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International Copper Study Group

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Arsenic in the Global Copper Value Chain: Trends in 2022 and Beyond

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International Copper Study Group:

Intergovernmental Organization

- Membership open to any country involved in copper production, use or trade.
- Headquarters in Lisbon, Portugal with International Lead, Zinc and Nickel Study Groups
- Countries joining recently: Iran, Mongolia, DR Congo and Brazil.
- 25 ICSG member governments plus the European Union in 2022. 40 countries in 3 Groups.
- **Chile is a valued ICSG member country in 2022.**


Australia


Belgium


Chile


China


Finland


European Union


France


Germany


Greece


India


Italy


Japan


Iran


Luxembourg


Mexico


Peru


Poland


Portugal


Russian Fed.


Serbia


Spain


Sweden


United States


Brazil


Mongolia


DR Congo

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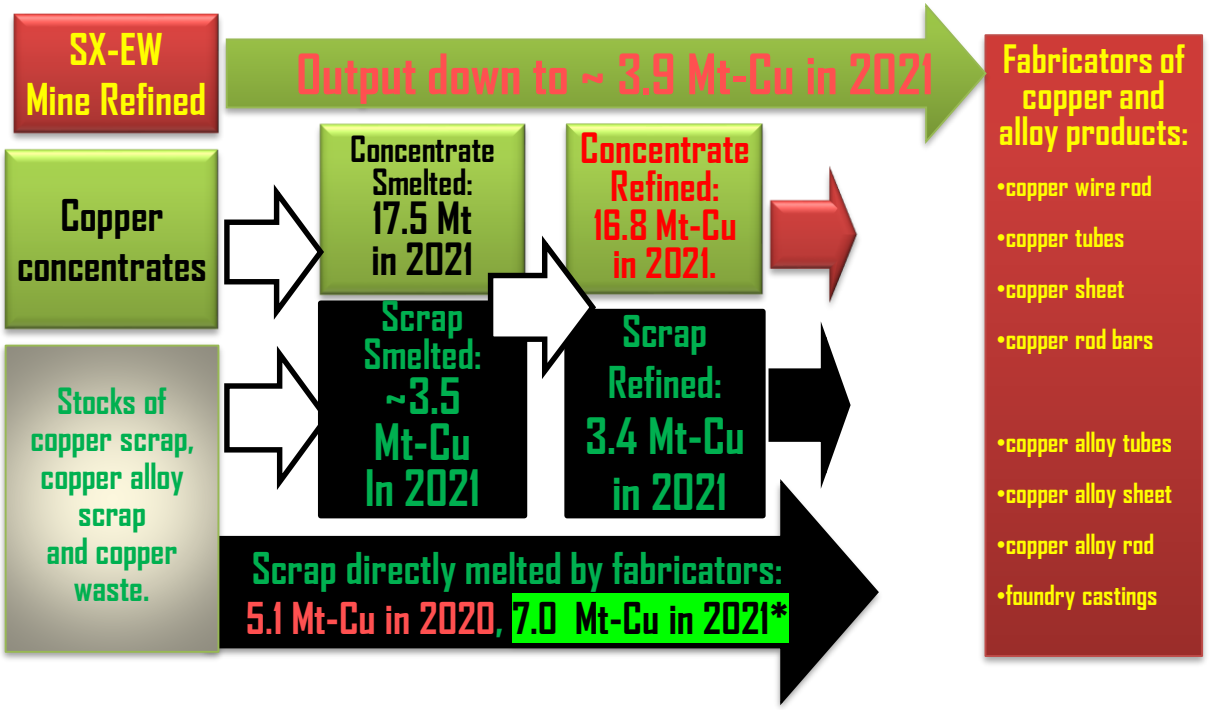
1. Introduction: Supply Side Value Chain, Global Copper Demand, Industrial Uses: Recent Data

Global Copper Flows: The Supply Side in 2021.

SX-EW Mine Refined + Concentrate Refined = 20.7 Mt-Cu

Scrap Refined + Scrap Direct Melt* = 10.4 Mt-Cu in 2021?



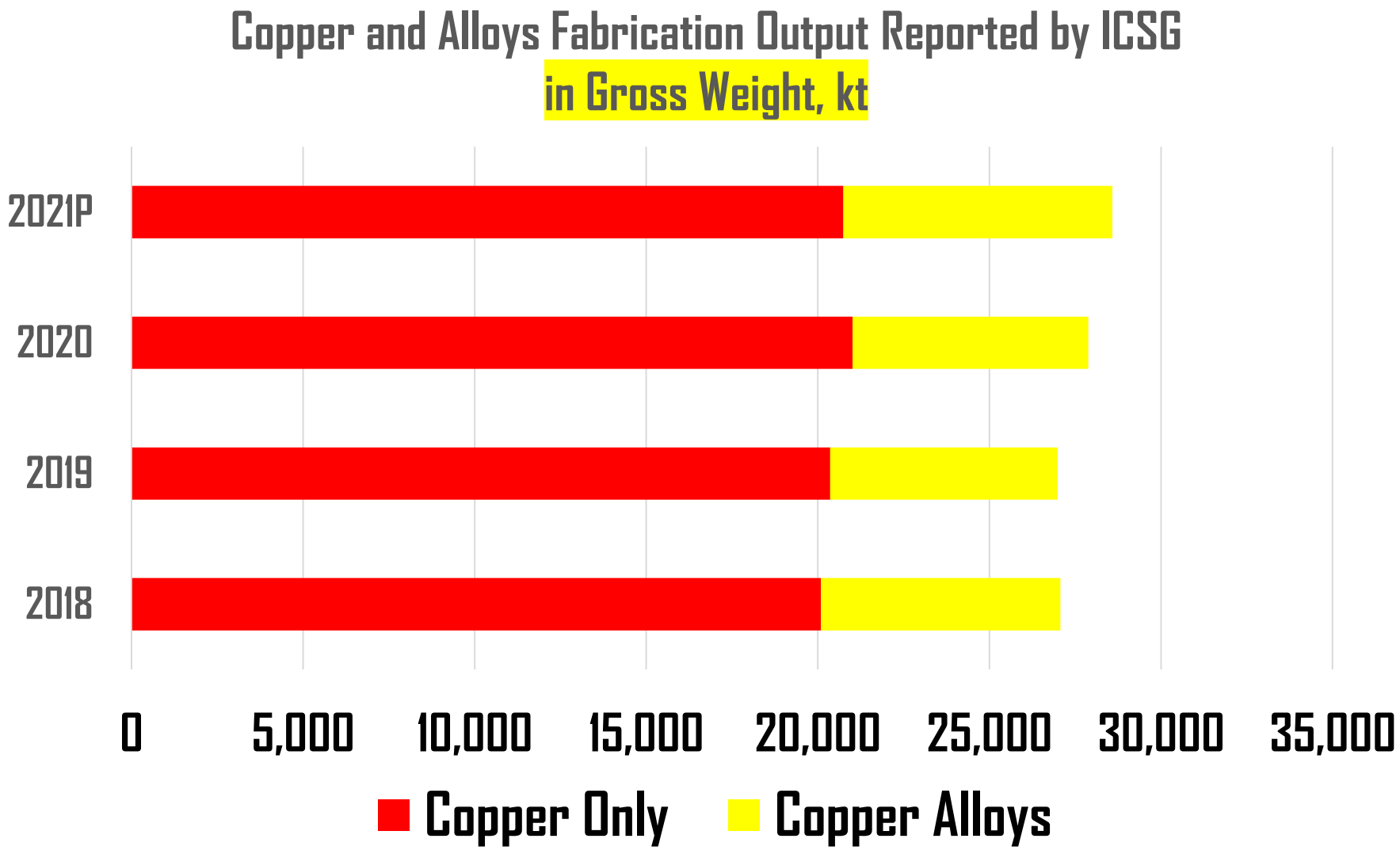
Global growth in scrap refined: 3.4 Mt-Cu in 2021 confirmed by Recyclables Survey

More scrap directly melted by fabricators in 2021* to reduce expensive refined use.

Peak global SX-EW output in 2020, 4 Mt-Cu, then contraction in 2021 to 3.9.Mt-Cu.

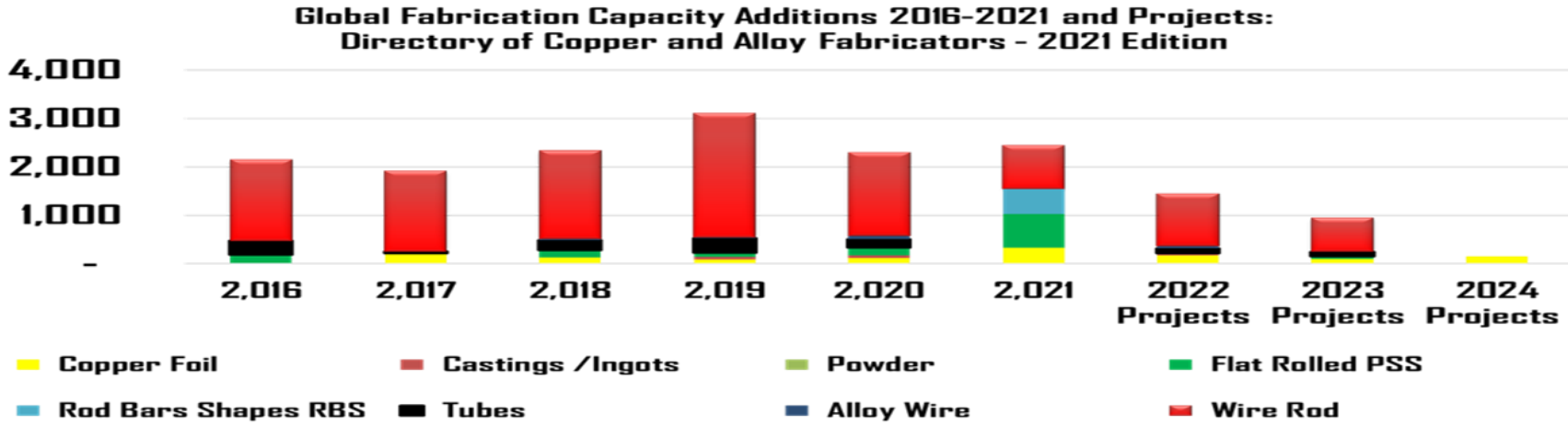
ICSG world reported fabrication output: +5.2% in 2021 vs 2019.

