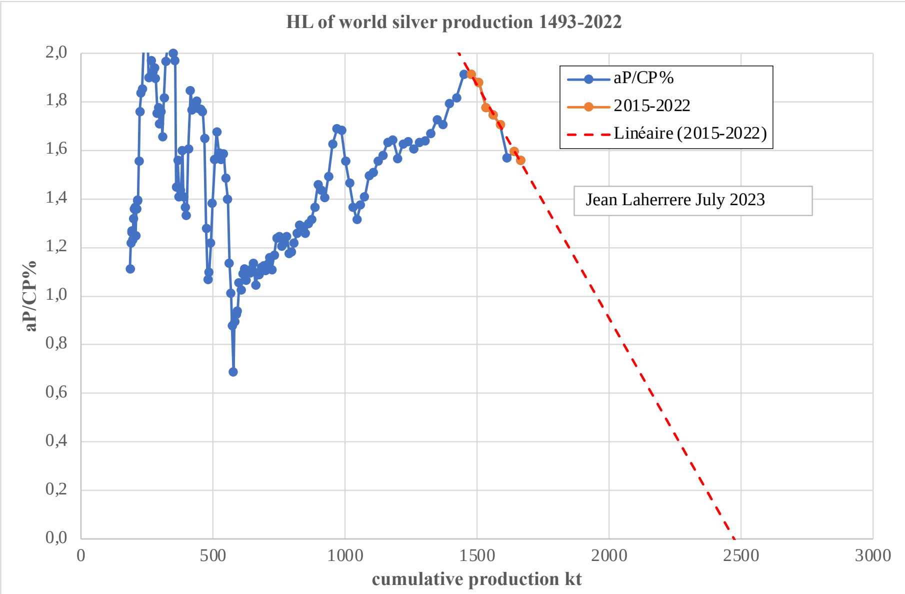


Rare earths price varies widely from 1 to 2 000 $/kg, but with a peak around 2011, and since some price increase when some decrease!

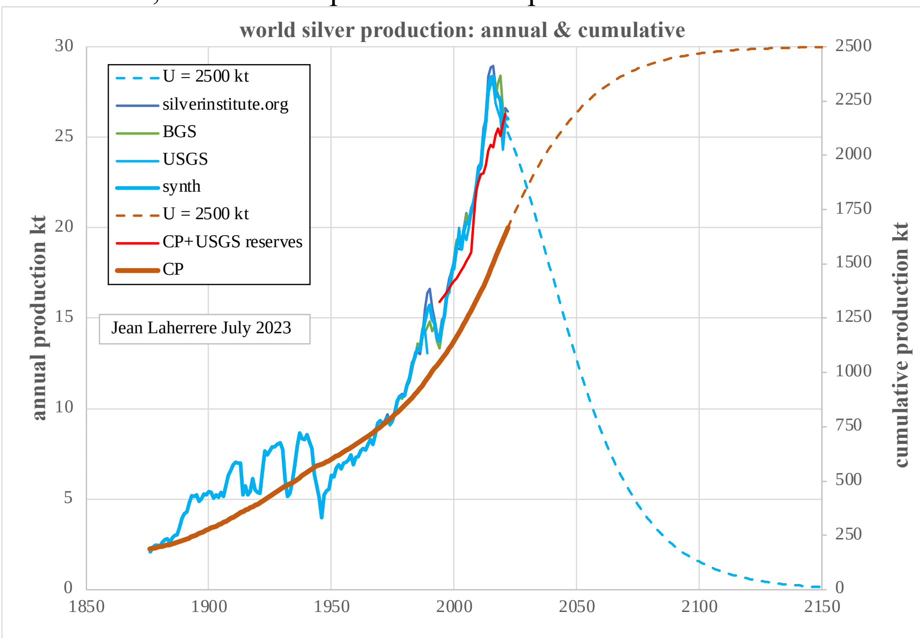


-silver

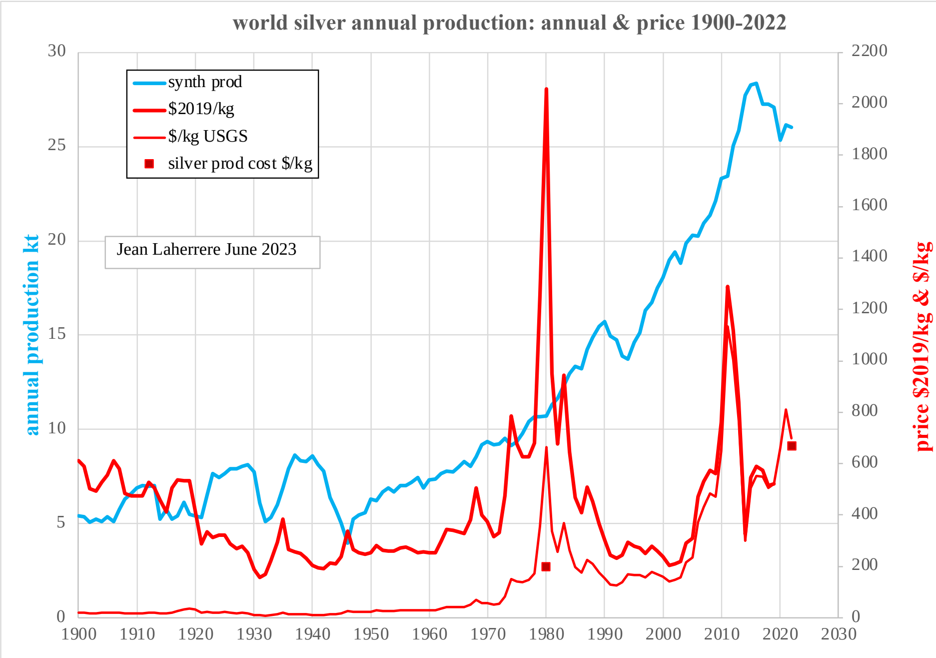
HL of silver production trends 2015-2022 fairly towards 2500 kt



With a 2500 kt ultimate, world silver production has peaked in 2016

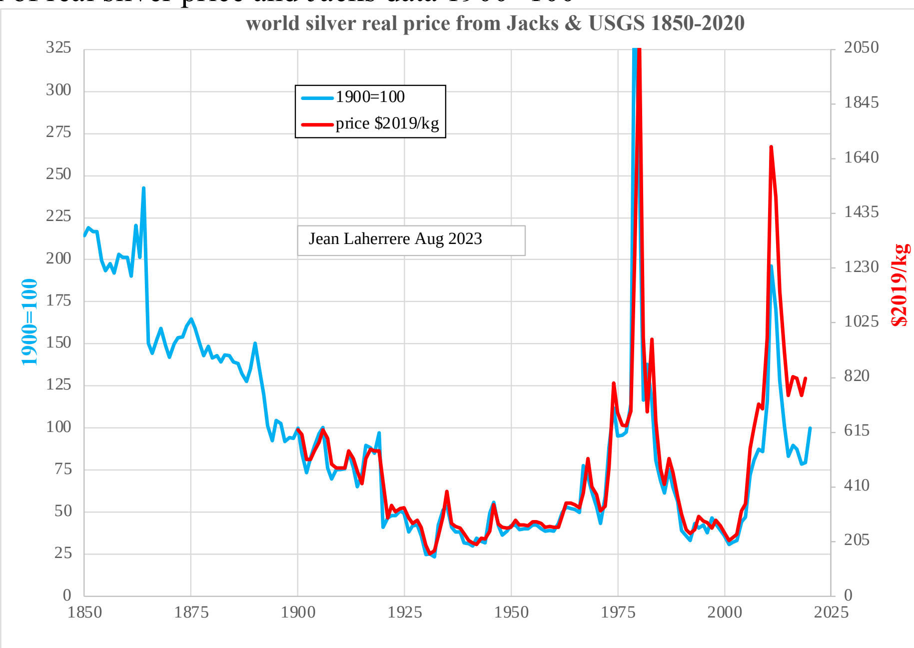


Silver price displays a sharp peak in 1980 and 2011. In 1980 this price burst was due to the *Hunt brothers who stockpiled silver and used their large cash reserves to buy up even more futures. Upon losing some $1.7 billion," the Hunts had become the (then) greatest debtors in financial history, and though New York banks allowed them $1.1 billion credit towards clearing their obligations, they were personally bankrupted and later convicted …*

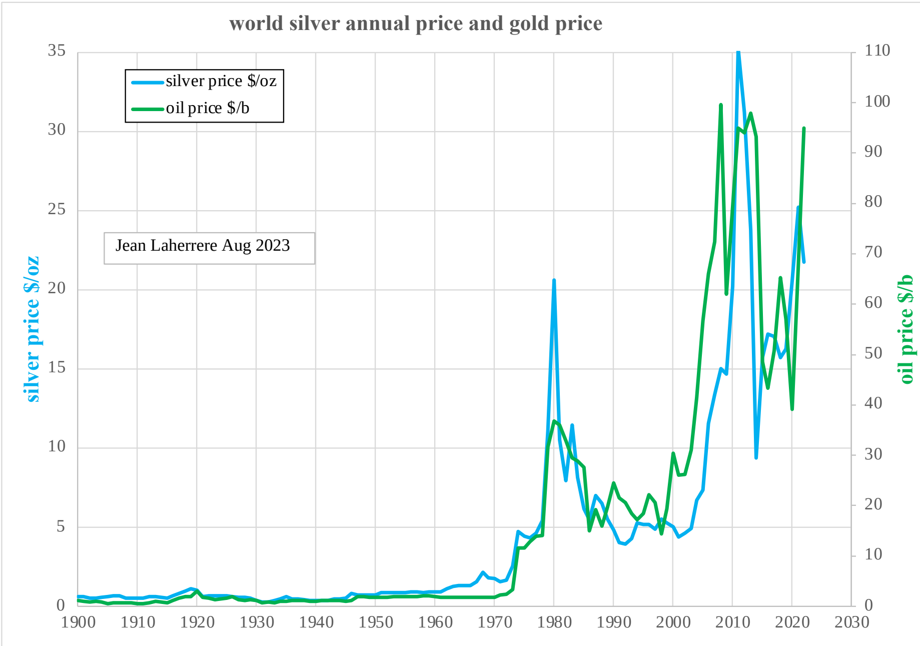


As silver production is on decline after 2016 peak, silver price is rising as the cost of production has increased from 200 $/kg in 1980 to 675 $/kg in 2022, close to silver price: silver price should increase in the future!

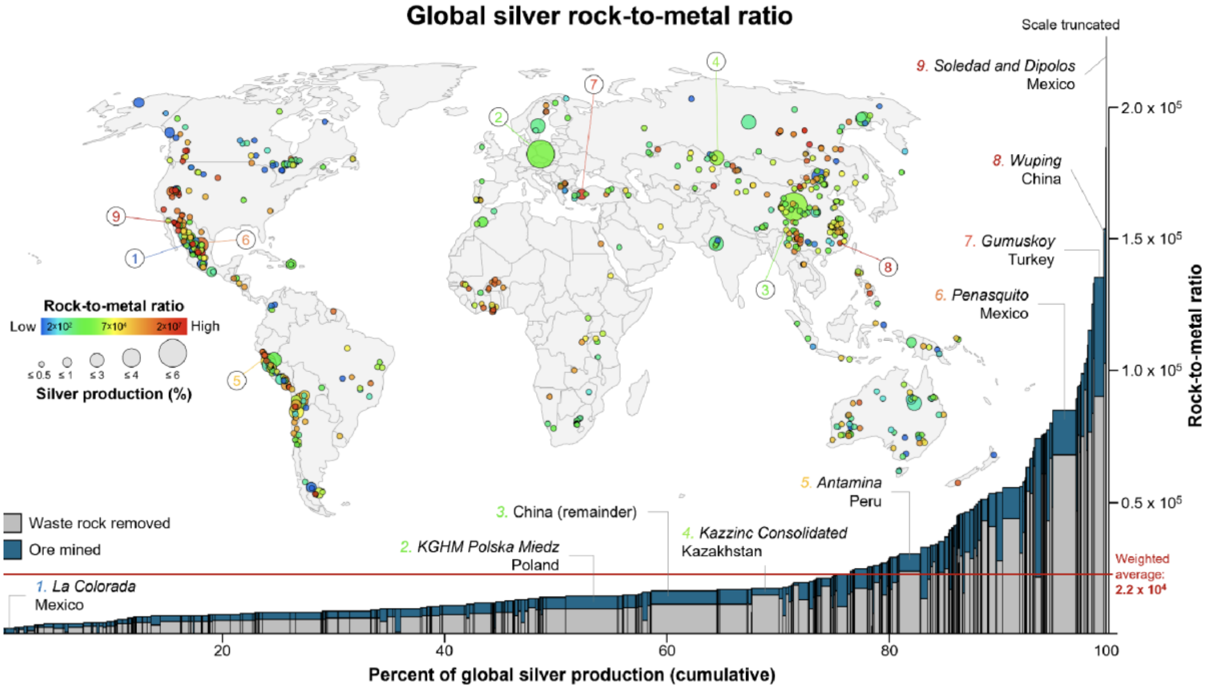
Comparison of real silver price and Jacks data 1900=100