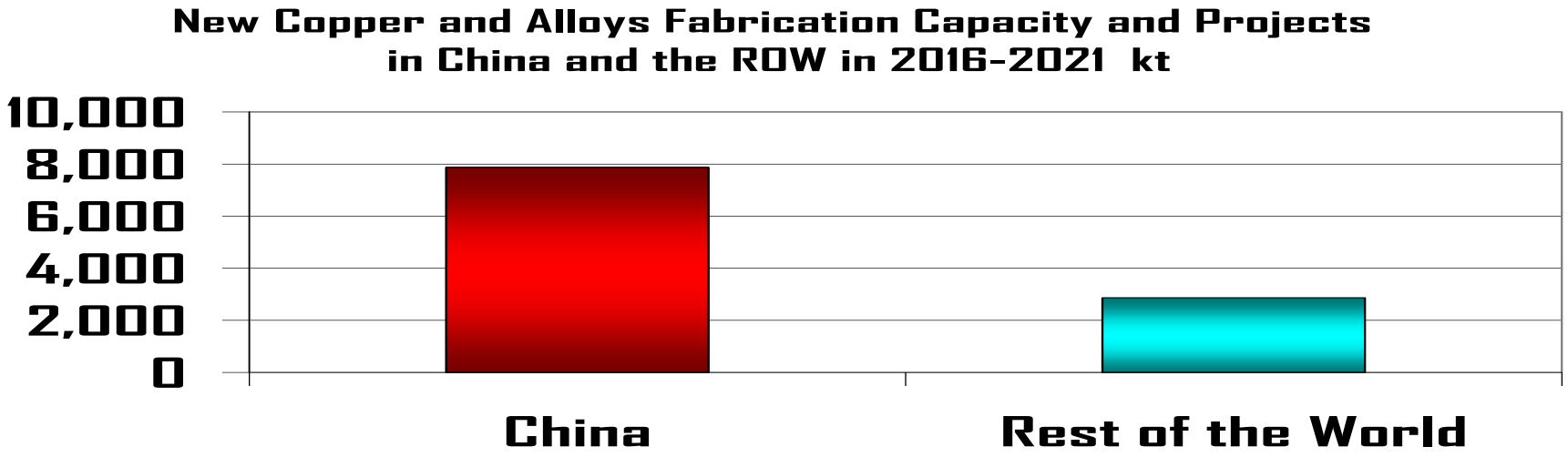
It did not contract in 2020, due to higher Chinese semis production.



New generation of fabrication plants, mainly but not only in China,

driving 2020-2030 copper demand from mines, scrap, smelters and refineries.

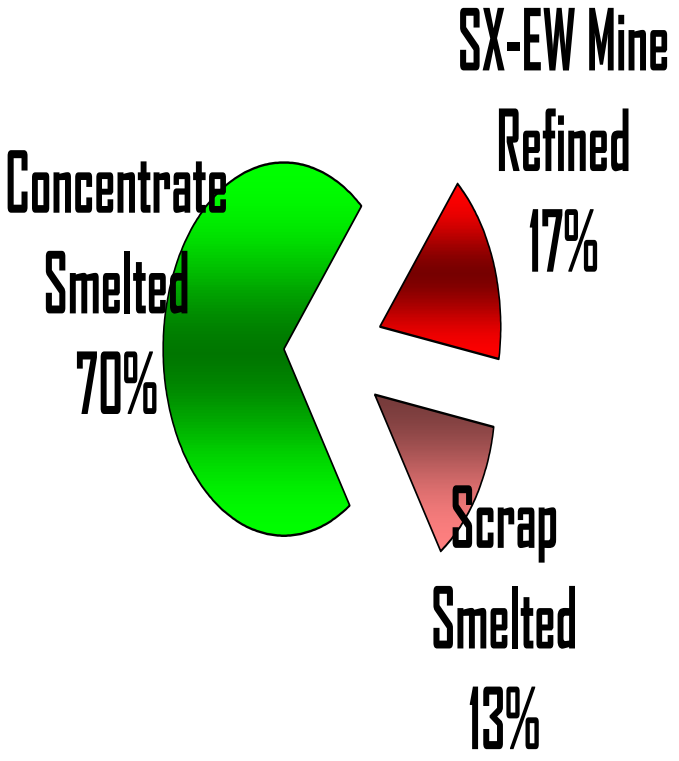




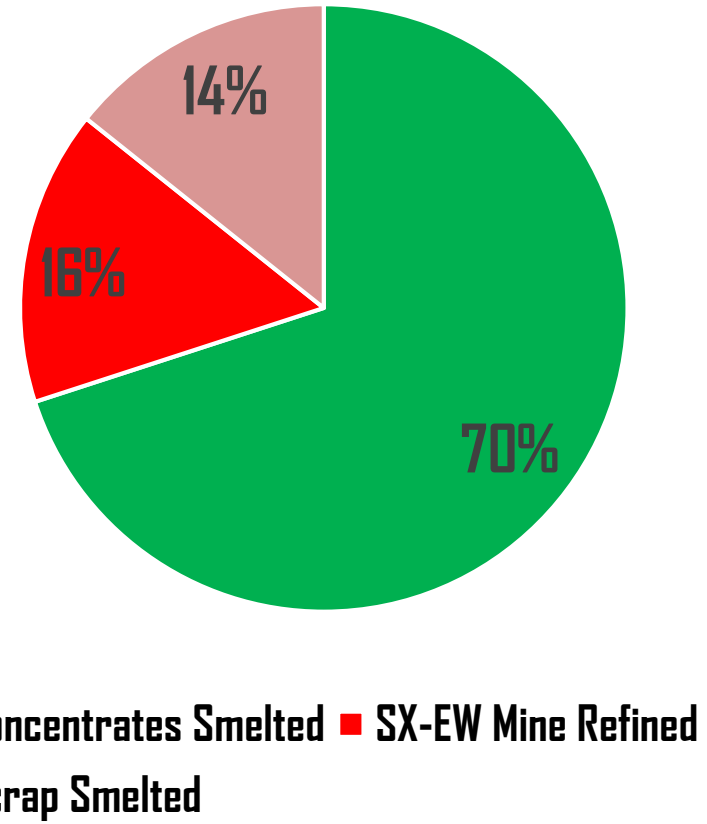
ICSG Directory of Copper First Use Fabrication Capacity: published every year.

With limited SX-EW, world smelters processed more concentrates with less copper content and used more scrap in 2018-2021.

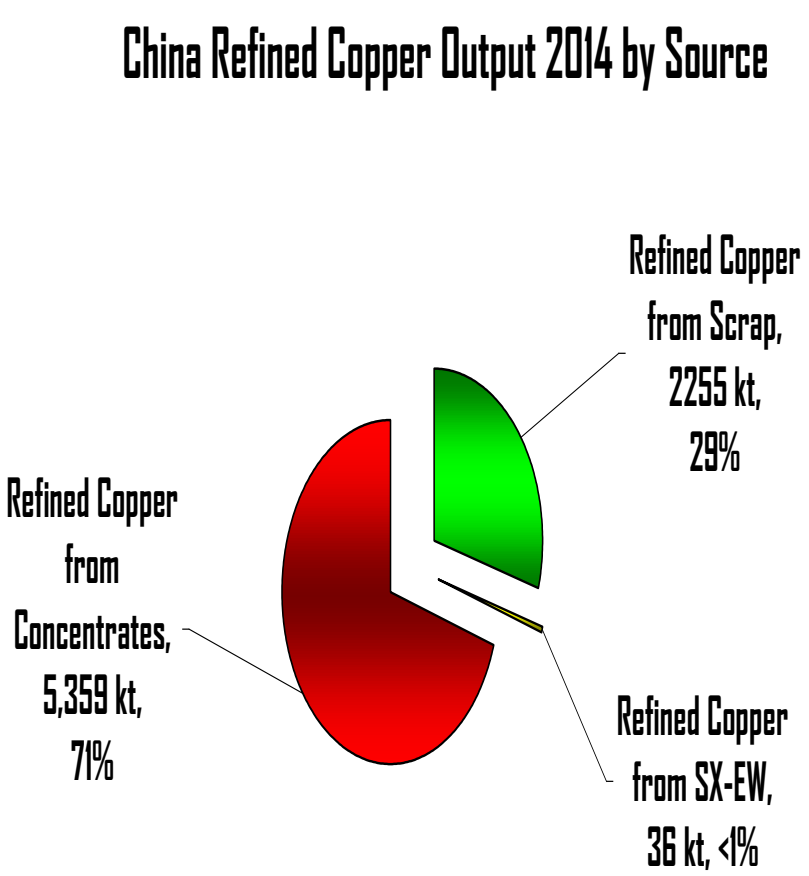
2018 Global Smelter Supply and Mine Refined

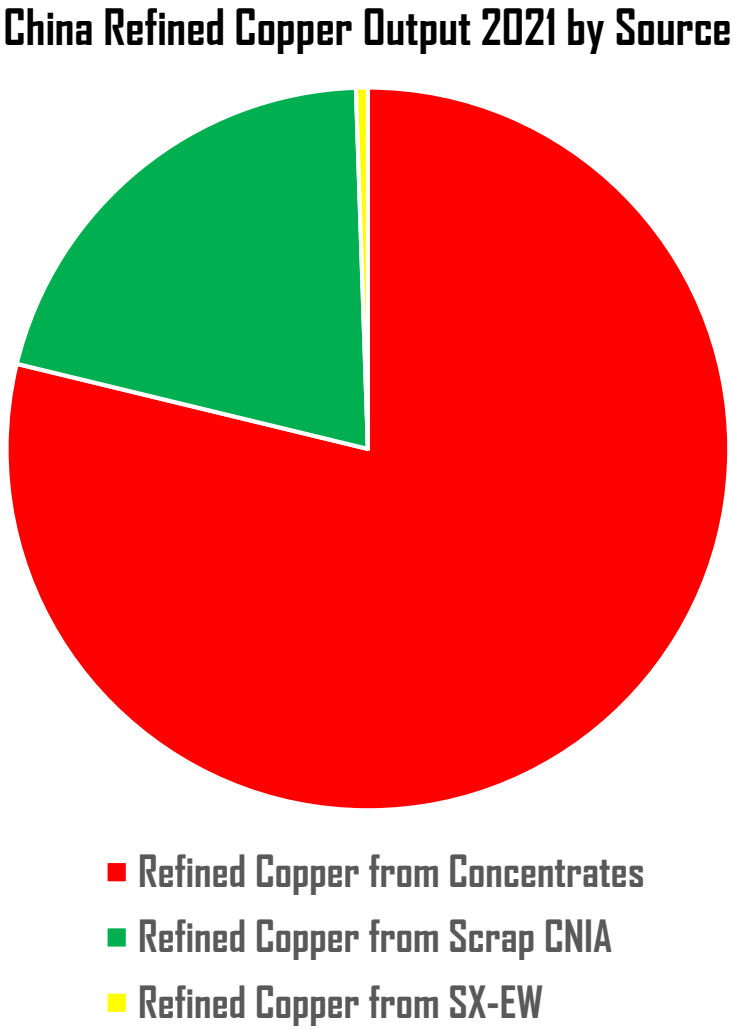


2021 Global Smelter Supply and Mine Refined



In 2021 China´s share of copper refined output from concentrates ~80% of all copper refined in China in 2021. Refined copper scrap share decreased to <20%.

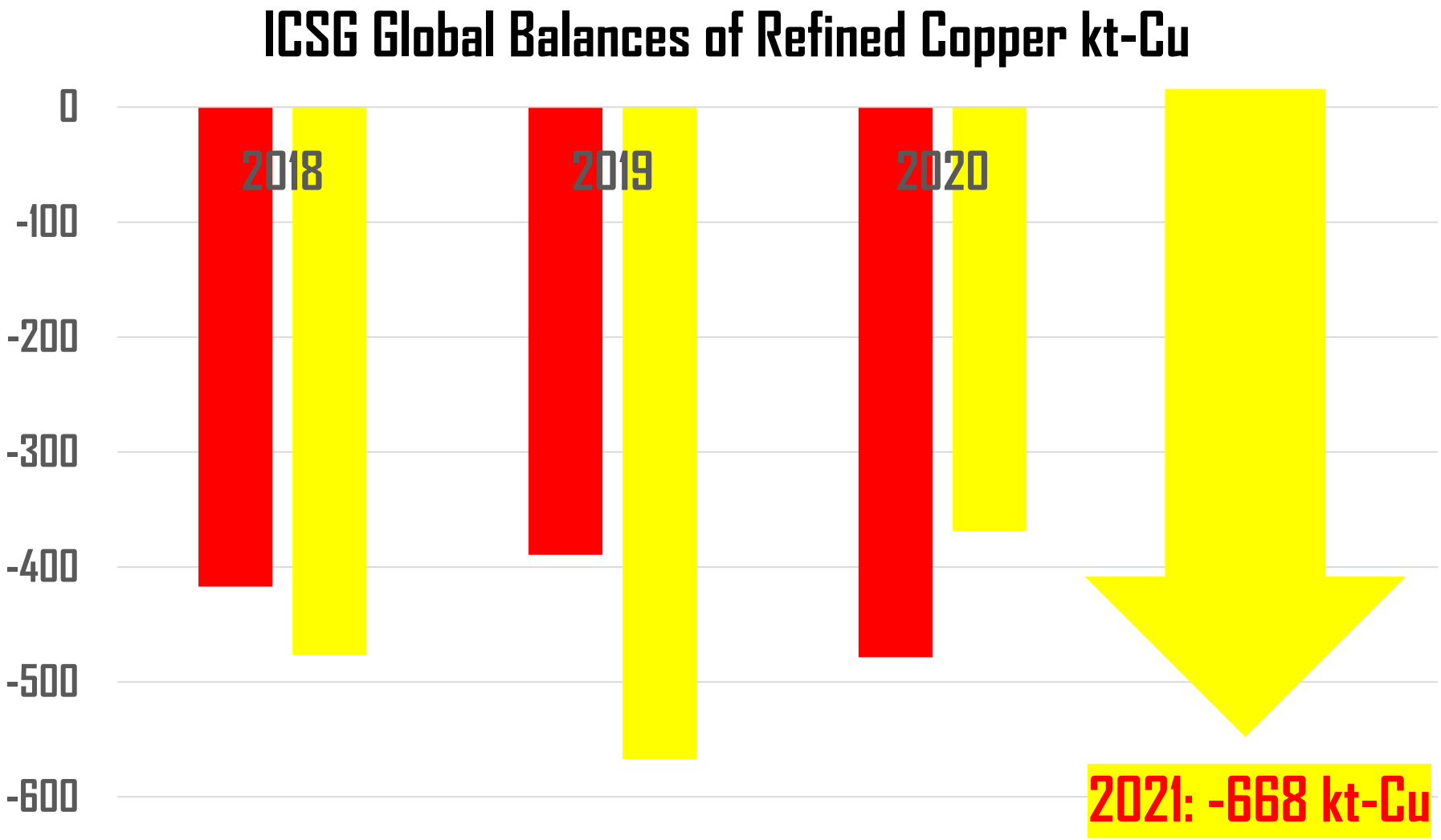




2018-2020: refined copper markets in deficit and sustained by de-stocking.

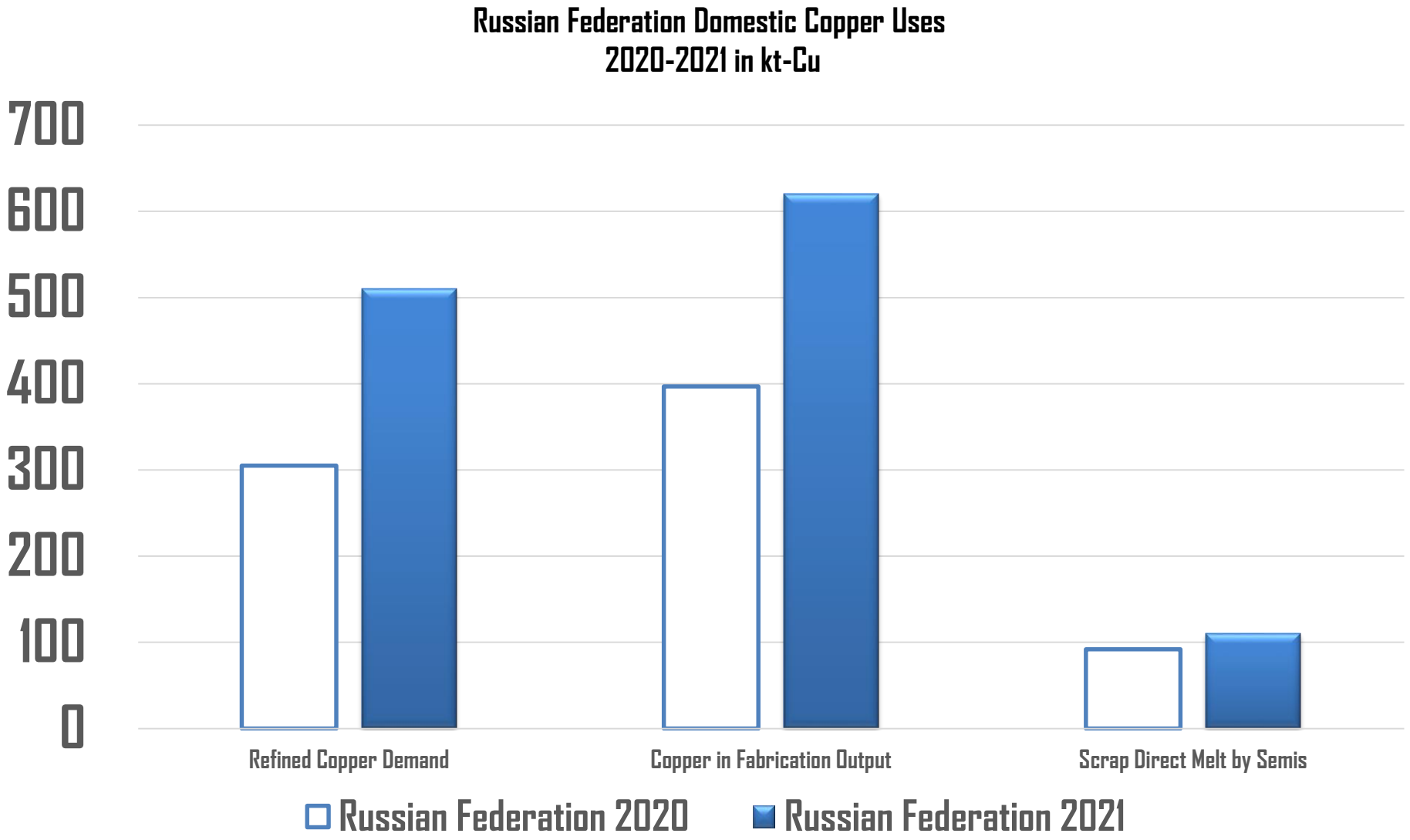
2021: deeper deficit on demand expansion, driven by fabricators recovery,

+ wealth protection from negative real interest rates. More stocks out of the exchanges.