Page 26 shows the good correlation between gold price and oil price, because gold needs a lot of oil to be produced it is the same with silver price and oil price

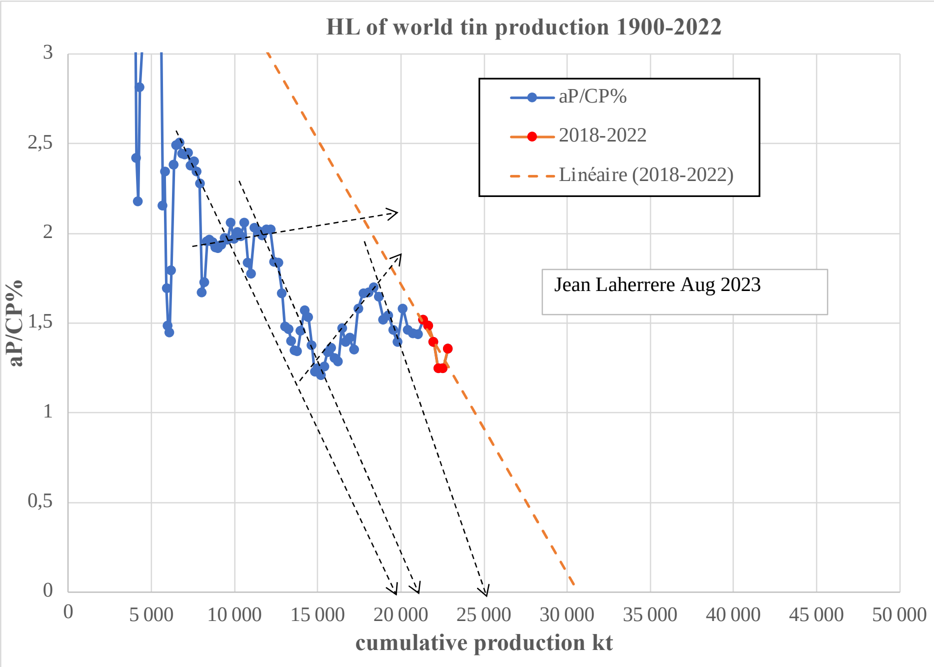


Nassar et al 2022 displays the rock to metal ration map with a weighted average of 2200

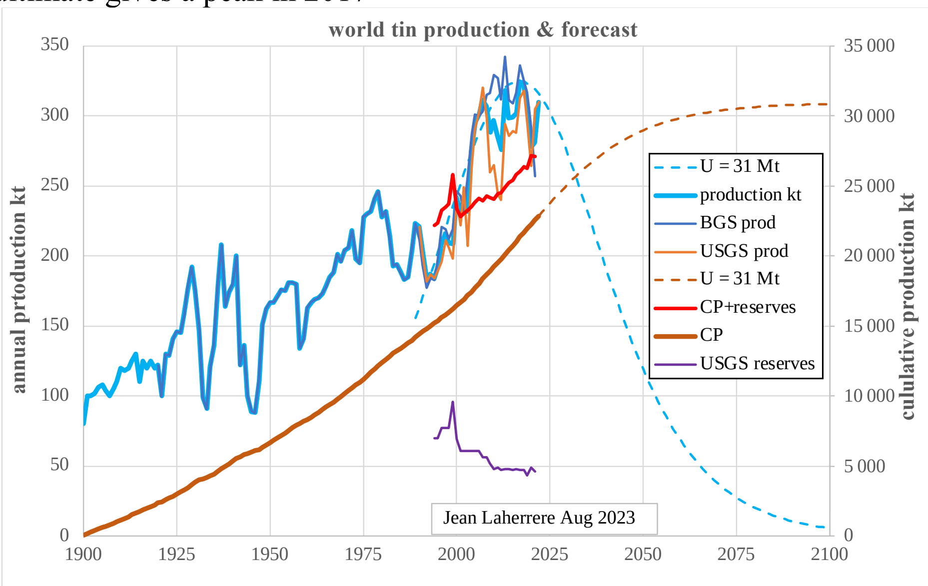


-tin = Sn

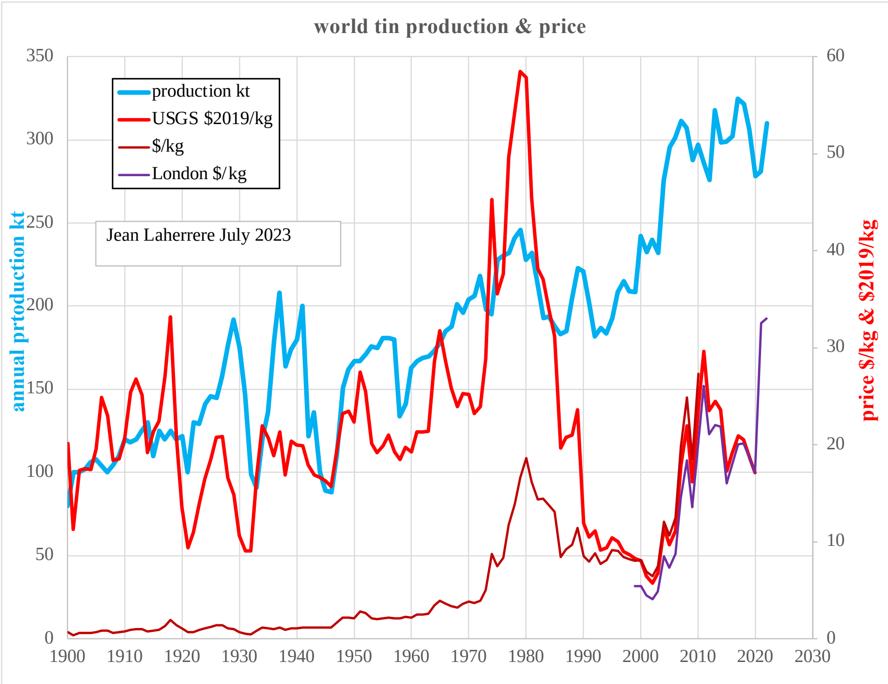
HL of world tin production trends (2007-2022) poorly towards 31 Mt, when USGS CP+reserves is 27 Mt



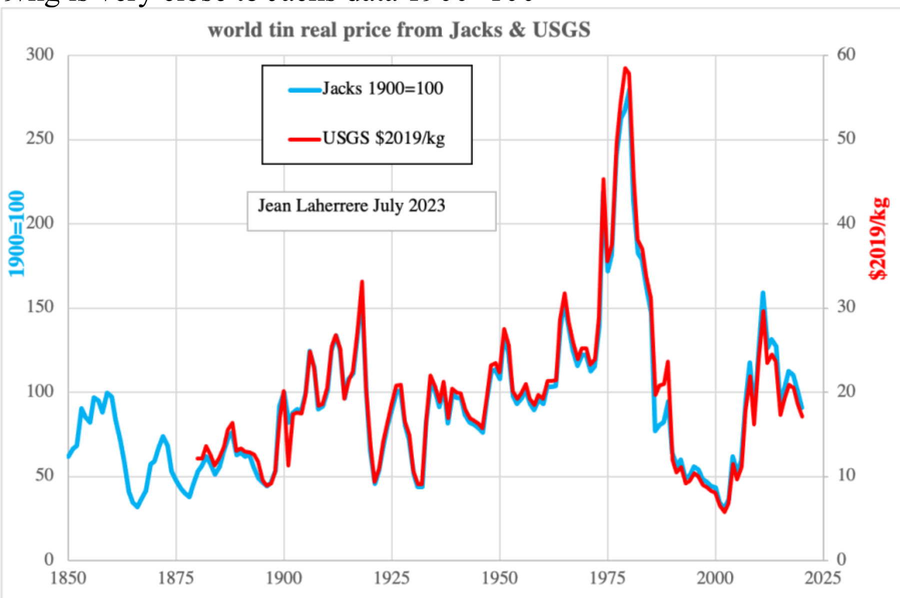
The 31 Mt ultimate gives a peak in 2017



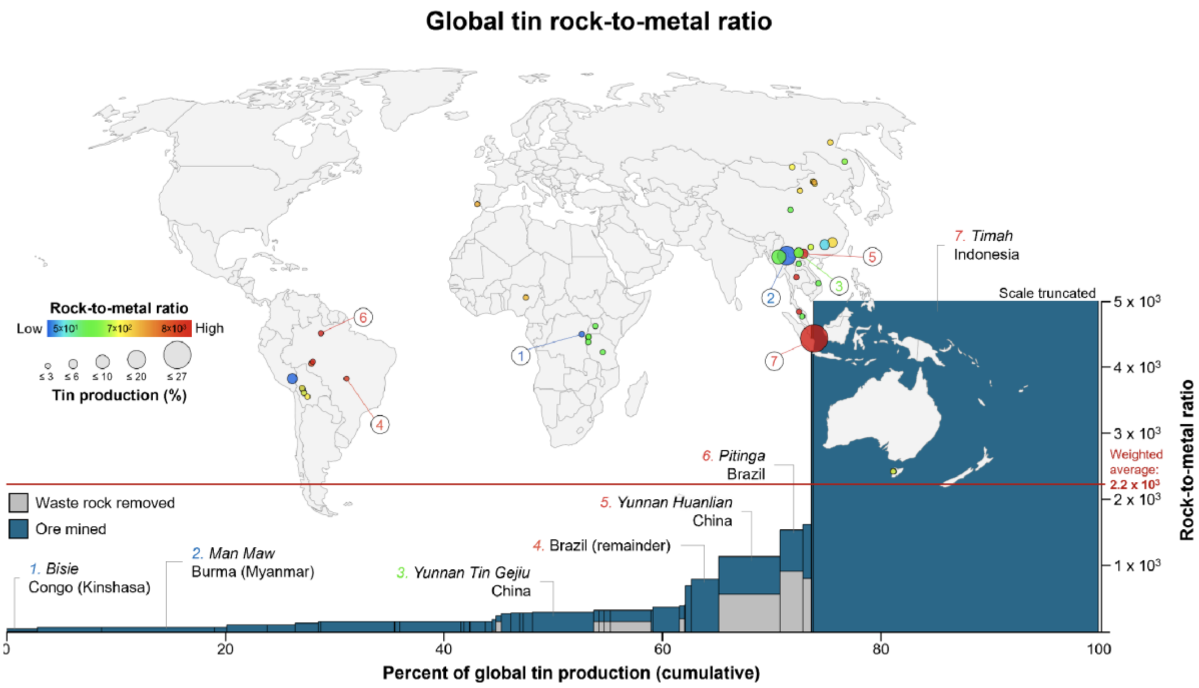
There is a good correlation between tin production and tin price since 1900, but being at production peak in 2017 tin, price should continue to rise.