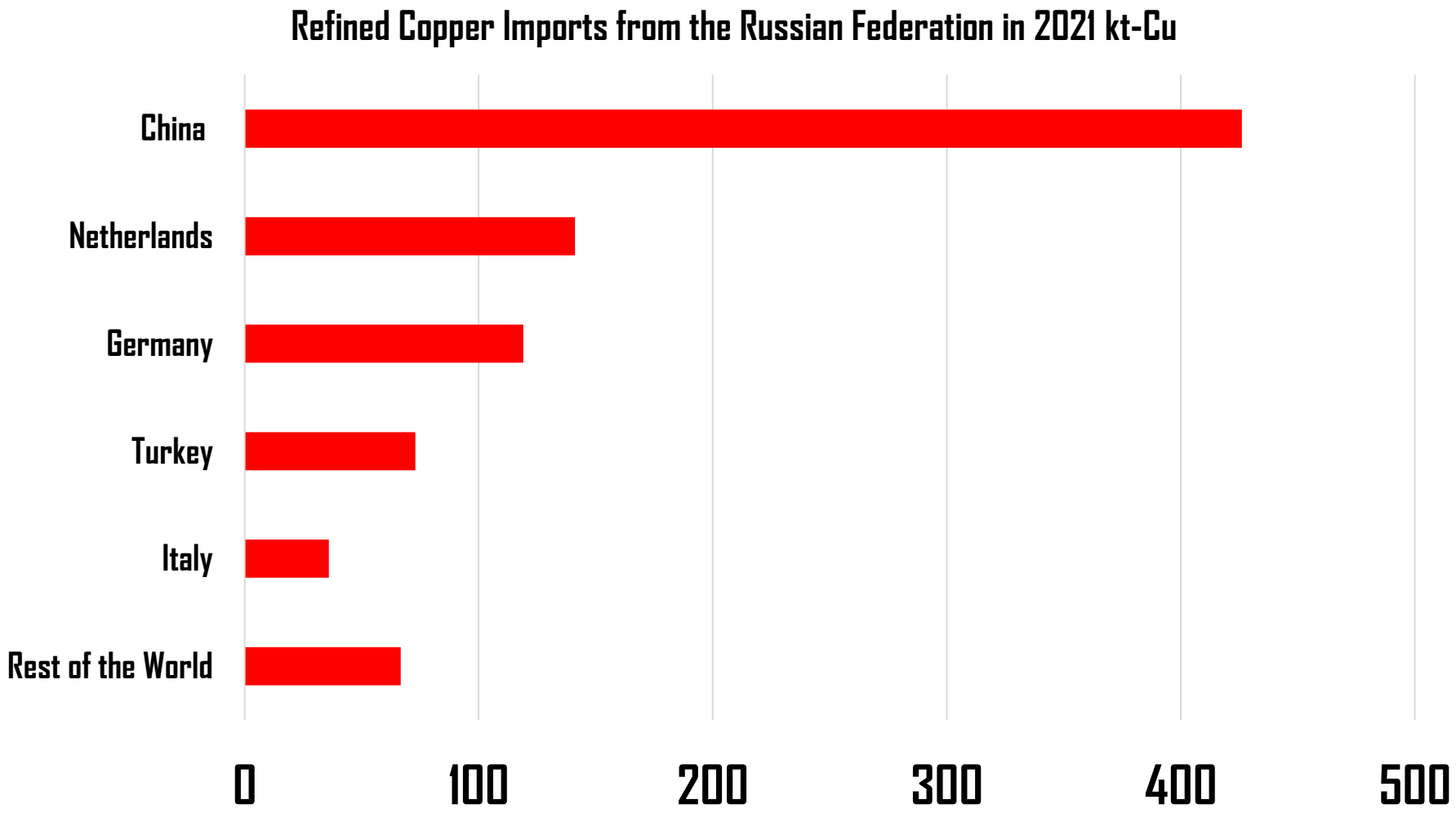


Russian Federation domestic copper uses increased ~67% in 2021

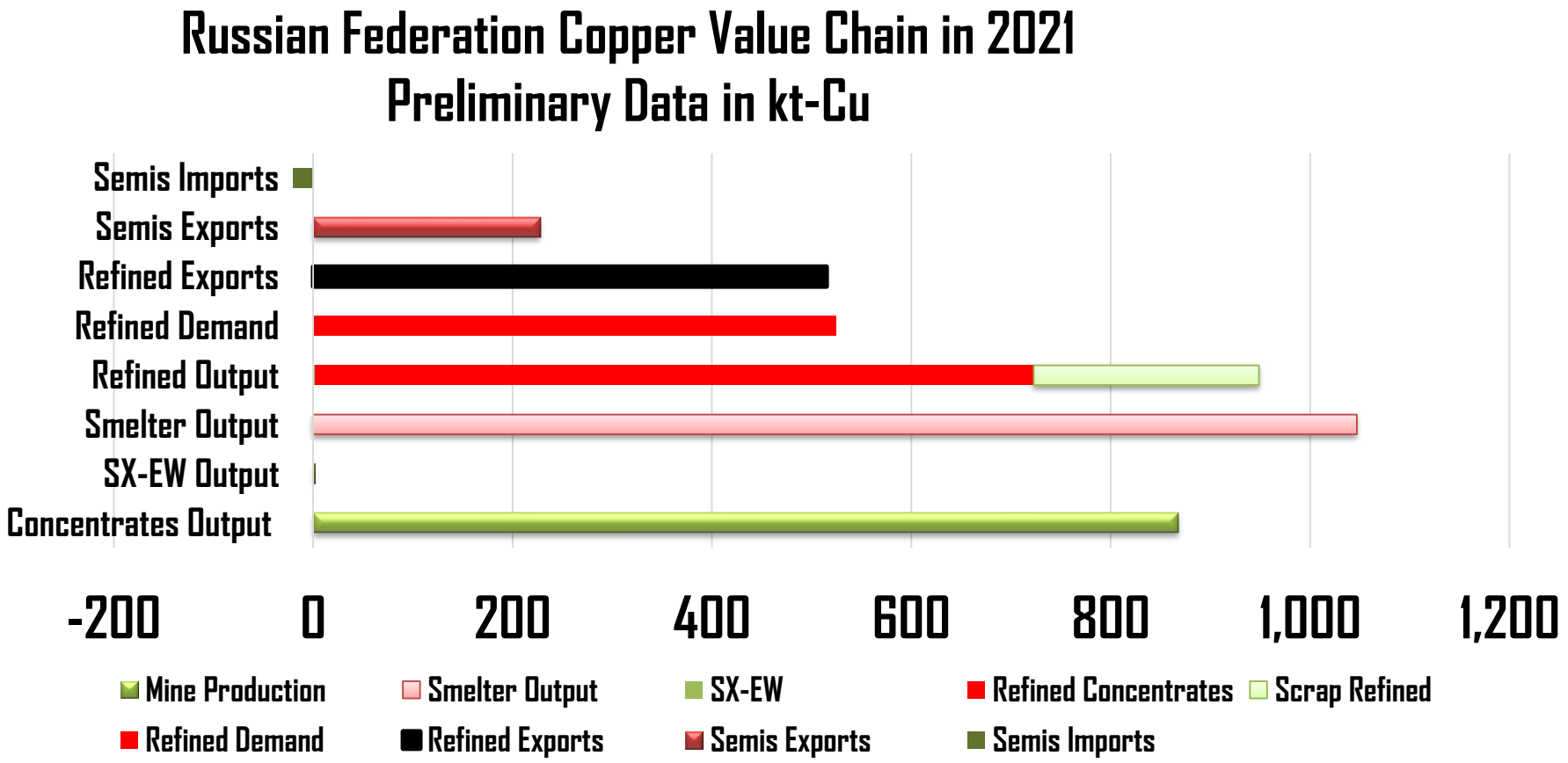
on a refined export tax, driving semis, mainly wire rod, to over 600 kt per year.



In 2022 >50% of the exports of refined copper from the Russian Federation in risk of being reallocated.



Restrictions to trade of Russian Federation copper products to contribute to tighter supply of copper metals ex-China.



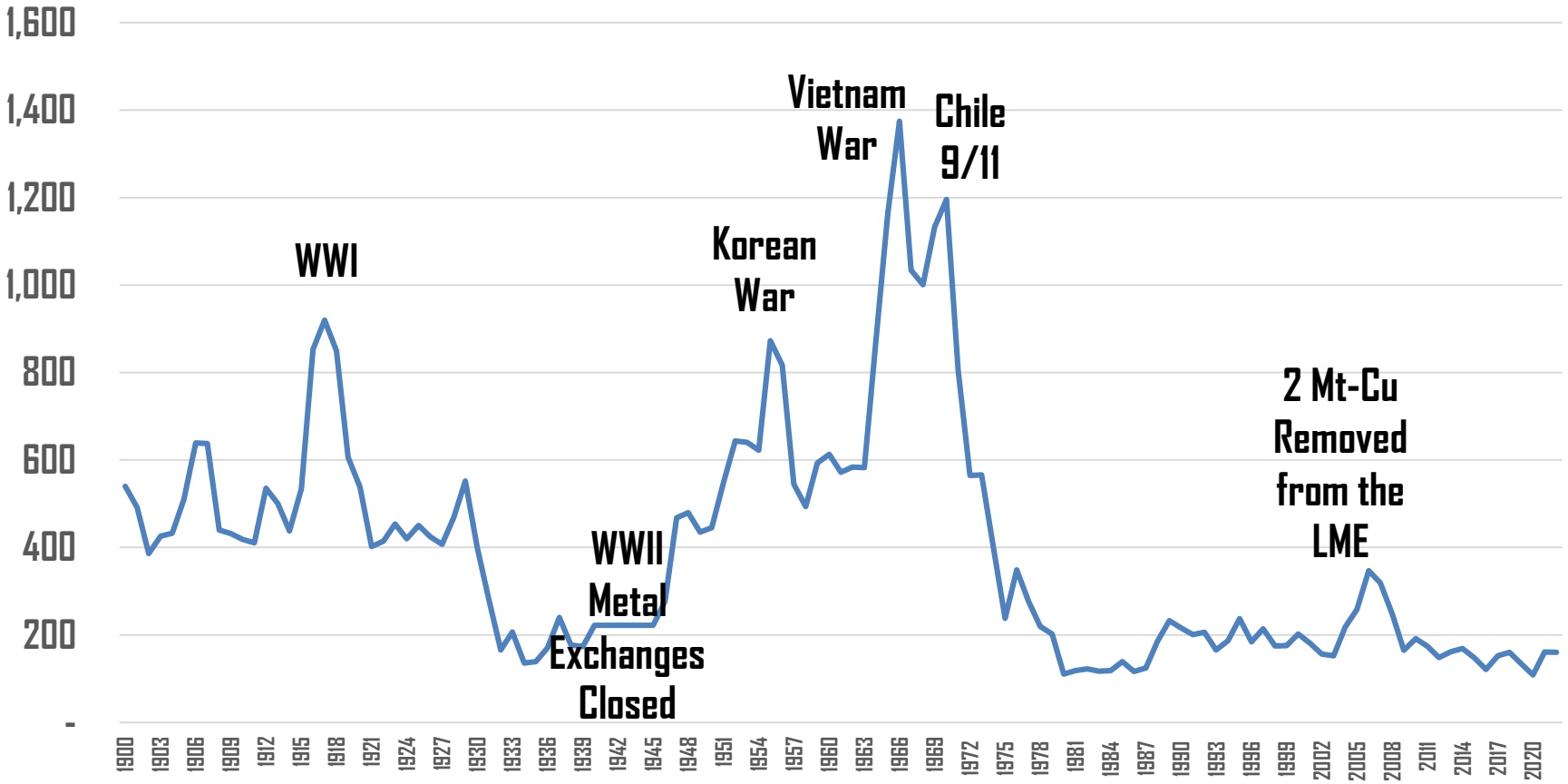
The energy price shock of 2021-2022: energy supply continues to tighten.

China "Dual Control System": energy consumption/output rate down: copper smelters to target higher grade feed producing greater output.

Now you can get a tonne of refined copper with less than 170 grams of gold.

One tonne of refined copper cost around 1 kg of gold when trade is restricted.

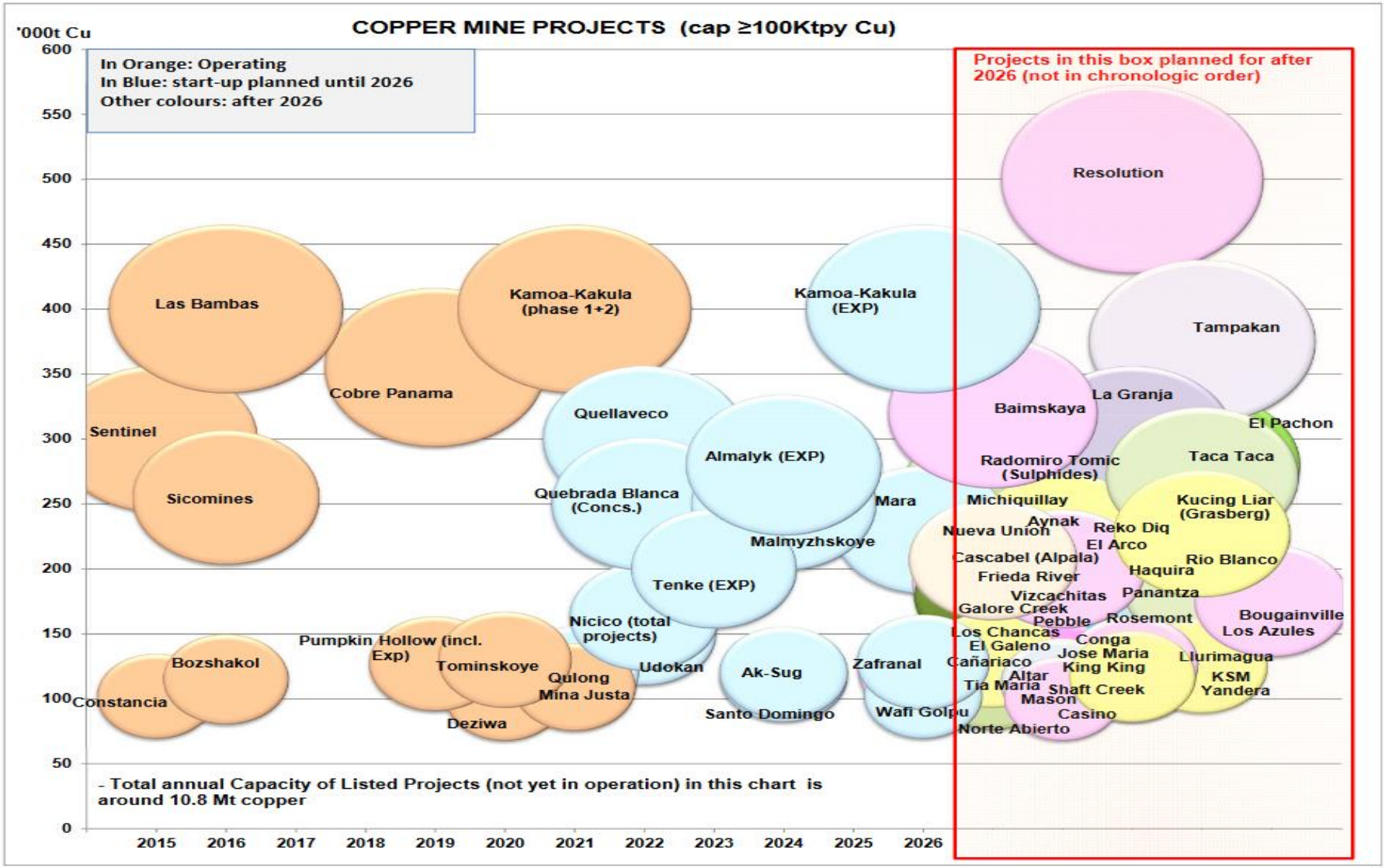
Price of One Tonne of Refined Copper in Grams of Gold.
ICSG March 2022



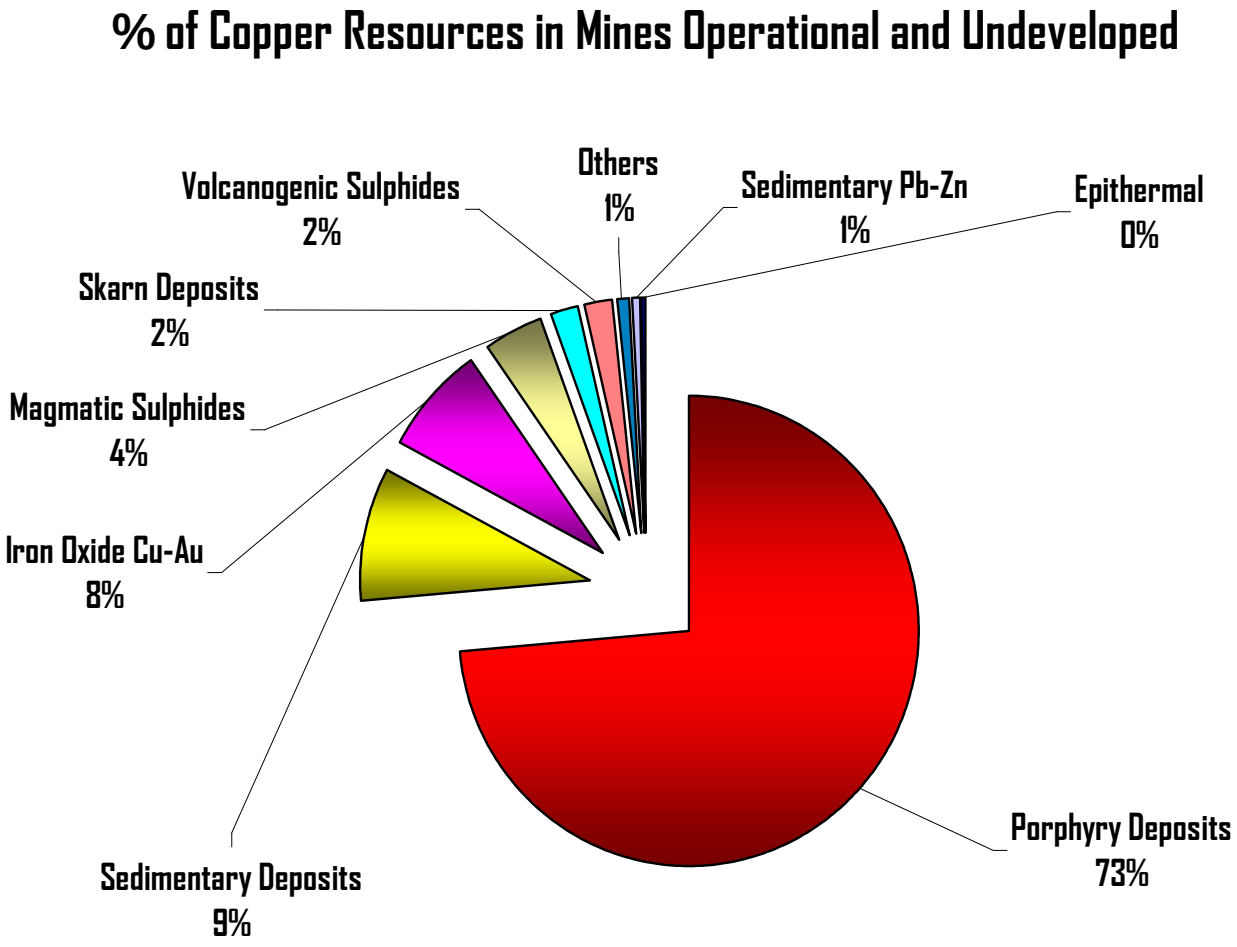
2. Copper Content in Global Copper Concentrate Output and Trade: Recent Data and Future Drivers

Record prices, even with 11 new mines commissioned recently.

Other 12 new mines and expansions to be commissioned in 2022-2026.

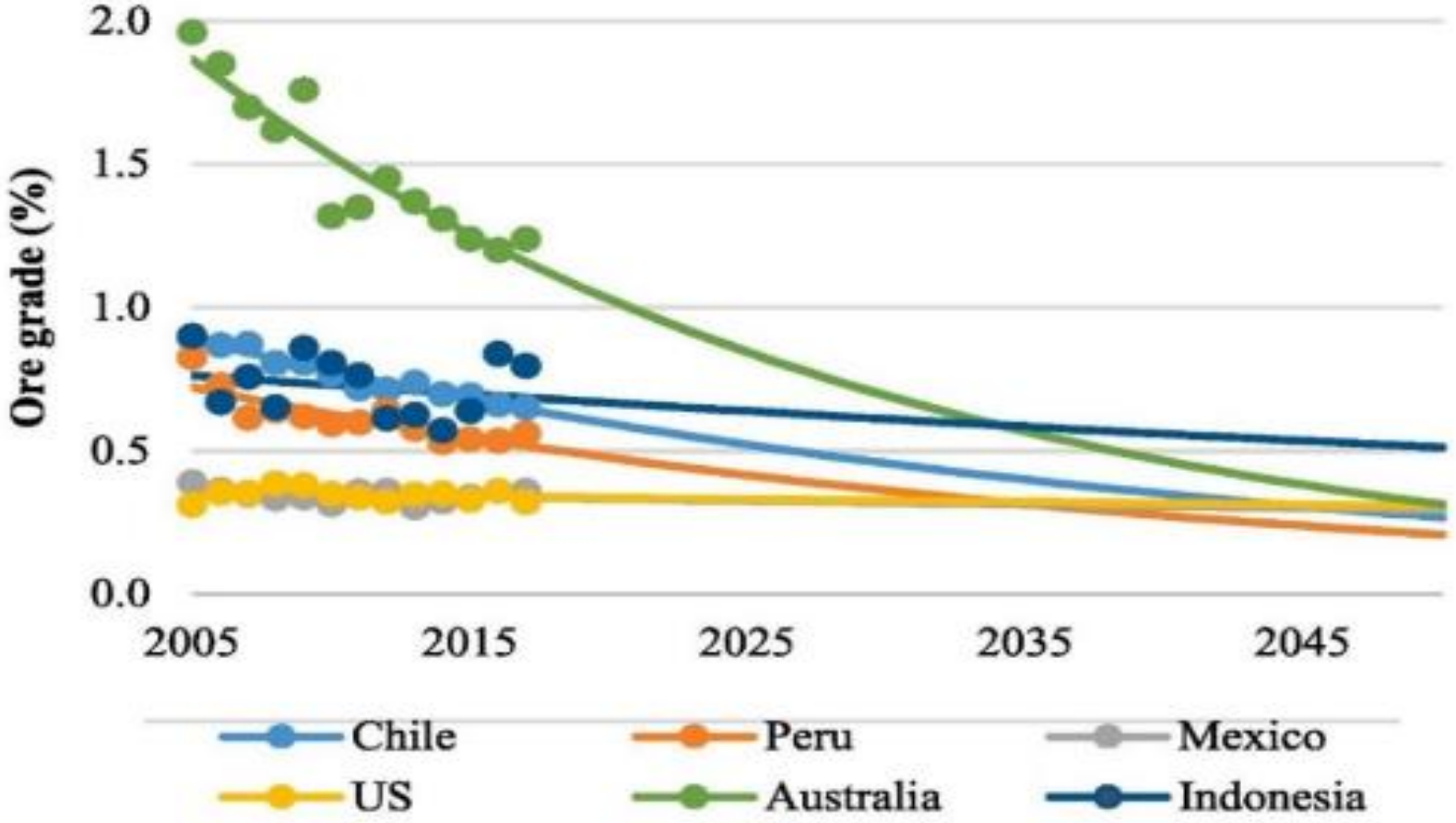


Most abundant low grade porphyry deposits were mined first, so copper ore grades in output averaging down 2020-2030.



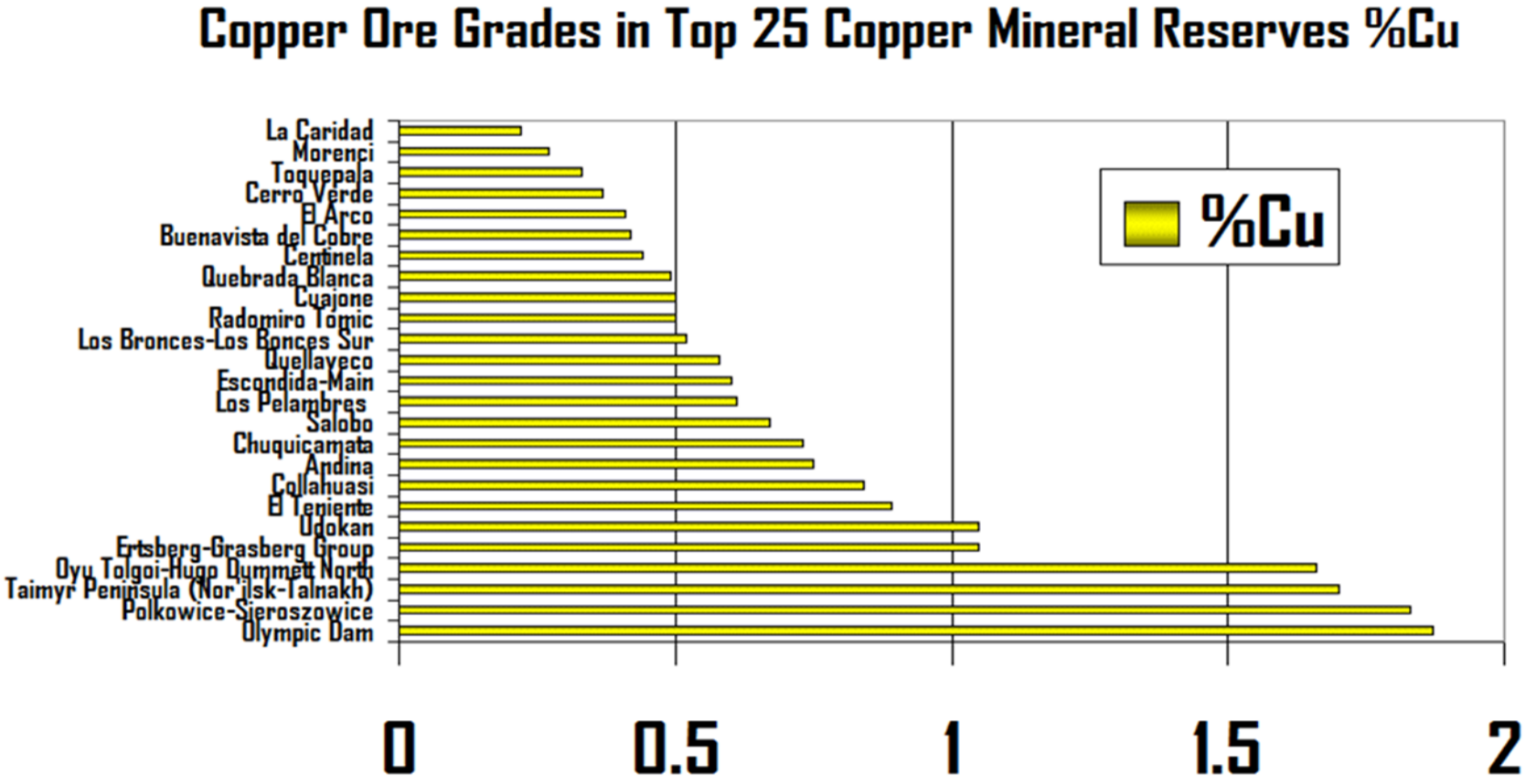
ICSG based on Mudd (2017)