USGS $2019/kg is very close to Jacks data 1900=100

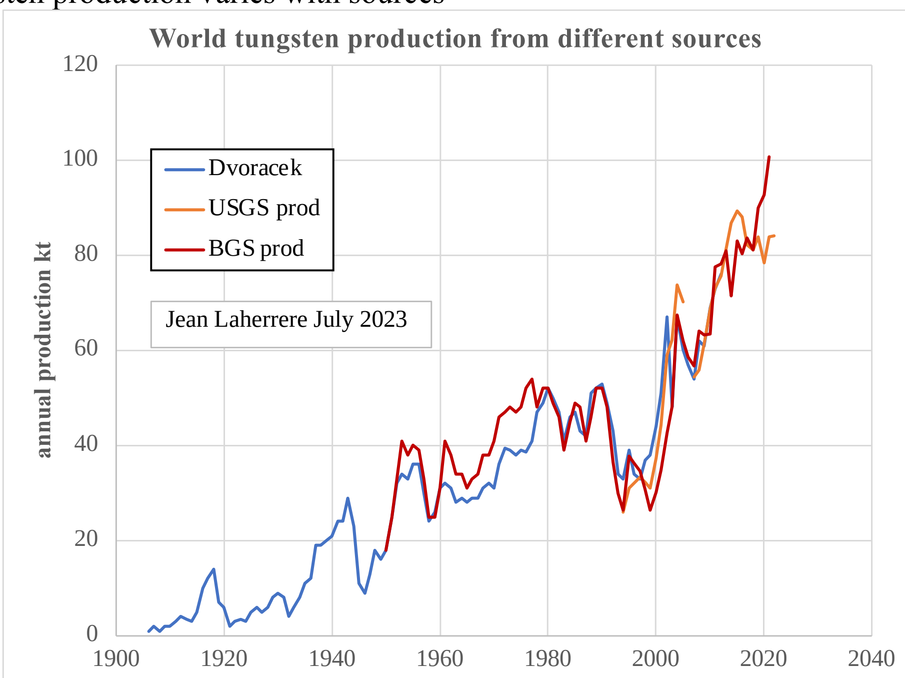


Nassar et al 2022 displays rock to metal ratio map and weighted average of 2200

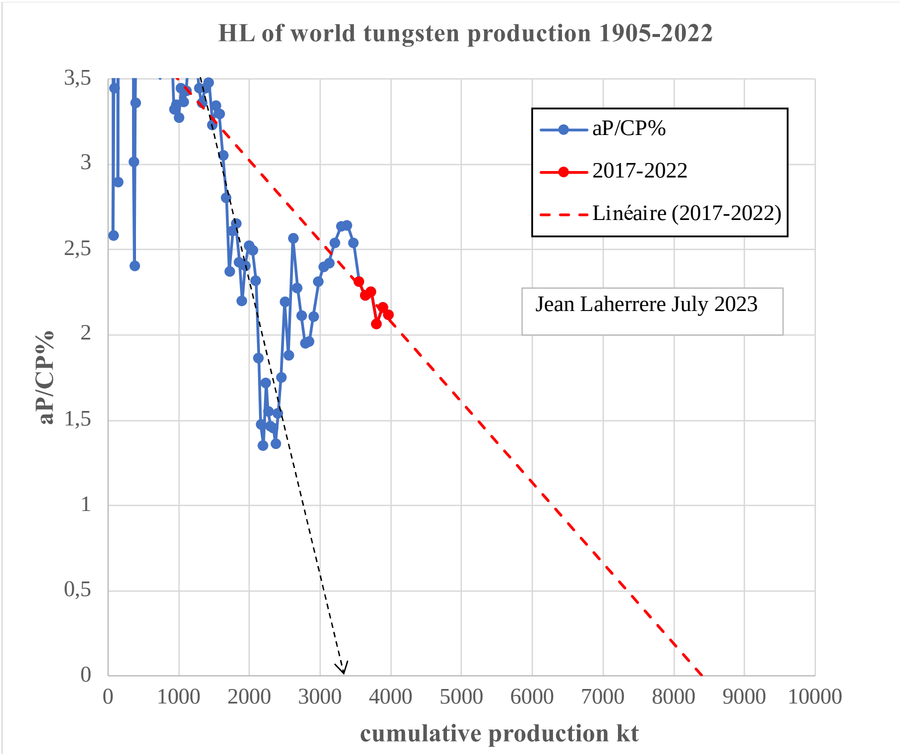


-tungsten = W

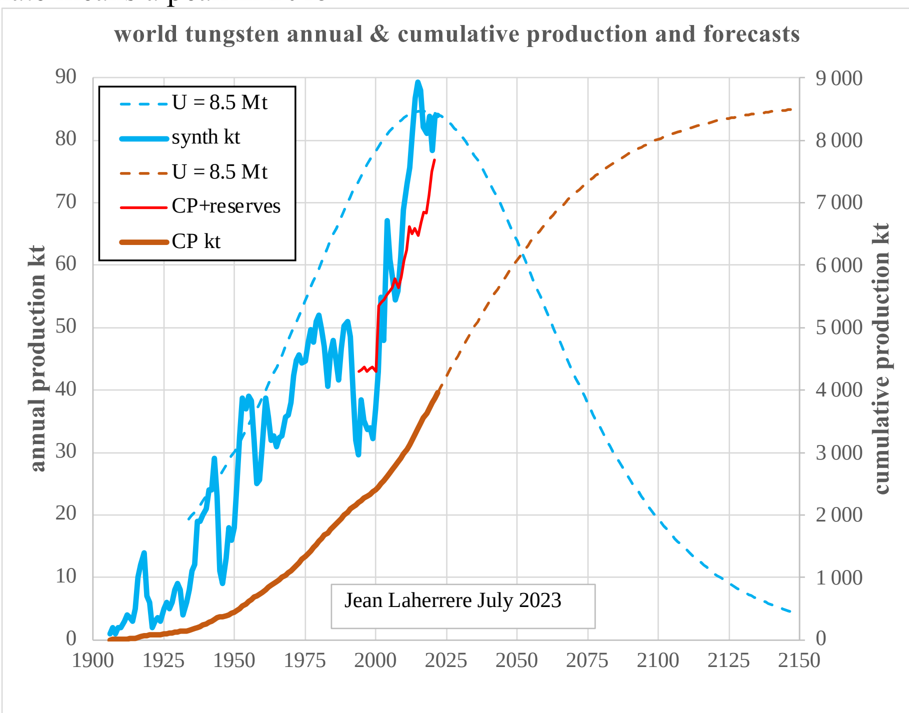
World tungsten production varies with sources



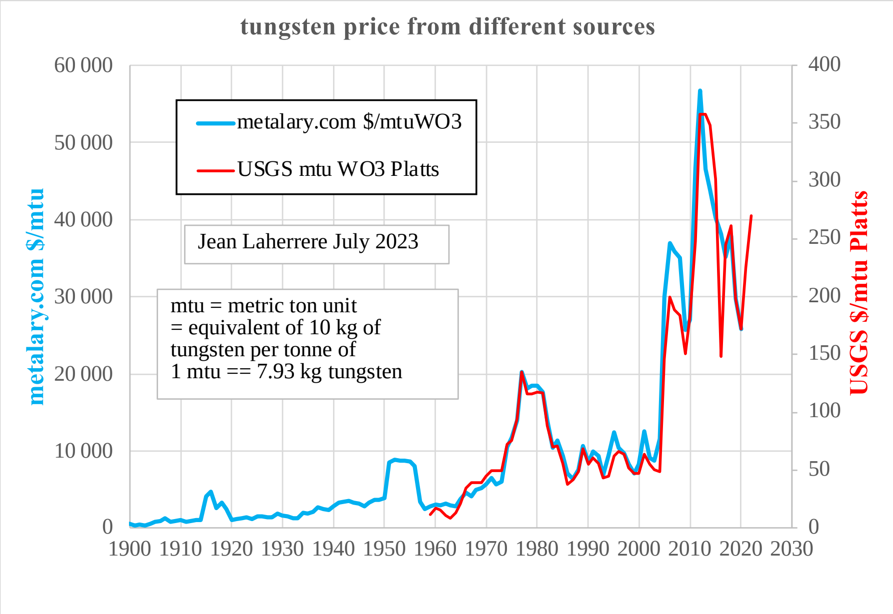
HL of tungsten production trends (2017-2022) poorly toward 8500 kt = 8.5 Mt when USGS CP+reserves is 7.7 Mt



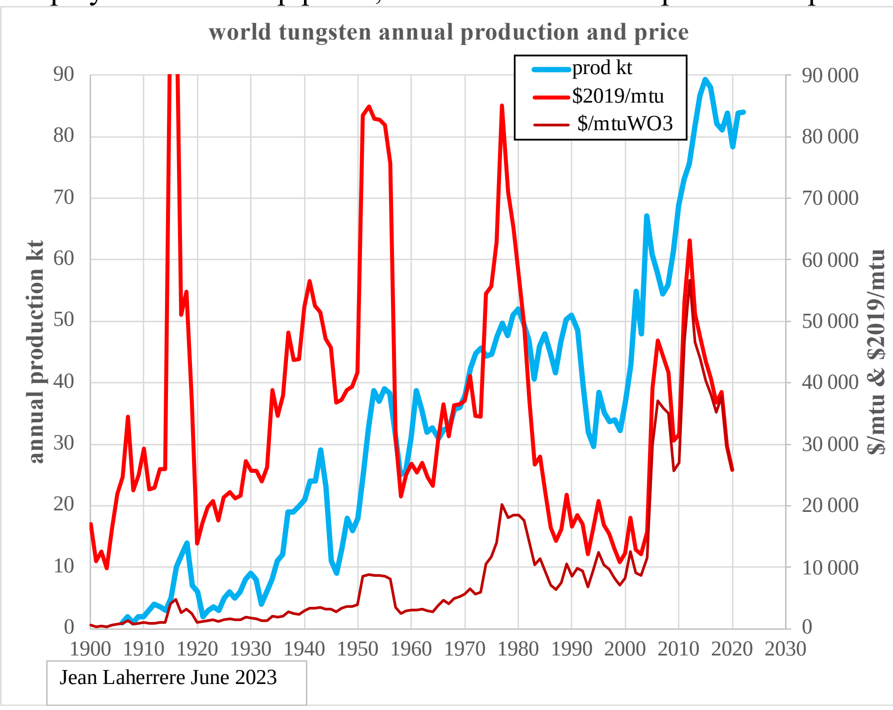
8.5 Mt ultimate means a peak in 2015



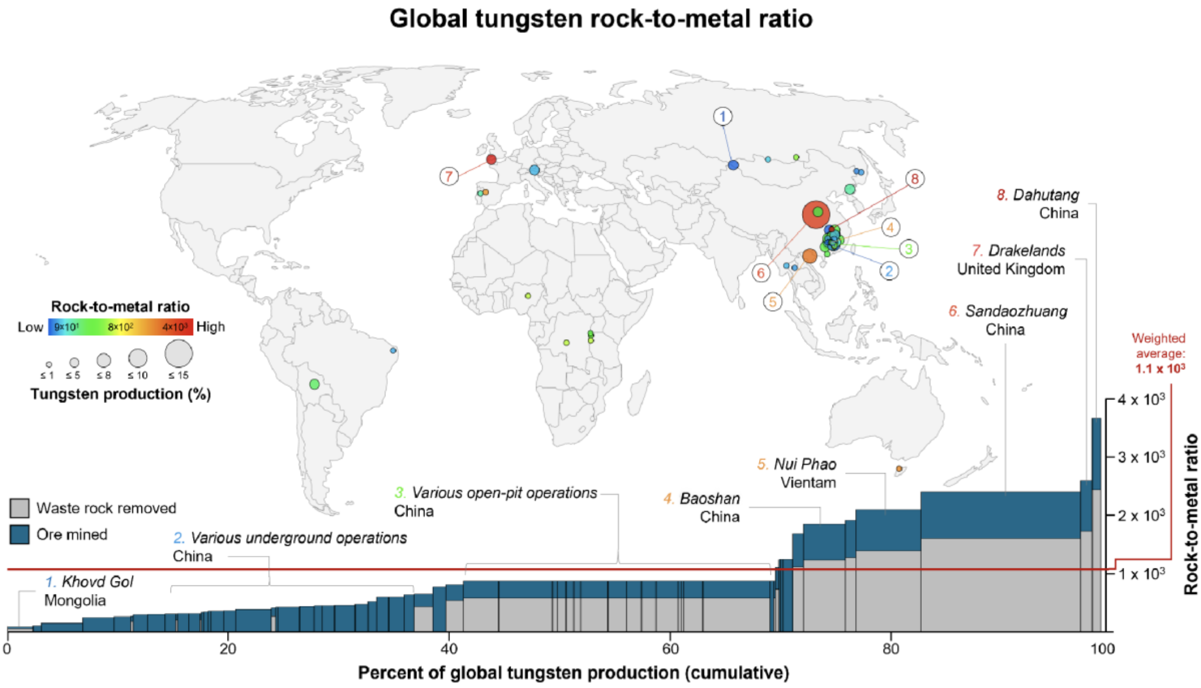
It is difficult to obtain a clear view of W price as data varies with sources.
The unit is often the mtu = metric ton unit, which a bad name because metric ton = tonne = 1000 kg
A metric ton unit of tungsten trioxide (WO_3) contains 7.93 kg of tungsten
Tungsten is only manufactured in China costing about 60-120 $/kg



W real price displays several sharp peaks, which correlate with production peaks



Nassar et al 2022 displays rock to metal ratio map, as weighted average of 1100:



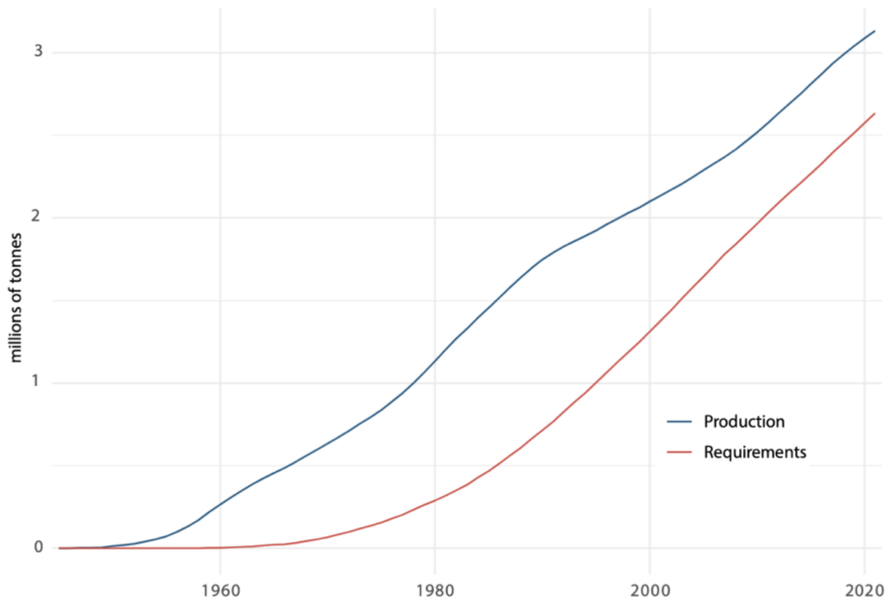
-uranium = U

World U requirements were easily filled by production

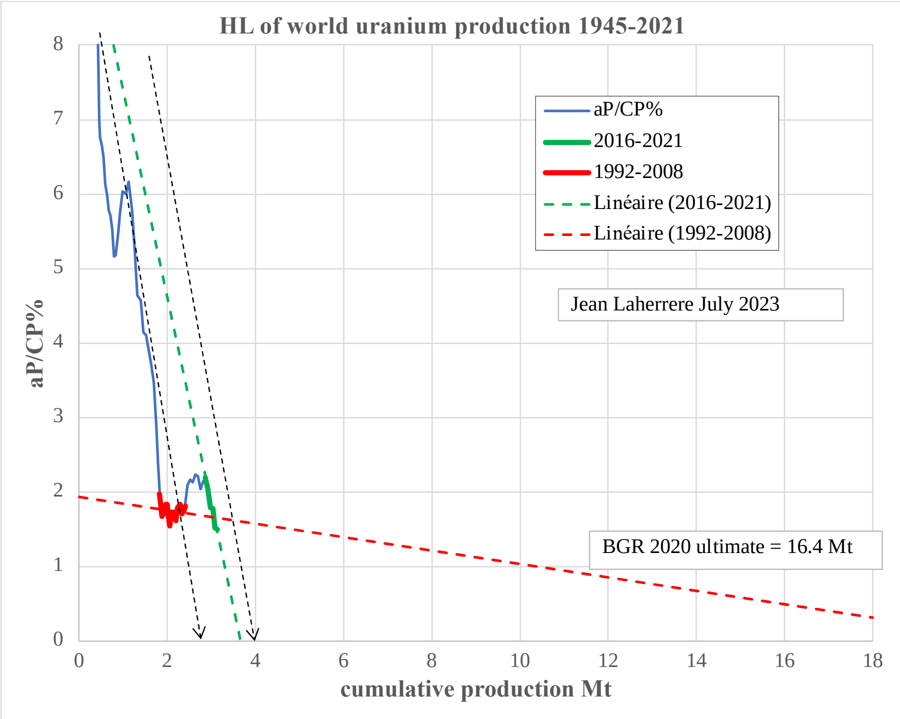
https://www.oecd-nea.org/jcms/pl_52718/uranium-2020-resources-production-and-demand

Figure 2.7. **World cumulative uranium production and requirements**

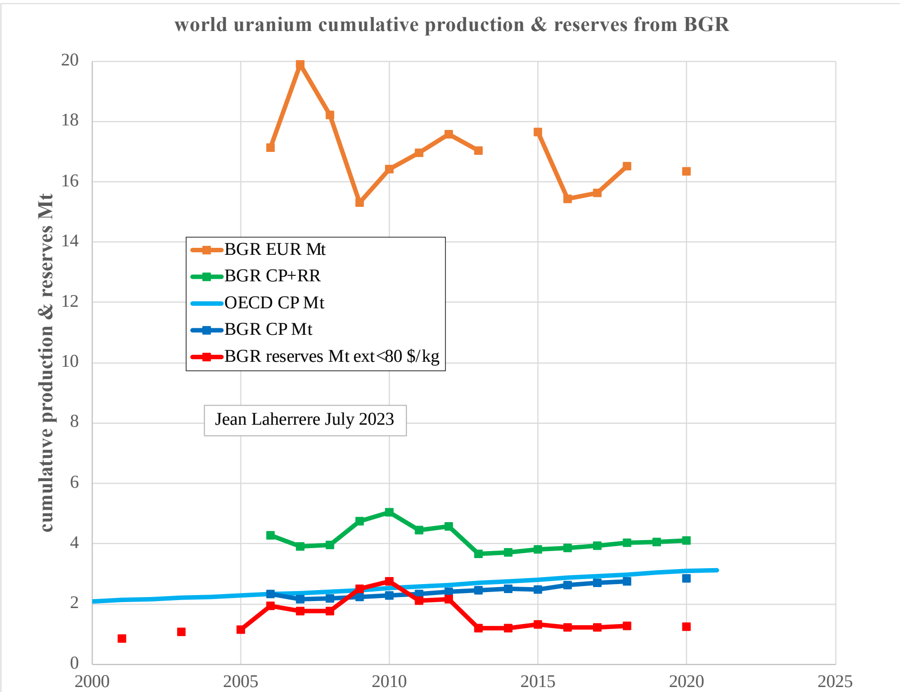
(1949-2021)



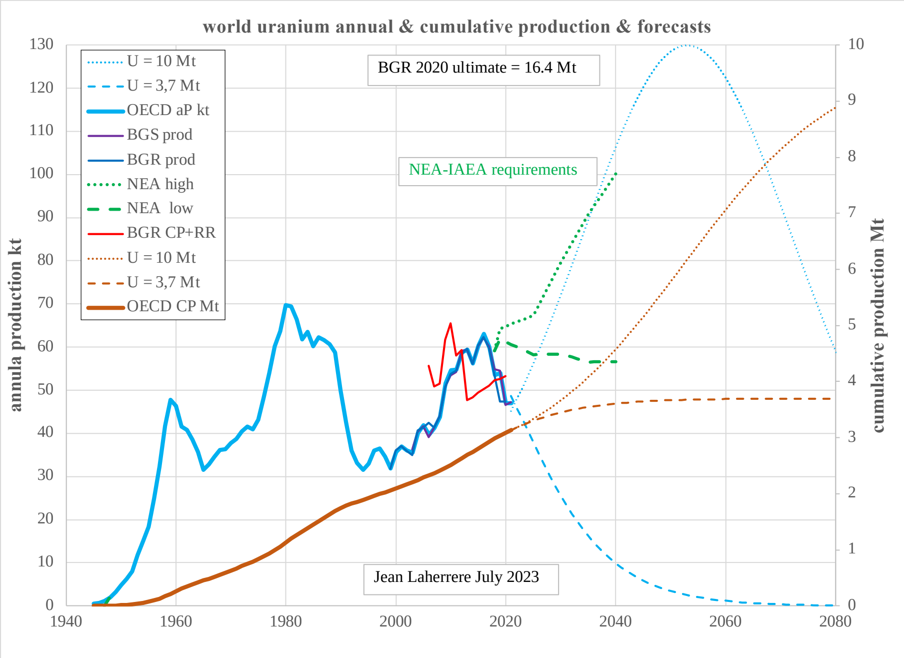
HL of world uranium production is erratic, trending to a large range:



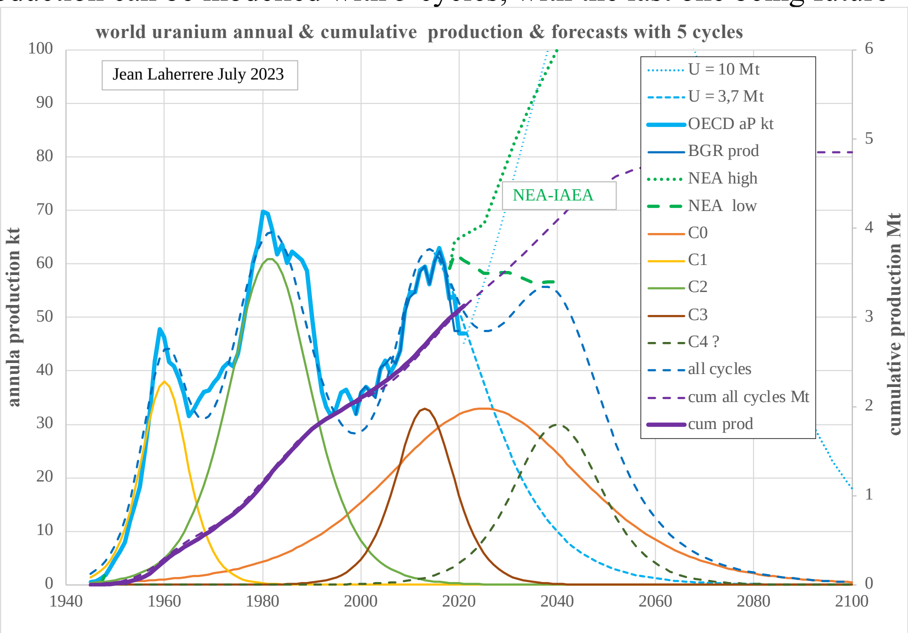
BGR reports U ultimates, since 2006, oscillating around 17 Mt, when CP+ reserves around 4 Mt



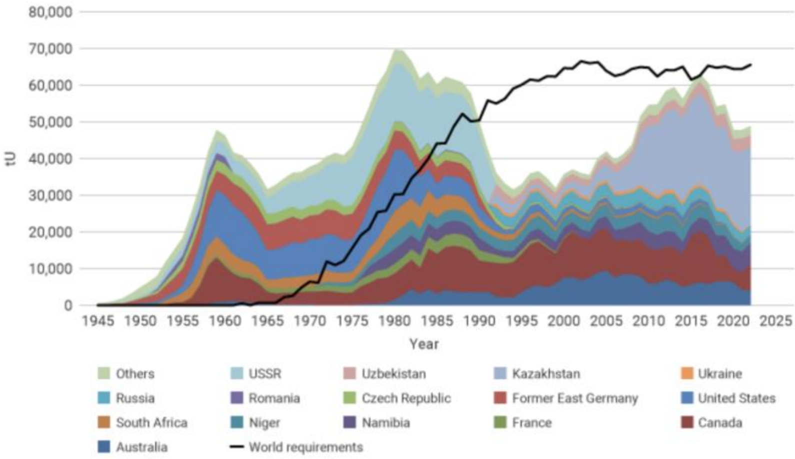
World U production is forecasted with U=3.7 Mt as U=10 Mt, which gives a peak around 2050 at 130 kt, in with NEA_IAIE future requirements up to 2040



World U production can be modelled with 5 cycles, with the last one being future

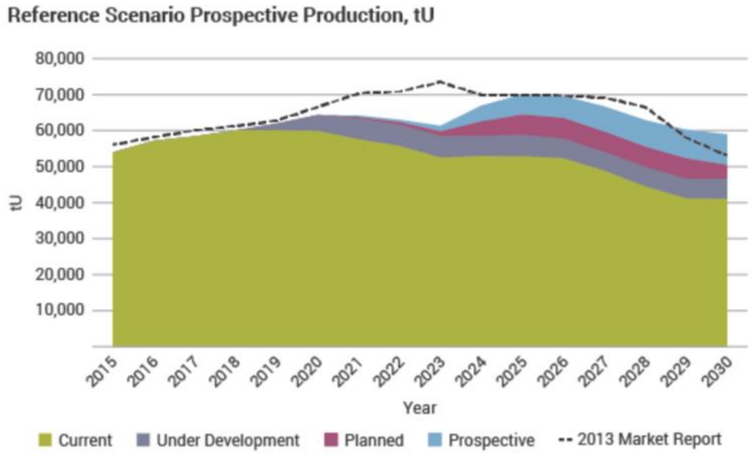


World Nuclear organization https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/uranium-markets.aspx reports in July 2023 U production: past and future and prices



World uranium production and reactor requirements, 1945-2022, tU (source: OECD-NEA, IAEA, World Nuclear Association)

The WNA forecasted U production displays an increase from 2015 to 2020, contrary to the previous graph showing a decrease from 2015 to 2020 (as in our production graph)?