Reduction in copper ore grades and projections: challenging for mining countries due to increasing costs to extract very low-grade ores.



https://www.researchgate.net/publication/358670677_Chemical_Composition_Data_of_the_Main_Stages_of_Copper_Production_from_Sulfide_Minerals_in_Chile_A_Review_to_Assist_Circular_Economy_Studies

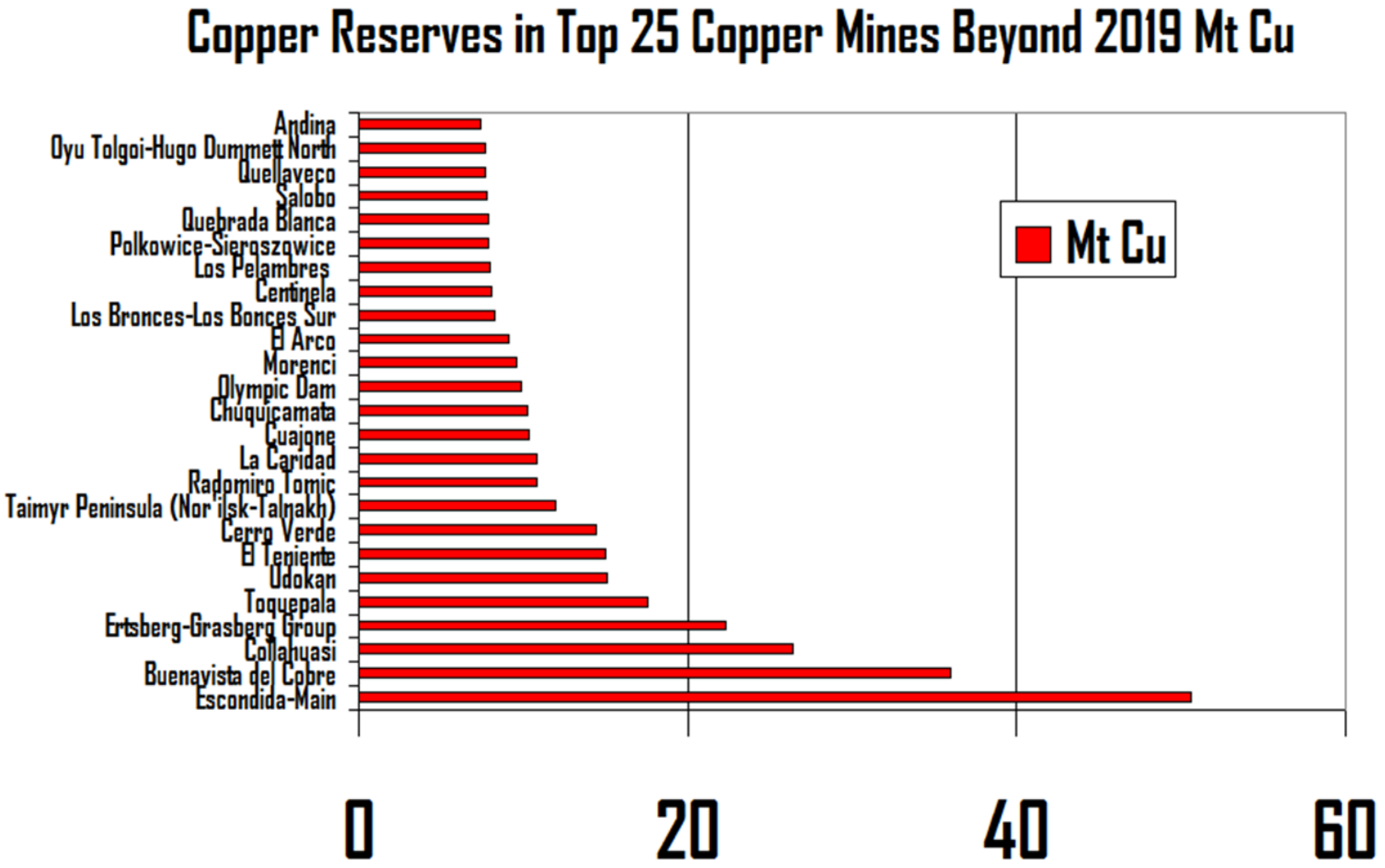
Most of the copper reserves being developed in 2020-2030 are in copper mines with low or falling copper ore grades.



Funding, social licenses, permits, water shortages, price volatility,

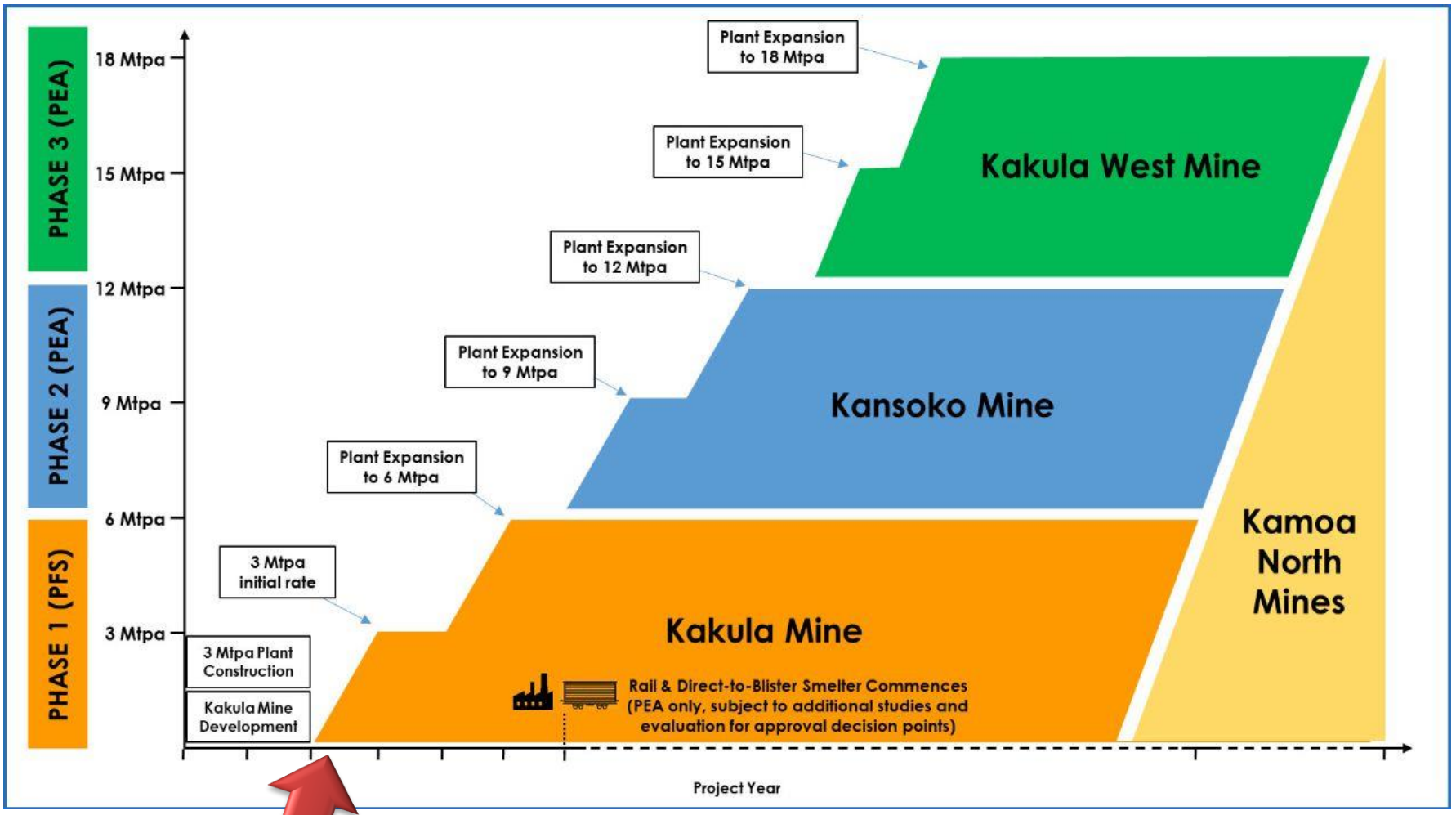
instead of low ore grades limit mine expansions and new projects.

Current technology to extract low grade reserves means low grade copper deposits have high chances of being mined if prices remain attractive.



Big expectations on new high ore grade capacity at DRC

Kakula, Kansoko, Kakula West and Kamoa North projects.