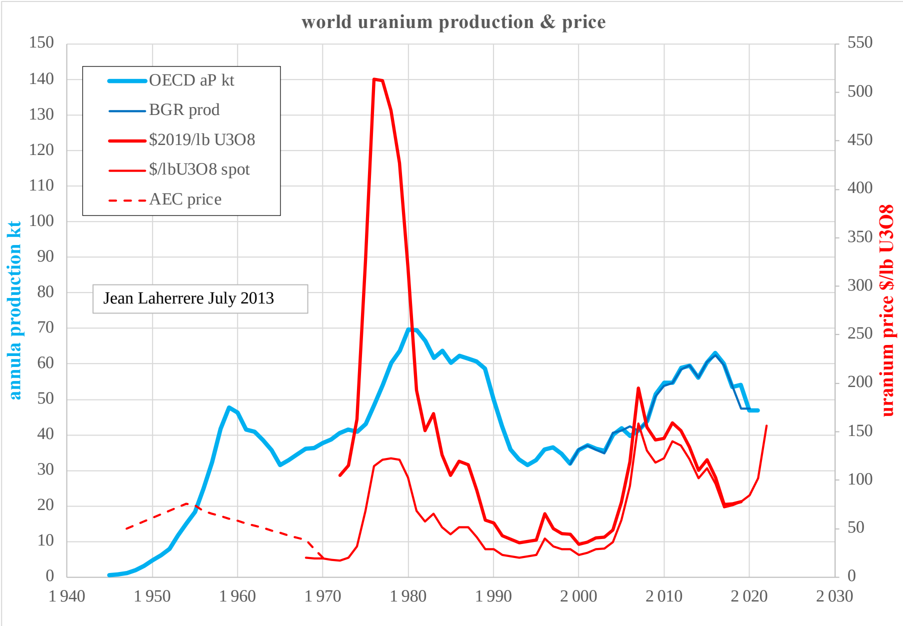


Reference Scenario for uranium production, tU (source: The Nuclear Fuel Report, World Nuclear Association)

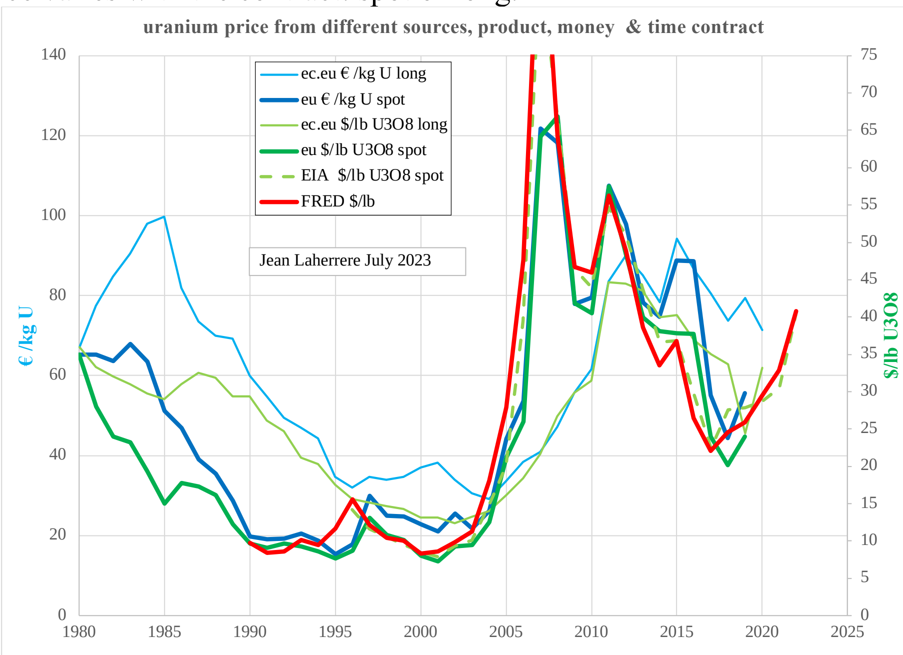
Graph of spot and long-term price

Spot and long-term uranium prices (2000-2022) (Source: Cameco, UxC, TradeTech)

World uranium production and price: price peaks are followed few years later by production peaks

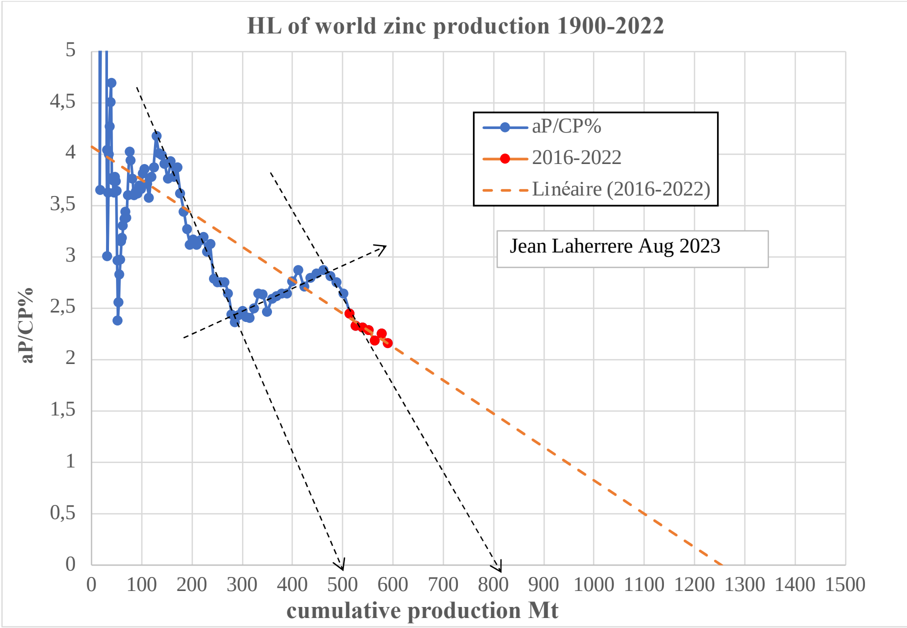


Uranium price varies with the contract: spot or long.

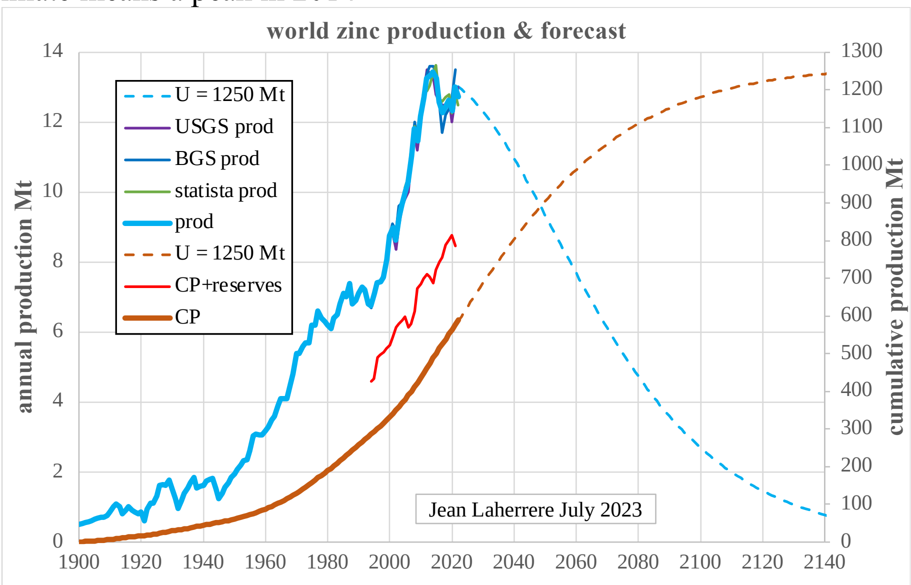


-zinc = Zn

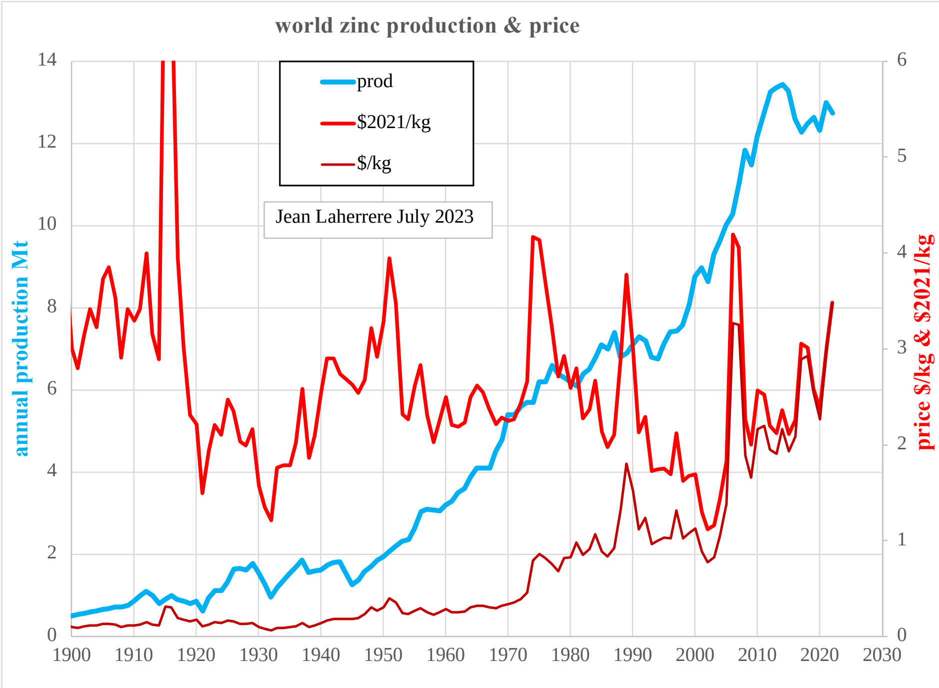
HL of world zinc production trends (2016-2022) towards 1250 Mt, when USGS CP+reserves = 800 Mt



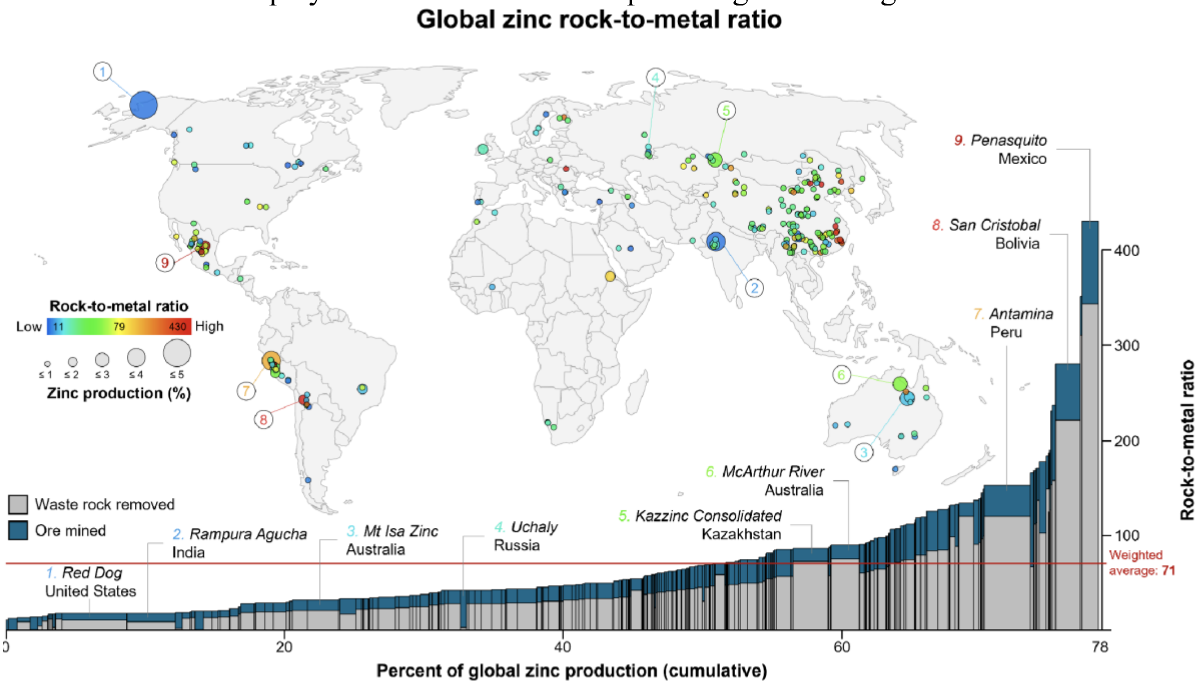
1250 Mt ultimate means a peak in 2014



Zinc sharp price peaks do not disturb much production.



Nassar et al 2022 displays rock to metal ratio map as weighted average of 71



-Synthesis

Ranked by 2022 production in Mt

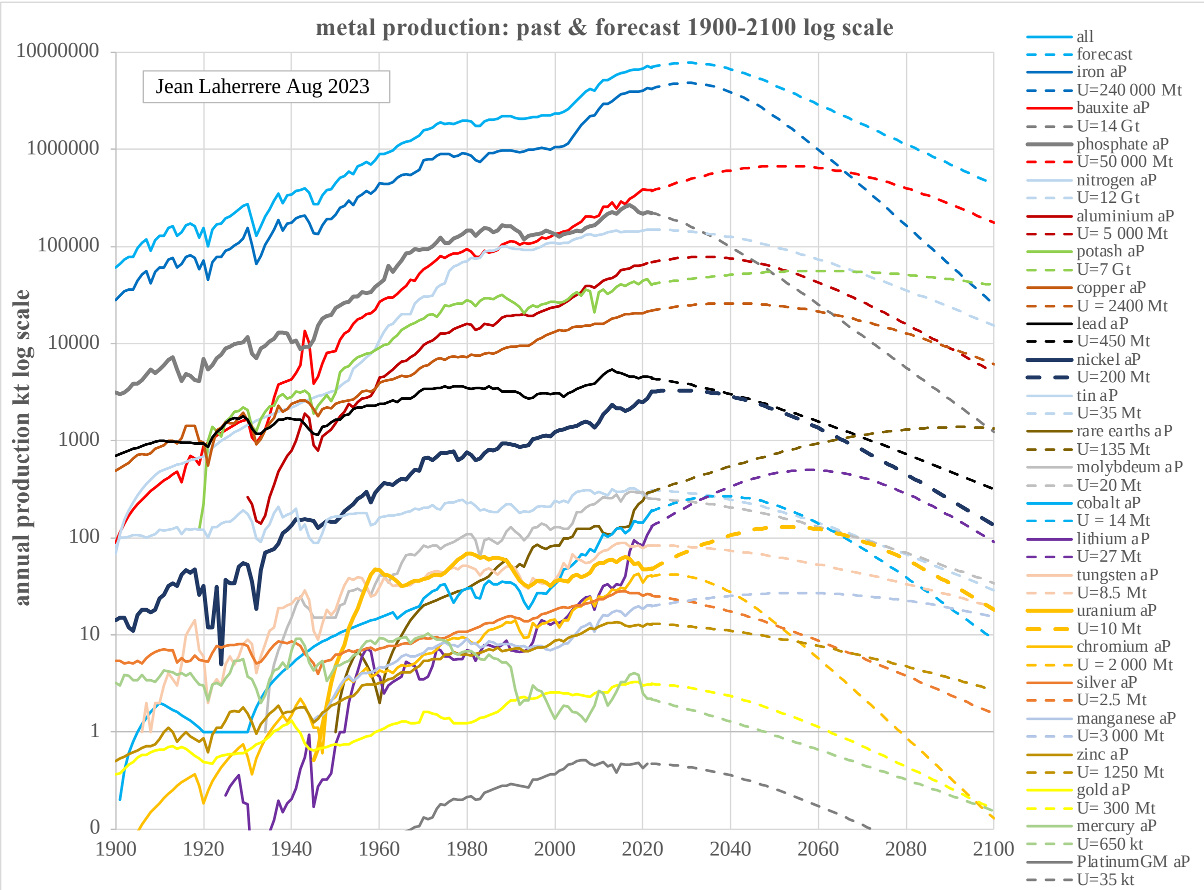
2023	Mt	Mt	Mt		Mt	Mt		Mt	$/t		
metal Mt	2022 prod	2040 forecast	peak value	peak time	cum 2022	ultimate	quality HL	2019 ultimate	2022 price $/t	peak res Valero	peak 2019
iron	4200	3900	4500	2024	103 000	240 000	F	220 000	50	2040	2023
steel	1900	1800	2000	2028	66 000	150 000	P	155 000	415		2030
bauxite	380	610	375	2052	9 000	50 000	VP	50 000	30 000		
phosphate	220	99	270	2017	9 800	14 000	P	12 000	240	2031	2017
nitrogen	150	120	150	2021	5 600	12 000	F	10 500	1 200		2019
potash	40	50	56	2060	1 800	7 000	P	8 000	1 000		2060
aluminium	65	74	78	2033	1 600	5 000	F	5 000	3 300	2050	2034
manganese	20	25	27	2055	660	3 000	P	2 500	2 000	2007	2047
chromium	41	38	45	2019	1 000	2000	VP	2 000	21 000	2015	2019
copper	22	26	26	2040	800	3 000	P	2 000	8 800	2012	2031
zinc	13	11	13	2015	590	1 250	P	900	3 800	1999	2012
lead	4.5	3	5.5	2013	300	450	P	425	2 500	1989	2013
nickel	3.2	2.8	3,3	2028	77	200	VVP	180	24 000	2017	2025
rare earths	0.3	0.5	1.4	2110	5	135	VP	125	1000-2 000 000	2092	2100
tin	0.3	0.25	0.3	2017	23	35	P	40	33 000	1979	2018
molybdenum	0.25	0.17	0.3	2020	9.2	20	P	30	39 000	2018	2038
lithium	0,13	0.42	0.6	2054	1.3	27	useless	22	37 000	2015	2060
cobalt	0.19	0.27	0.26	2038	3.5	14	VP	10	64 000	2042	2030
tungsten	0.08	0.07	0.09	2018	4.0	8.5	F	10	270		2034
silver	0,026	0,017	0,028	2015	1,7	2,5	F	3	700 000	1995	2018
mercury	0,002	0,001	0,01	1973	0,6	0,65	P	0,7	33 000	1960	1971
gold	0,003	0,002	0,003	2019	0,19	0,3	P	0,3	57 000 000	1994	2019
PGM	0,00045	0,0003	0,0005	2006	0,002	0,035	F	0,03	70 000 000 plat		2007
PGM	0,00045	0,0006	0,0005	2006	0,002	0,09	useless	0,09	71 000 000 plat		2065

Rank

Rank by peak time, annual 2022 production, ultimate

rank	metal	peak time		metal	aP2022 Mt		metal Mt	U	cum 2022	remaining U
1	mercury	1973		iron	4200		iron	240000	103000	137000
2	PGM	2006		steel	1885		steel	150000	66000	84000
3	lead	2013		bauxite	380		bauxite	50000	9000	41000
4	zinc	2015		phosphate	220		phosphate	14000	9800	4200
5	silver	2015		nitrogen	150		nitrogen	12000	5600	6400
6	phosphate	2017		aluminium	67		potash	7000	1800	5200
7	tin	2017		potash	40		aluminium	5000	1600	3400
8	tungsten	2018		copper	22		manganese	3000	660	2340
9	gold	2019		lead	5		copper	2400	800	1600
10	chromium	2019		nickel	3		chromium	2000	1000	1000
11	molybdenum	2020		tin	0,3		zinc	1250	590	660
12	nitrogen	2021		rare earths	0,3		lead	450	300	150
13	iron	2024		molybdeum	0,3		nickel	200	77	123
14	steel	2028		cobalt	0,2		rare earths	135	5	130
15	nickel	2028		lithium	0,1		tin	35	23	12
16	aluminium	2033		tungsten	0,1		lithium	27	1	26
17	cobalt	2038		uranium	0,05		molybdenum	20	9	11
18	copper	2040		chromium	0,04		cobalt	14	4	11
19	bauxite	2052		silver	0,03		uranium	10	3	7
20	lithium	2054		manganese	0,02		tungsten	8,5	4	5
21	manganese	2055		zinc	0,01		silver	2,5	2	0,8
22	potash	2060		gold	0,003		mercury	0,65	0,6	0,05
23	bauxite	2072		mercury	0,002		gold	0,33	0,2	0,14
24	rare earths	2110		PlatinumGM	0,001		PGM	0,035	0,002	0,033

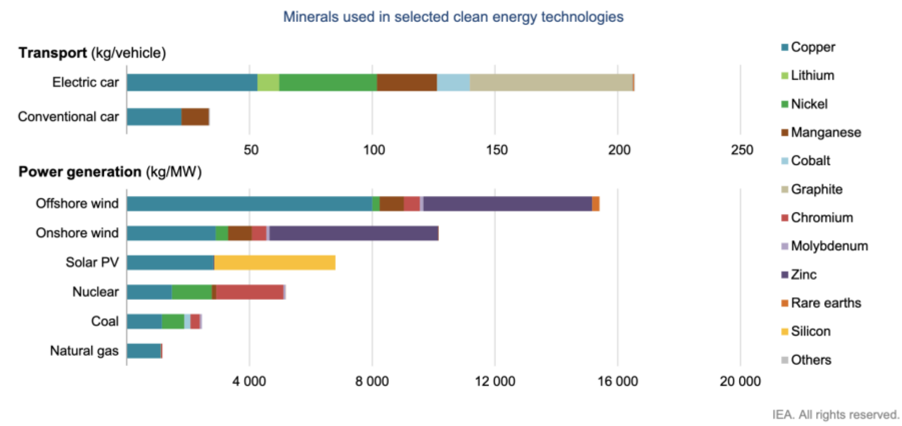
Metal past production and future production are plotted in a log scale, which allows to compare growth:



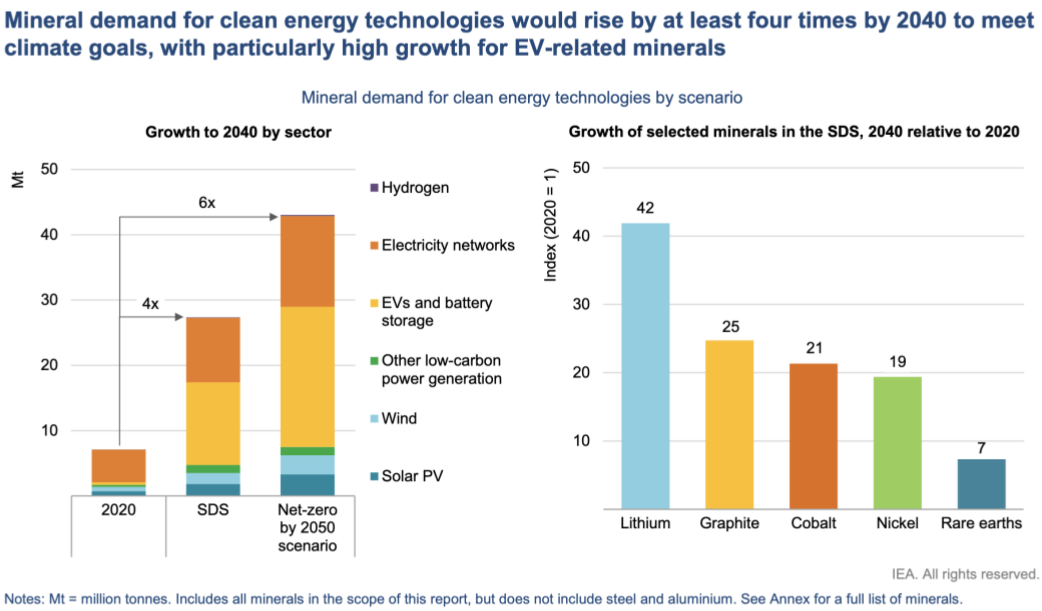
-future needs of metal

IEA claims https://www.iea.org/data-and-statistics/charts/minerals-used-in-electric-cars-compared-to-conventional-cars that electric cars will need much more metals than conventional cars

The rapid deployment of clean energy technologies as part of energy transitions implies a significant increase in demand for minerals



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.