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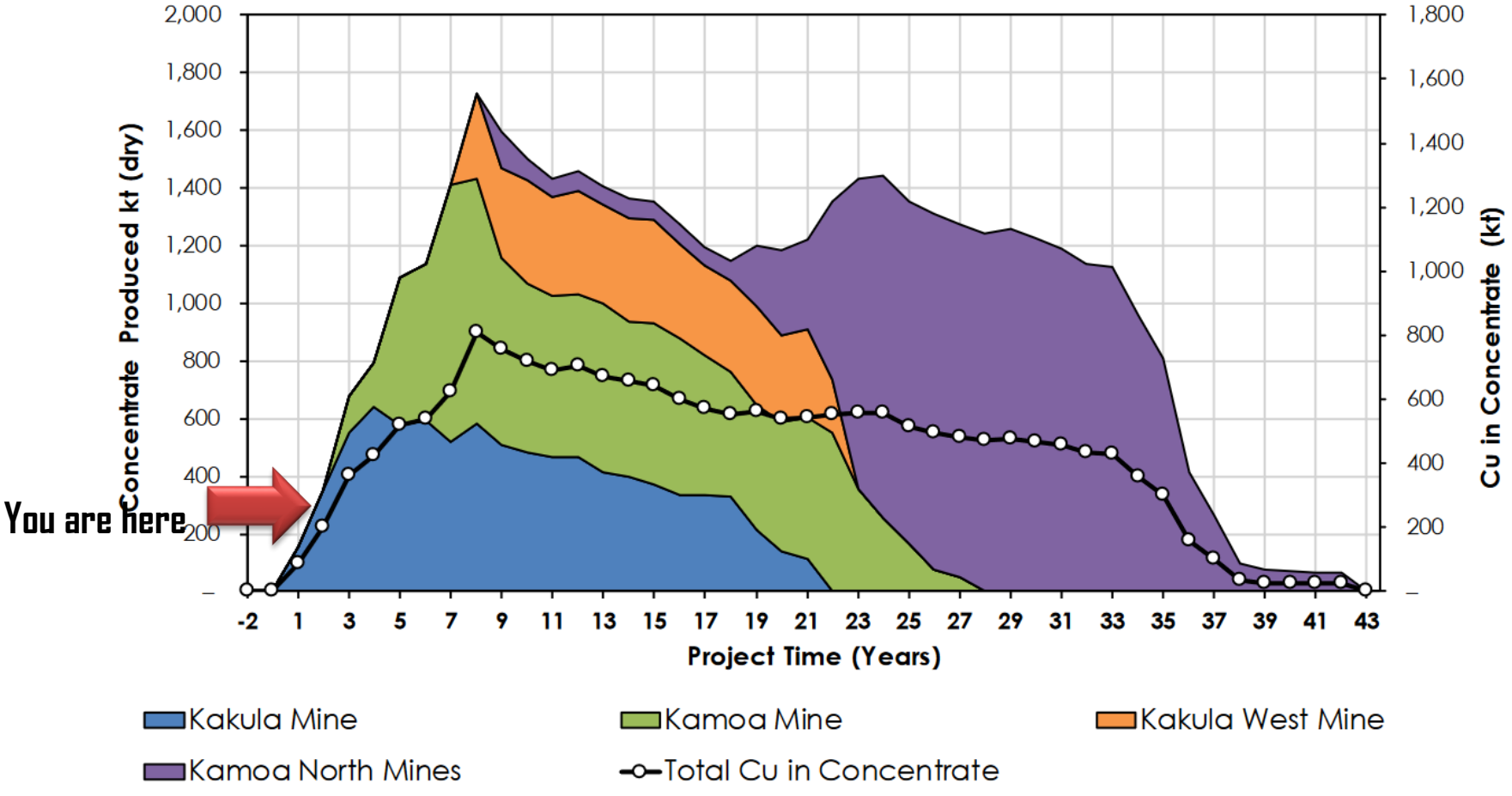
2022 production guidance for Kamoa-Kakula in the DRC:

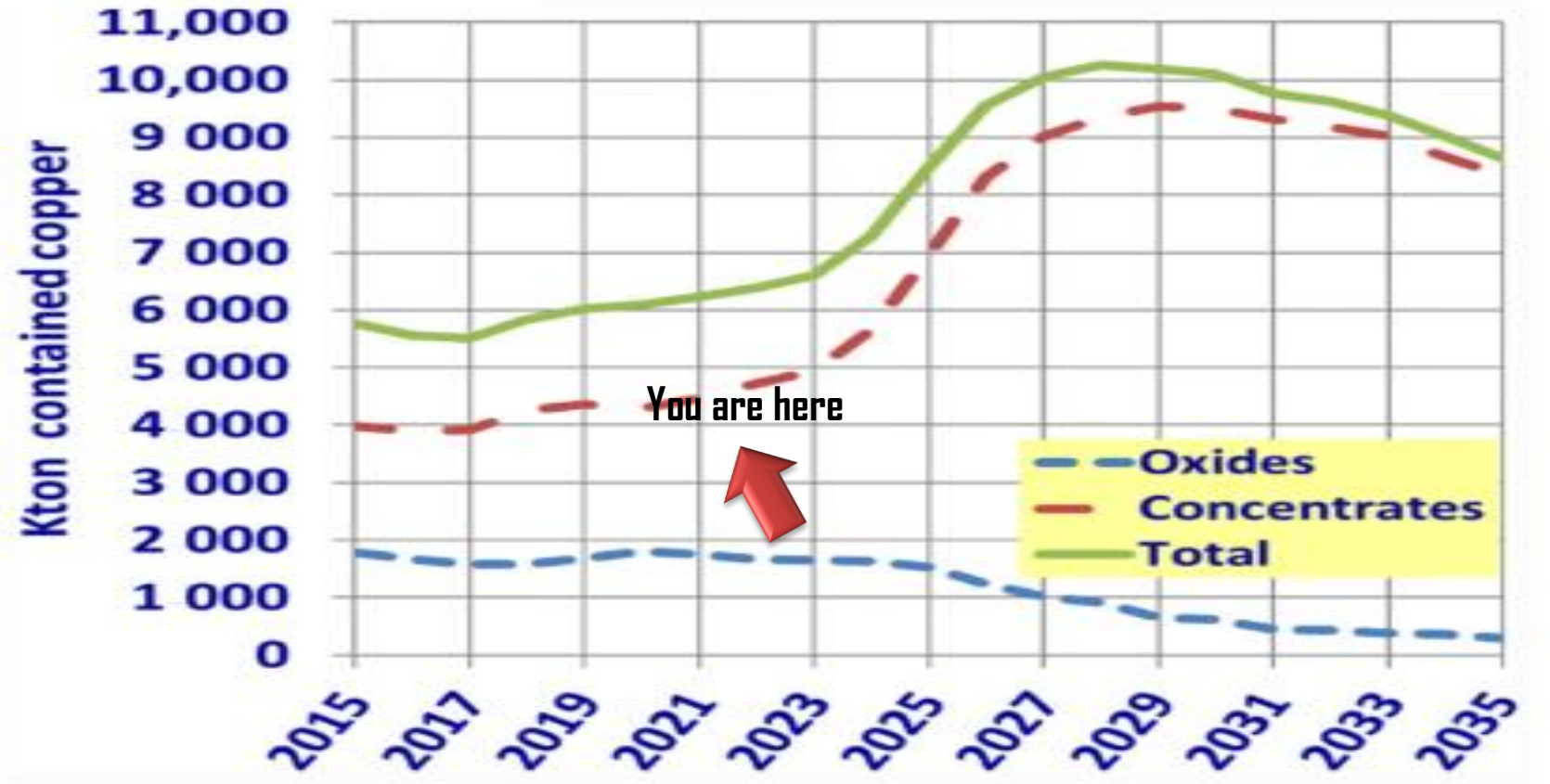
290-340 kt-Cu, low arsenic concentrates to be exported to China.

Output from first two phases projected: >450ktpy by 2023-2024.



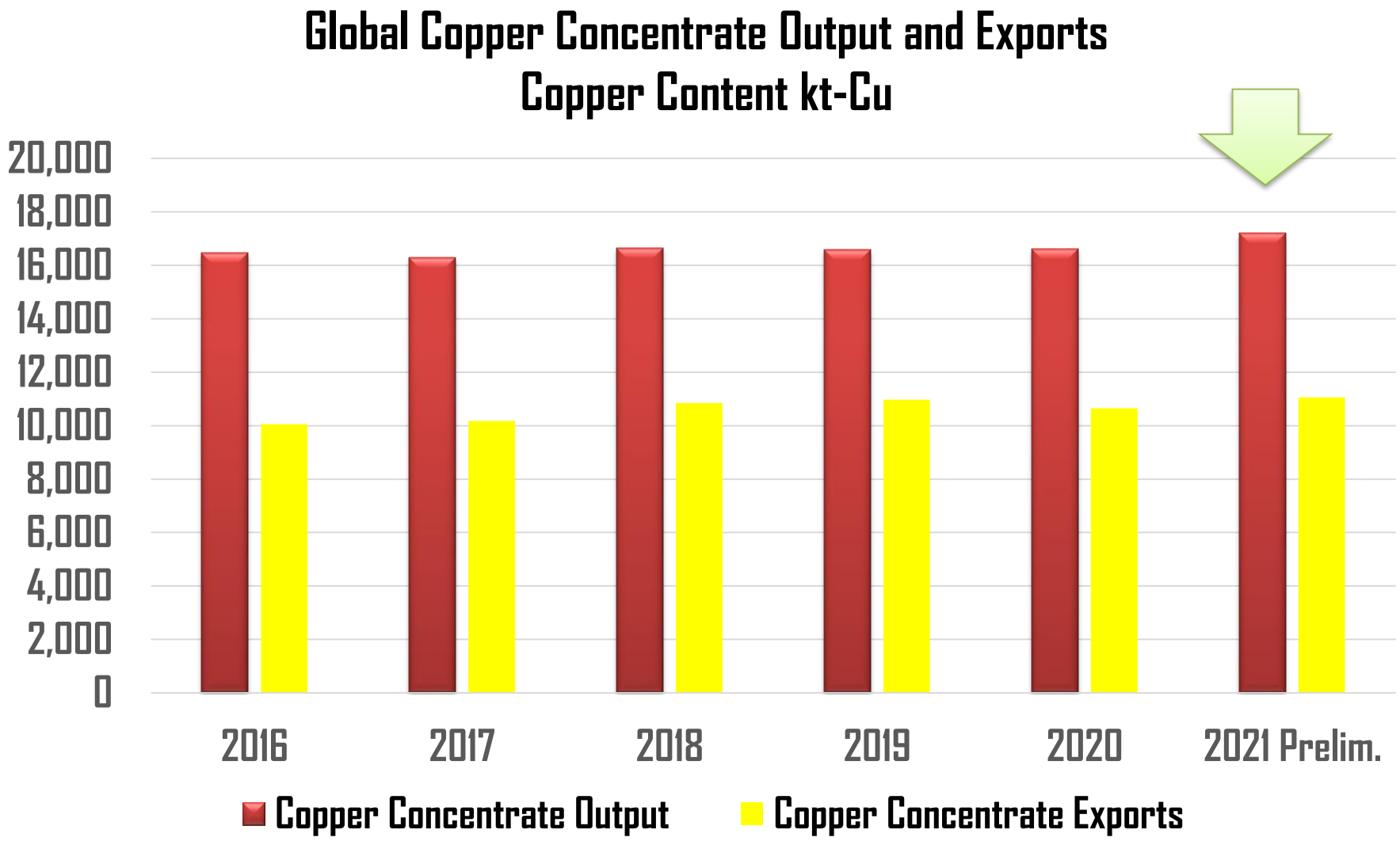
Chile copper concentrates oversupply ahead?

Massive Chilean copper concentrate supply growth expected in 2023-2028.