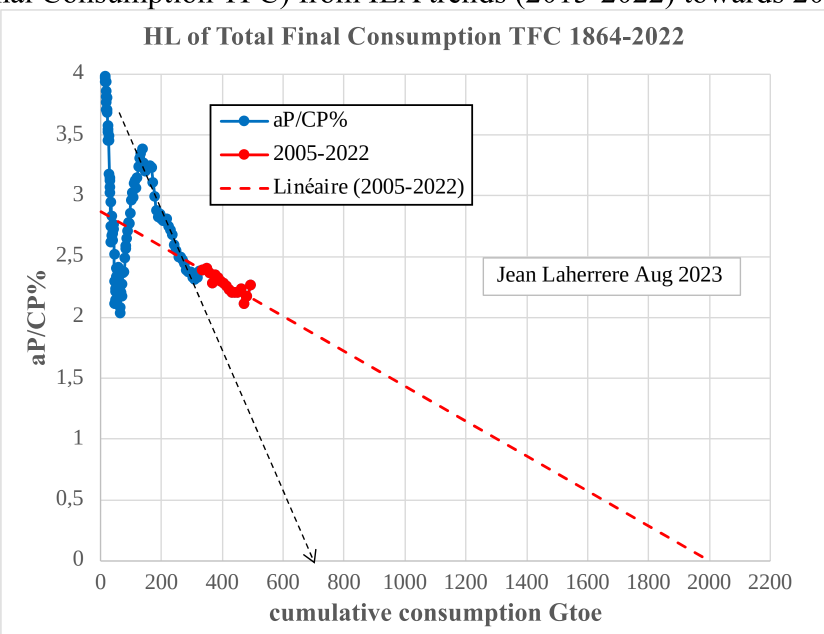


Comparison of IEA forecasts 2040/2020 and my forecasts: the difference is huge: more than 10 times for cobalt and nickel

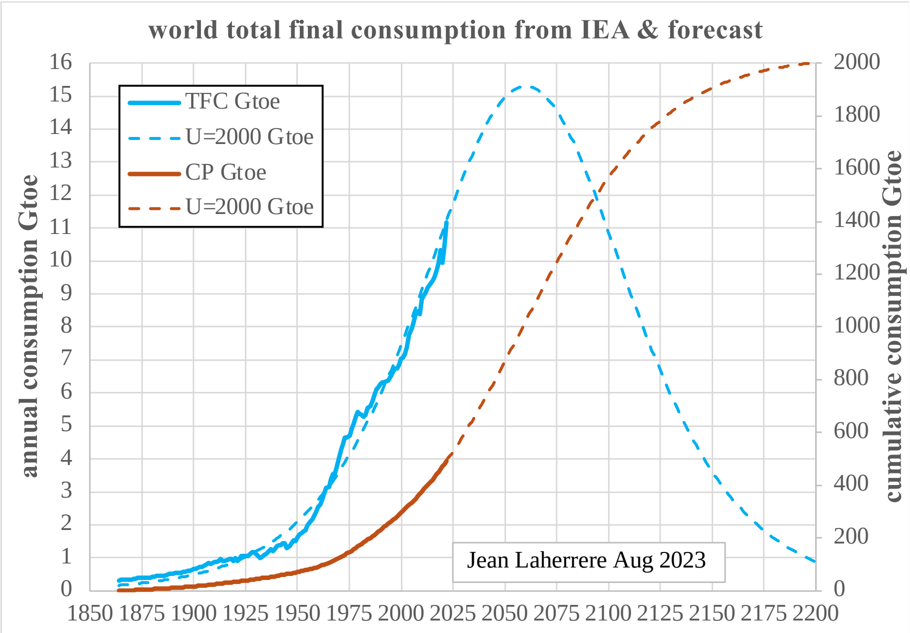
	IEA2040/2020	my forecast
lithium	42	5,1
cobalt	21	1,8
nickel	19	1,1
rare earths	7	2,3

Institute for Energy Research report "The Challenges and Costs of Net-Zero and the Future of Energy" : *"net-zero" carbon dioxide (CO2) emissions results in a 42-fold increase in lithium demand, a 25-fold increase in graphite demand, a 21-fold increase in cobalt demand, a 19-fold increase in nickel demand, and a 7-fold increase in rare earth demand by 2040.*
Using major metals production forecasts, LeVine found that by 2030, there will only be enough metals for 15.6 million EVs, while automakers claim they want to produce over 40 million.

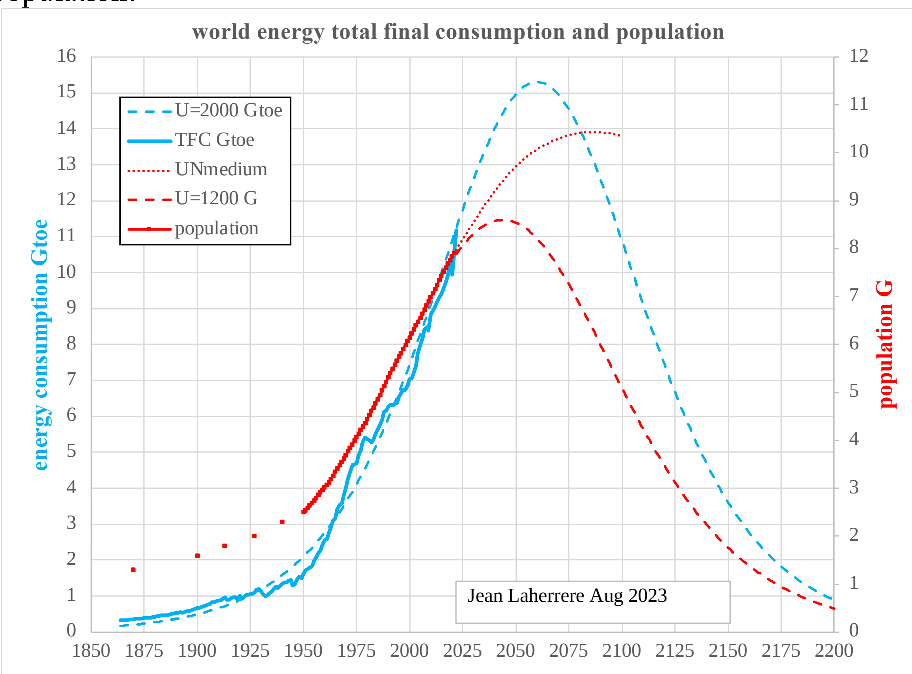
HL of Total Final Consumption TFC) from IEA trends (2015-2022) towards 2000 Gtoe



2000 Gtoe ultimate gives a peak in 2060: it means that beyond 2060 the world will lack energy to supply and to feed the world, in particular to reduce CO2 emissions with carbon capture

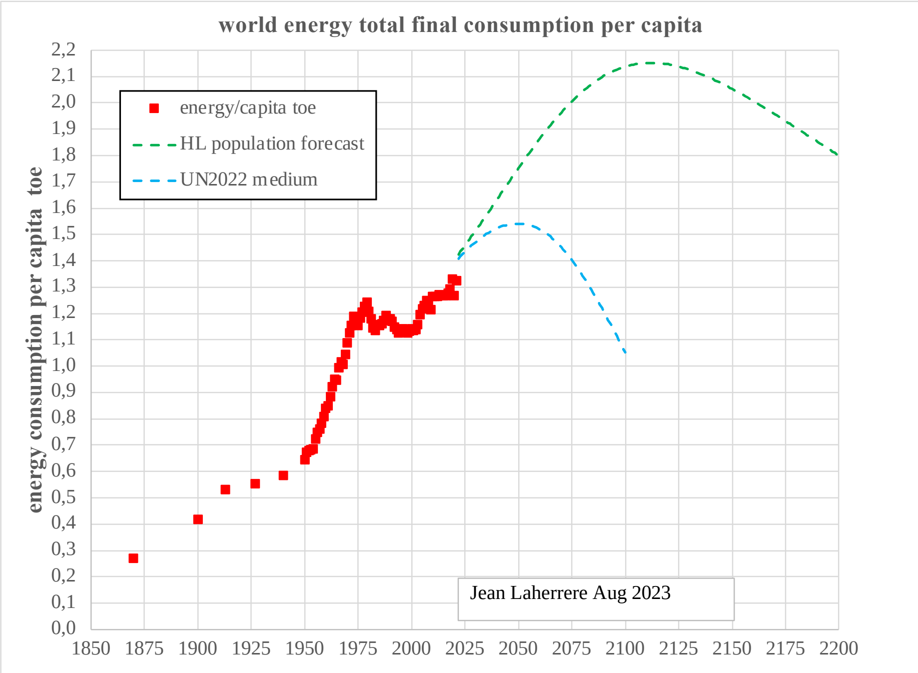


World energy consumption is compared with population with forecast from UN2022 medium with peak in 2085 at 10,4 G, as HL forecast in 2045 at 8.6 G: energy consumption grows faster than population!



I remind my 2022 paper "In 2021, 68% of the world is going into extinction"
https://aspofrance.org/2022/09/18/in-2021-68-of-the-world-is-going-into-extinction

The energy consumption per capita was 0.4 toe in 1900 and increased sharply during the “30 Glorious” 1949-1979 to 1.2 toe, then plateau and increase since 2000 to 1.3 in 2021. In future energy consumption per capita will continue to increase to 1.5 toe in 2050 for the UN 2022 medium fertility forecast and to over 2 toe in 2100 in the case of HL forecast.



It appears that the world future problem is not resources or energy but fertility: South Korea has hard and clever workers, but their fertility is very low= 0,88 children per woman and South Korea population, which peaked in 2020 at 52 M, will be 24 M in 2100 (UN medium)!

There are very few publications on energy peak when there are many on fossil fuels peak and metal peak.
Our modern society is run by energy and not by economy: it is why it is important to forecast energy peak.
HL is not a good tool to forecast peak (reliable reserves when available are better), but for energy it is the only way I know to do it.

In 2008 I presented in Oslo to Statoil a paper "Advice from an old geologist-geophysicist on how to understand Nature" http://aspofrance.viabloga.com/files/JL_Statoil08_long.pdf with the following chapter on uncertainty
Uncertainty
The more I know, the more I know that I do not know, and the others neither
-science is in need of breakthrough = Lee Smolin L. 2006 "The troubles in physics - the rise of string theory, the fall of science, and what comes next" Houghton Mifflin
-string theory has not achieved anything concrete since 30 years
-quanta mechanics is incompatible with the theory of relativity
-standard model of particles seems to forget that particles are also waves
-I bet that the Higgs boson will not be found in the LHC (starting its experiments this month)
-the electron discovered more than 100 years is badly known (size, location), only its probability : is it a particle, a wave, both or neither?
-it is assumed for 70 years that the Universe is constituted by more than 95 % of unknown dark energy and dark matter (slight change of Newton's law makes dark matter disappear)
-Poincare has shown that the 3 bodies problem cannot be resolved with equations, only computers can approximate the problem with no certainty
-Heisenberg ; uncertainty principle = if a particle location is known with accuracy, its move is unknown, and reciprocally

-Lorentz : a butterfly (it was first a seagull) flipping its wings in Texas can create a tornado in Brazil = chaos and importance of small effects. Uncertainty on initial conditions makes the solar system evolution uncertain in 100 Ma, like a pool ball after ten bounces
-prion (mad cows), AIDS, SARS were unknown 30 years ago, what is next?
-bacteria was the first living creature and will be the last. Human beings dominate the Earth with their size and complexity, but not by their weight or number, and depend upon bacteria for their digestion

I was wrong on Higgs boson found in 2012 at the CERN by two detectors CMS & Atlas but its discovery did not improve the particles standard model, which introduces the quark, which makes protons and neutrons. In 2023 we still do not know what really a quark is. Nobody knows what is inside the atom's nucleus!

The Higgs boson is just an anomaly found on a graph of events versus energy in Gev from a plot of points versus a background-only fit : it looks to be uncertain but the CERN speaks about a high certainty of 99.9999%!

Higgs boson is called "God particle", but it should be called "Santa Claus particle"!

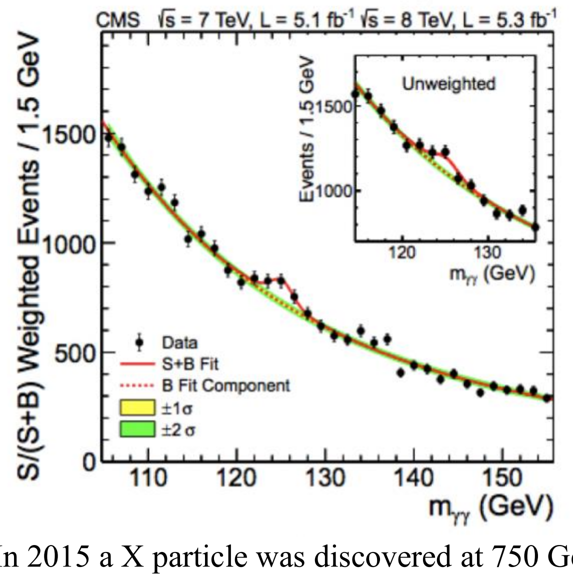
The problem is that in the present world there are many Gods: which one is right?

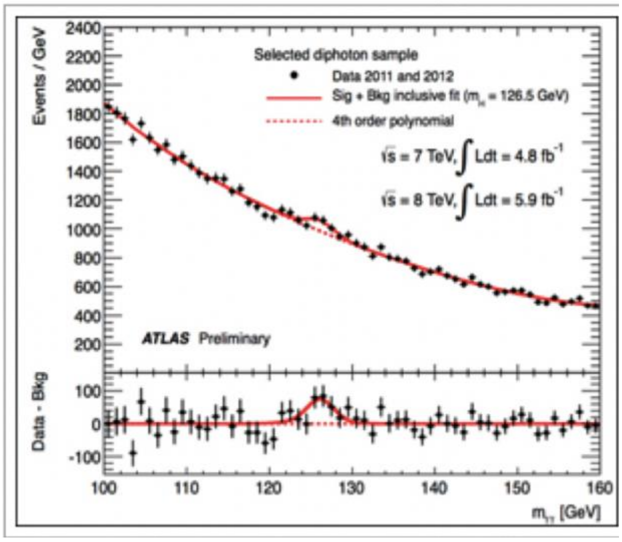
But the USDOE spoke about "New Particle Discovered May be the Long-Sought Higgs" https://science.osti.gov/hep/Highlights/2012/HEP-2012-10-b

In my 2019 paper "Le pic pétrolier ? implication économique, climatique et démographique » Sciences Po forum 19 mars https://aspofrance.files.wordpress.com/2019/03/sciencespo-19mars2019pres.pdf I display the graph which justifies the discovery of the Higgs Boson

La particule trouvée en Juillet 2012 avec une énergie de 126,0 ±0,4 GeV pour Atlas, mais 125,3 ± 0.6 GeV pour CMS (plage commune 125,6 -125,9), est déclarée être le boson de Higgs. En 2000 une particule de 115 GeV avait été présentée comme le boson de Higgs, puis rejeté. En 2015 la particule X (750 GeV) a été proposée, puis considérée comme un artefact en 2016.

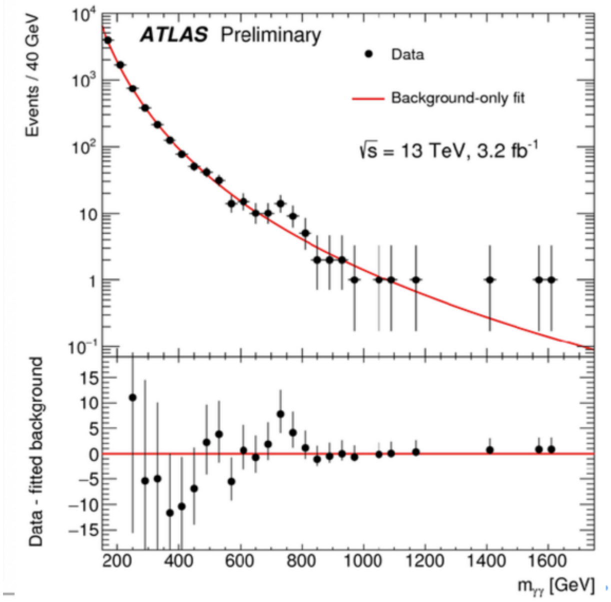
Détecteur CMS = boson Higgs → → Détecteur Atlas = boson Higgs →

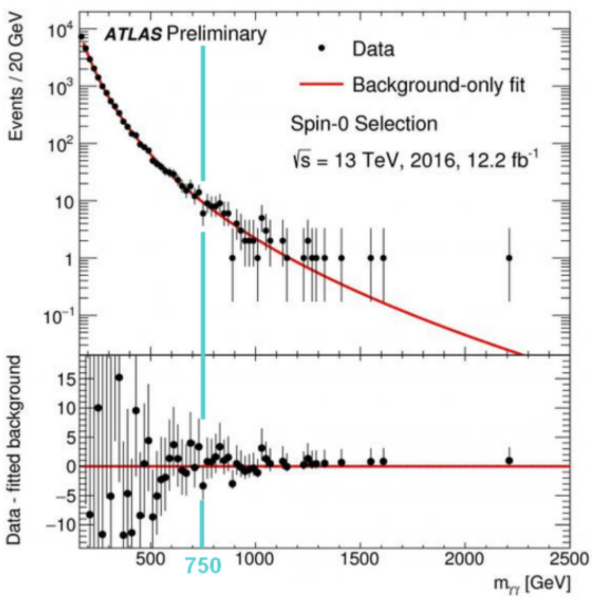




In 2015 a X particle was discovered at 750 GeV but later in 2016 stated as artefact

2015 particule X à 750 GeV 2016 = X = artefact





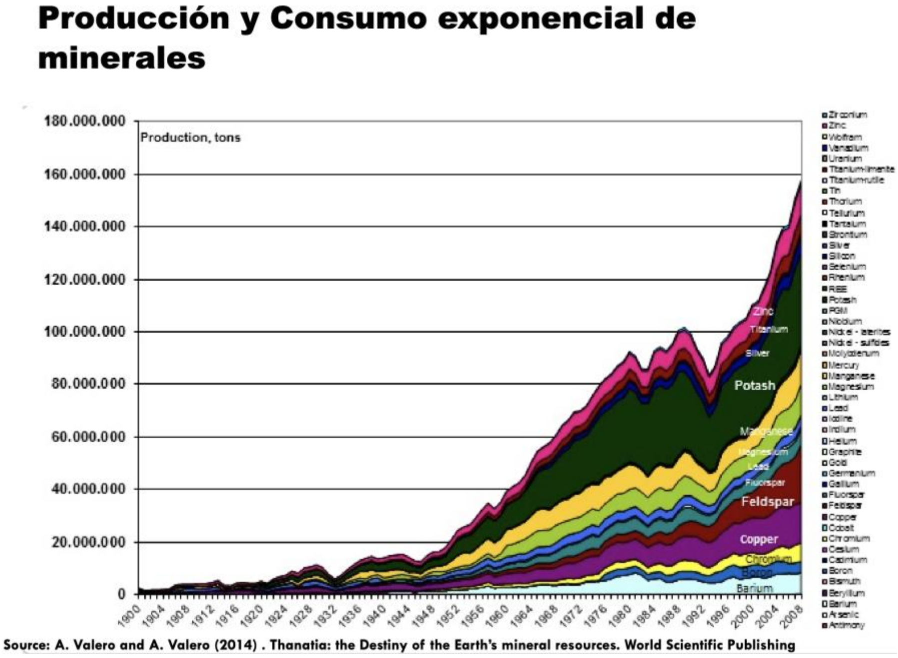
It looks more feeling than science!
It is necessary to look at these graphs to realize the uncertainty of Higgs boson and 11 years after its discovery I do not see any improvement in the explanation of the particles model.

Dark matter is a hypothetical form of matter thought to account for approximately 85% of the matter in the universe (Wikipedia)
Dark energy was introduced in the 1990s to account the universe's expansion and is assumed (Wikipedia) to represent 68% of the total energy in the present-day observable universe, assuming that the Newton equation is right.
In 1983 M.Milgrom proposed the MOND theory, changing slightly the Newton equation without any consequence to our galaxy behavior, but making dark matter unnecessary; but MOND is rejected by the present University world for wrong reasons (entropy).
But nobody knows what dark matter and dark energy are and where they are!
It is clear that a new theory on particles, is needed as for universe!

-Conclusion
Out of the 24 metals of this study, 12 metals have past peaks.
Iron could peak soon, nickel in 2028, cobalt in 2038, copper in 2040.
Metal production needs more energy against the grade decline and energy could peak around 2060.
Energy consumption per capita is increasing since 2000 and will continue at least up to 2050.
Europe wants to stop the sale of thermic vehicles by 2035, but electric cars need much more metals than thermic cars and the needed metals would not be available and the 2035 limit will be extended as unrealistic!
It is obvious for me that all the official forecasts on net zero carbon with carbon capture are unrealistic because needing too much energy, it is the same about replacing thermic cars with electric cars by lack of metals (another problem could be lack of electricity or security).
All these forecasts are political lies: it is like Santa Claus!
It is the same with the dark matter and dark energy: they are also lies.
My only conclusion: most I read in the medias are lies and the more I know, the more I do not know.

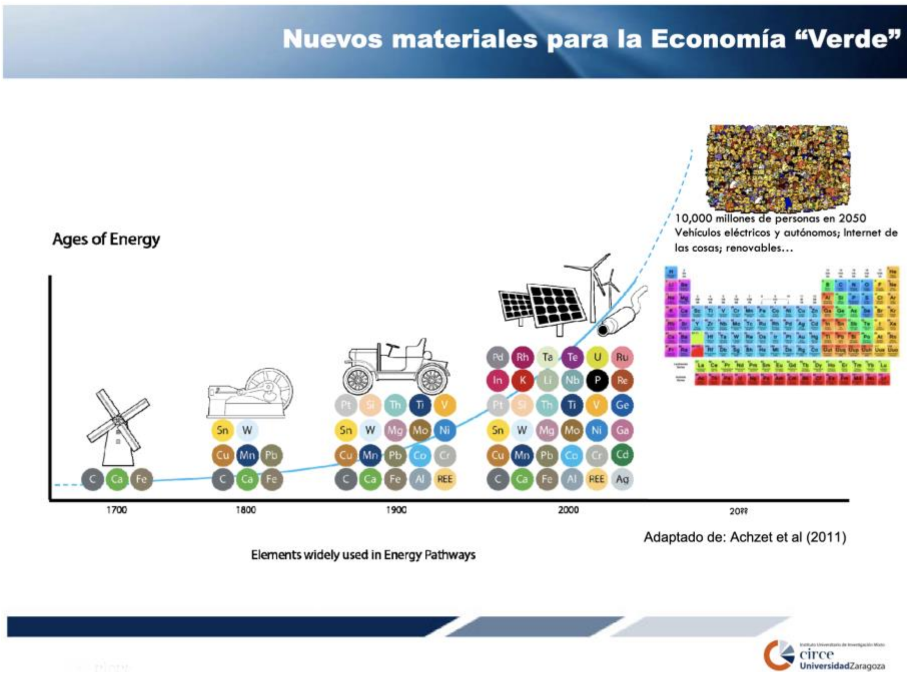
-Annex:
-Graph on metals we mined from https://www.visualcapitalist.com/all-the-metals-we-mined-in-one-visualization/

-Alicia Valero 2018 graphs:
https://lanzarotebiosfera.org/wp-content/uploads/conciencia2018/Alicia_Valero.pdf



Fe and Al are missing! Potash =K2O is displayed as the largest

New materials for green economy compared with 3 in 1700, 8 in 1800 and 20 in 1900:



https://www.sciencedirect.com/science/article/abs/pii/S0921344917301635

Assessing maximum production peak and resource availability of non-fuel mineral resources: Analyzing the influence of extractable global resources

Guiomar Calvo, Alicia Valero, Antonio Valero 2017

https://doi.org/10.1016/j.resconrec.2017.06.009