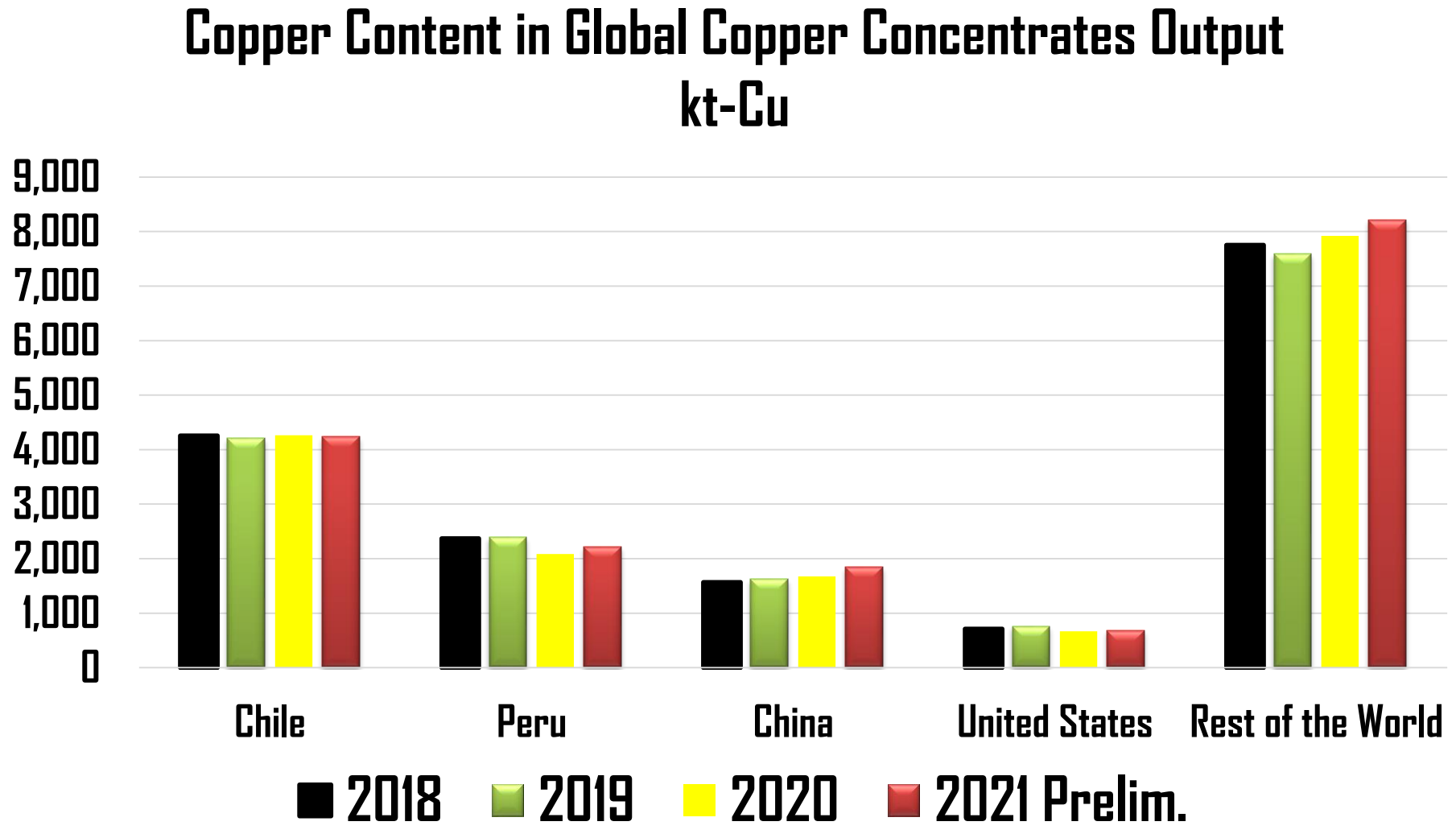


Source: Lagos, G.; Peters, D.; Lima, M.; Jara, J.J.
"Potential copper production through 2035 in Chile". Mineral Economics 2020, 33, 43–56.

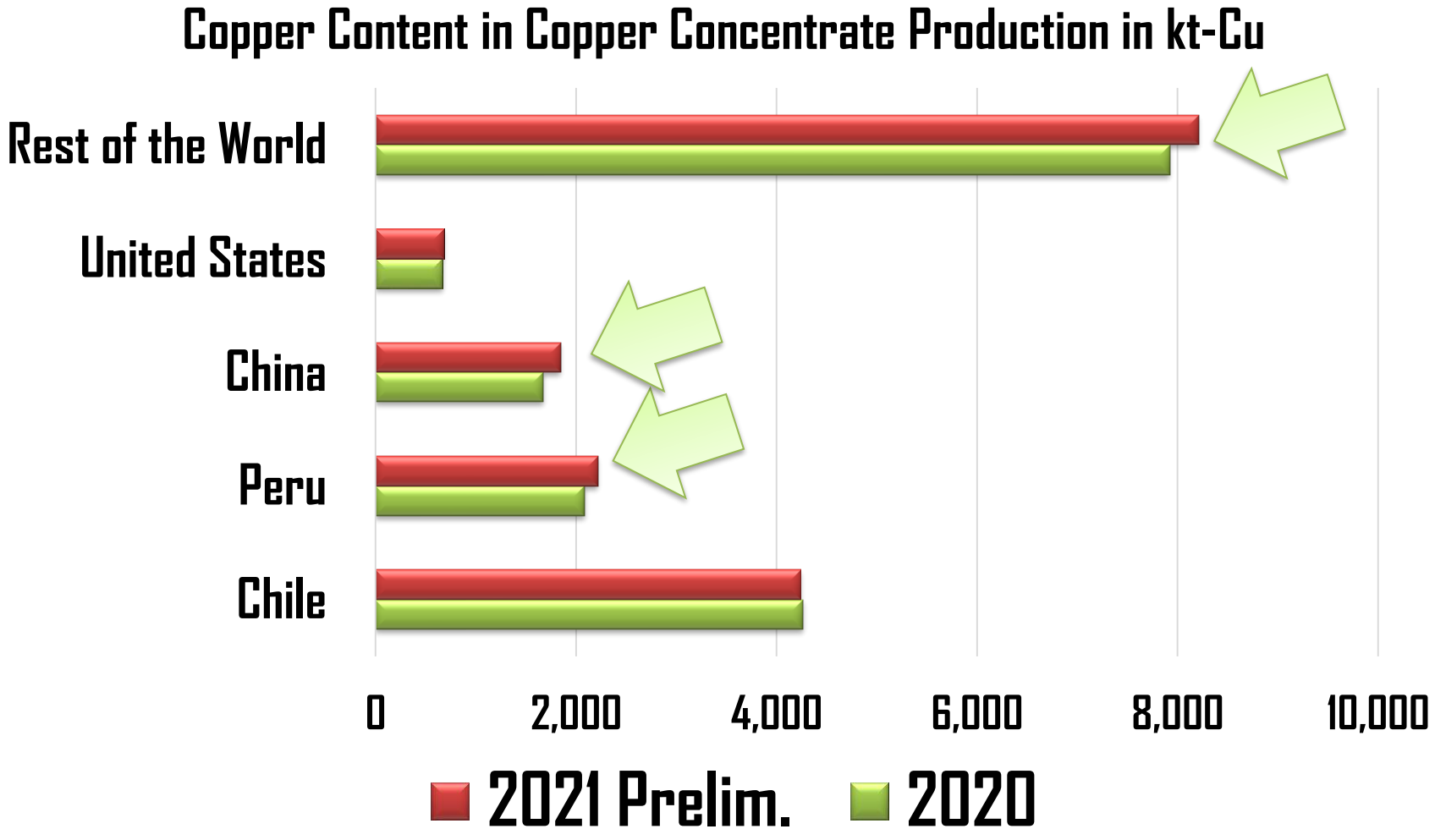
After years of constrained concentrate output and exports, growth in global concentrate supply observed in 2021.



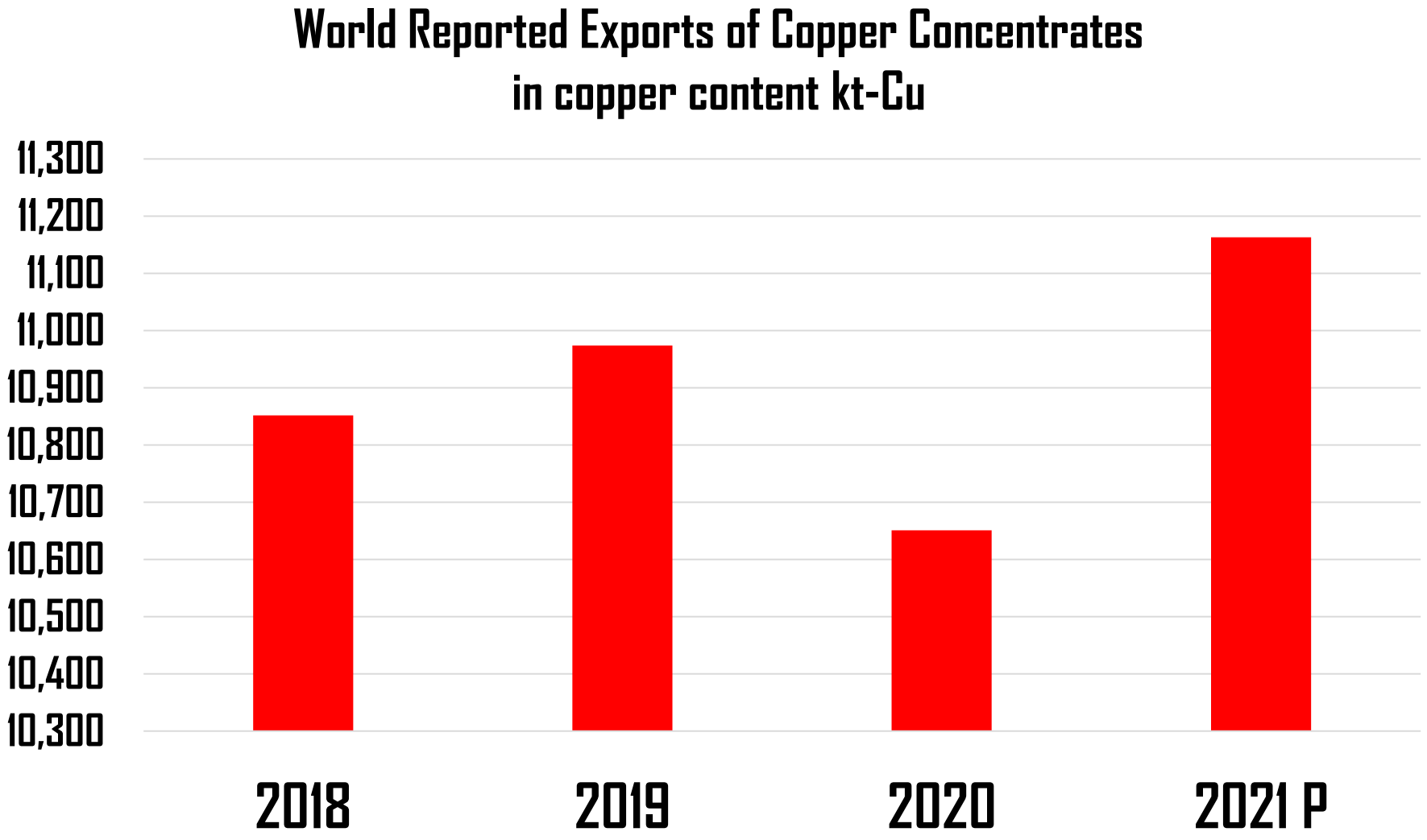
Copper content in global copper concentrates output: stagnated around 16.5 Mt-Cu per year in 2017-2020 but finally >17.2 Mt-Cu in 2021 on China, ROW expansions and Peru recovery.



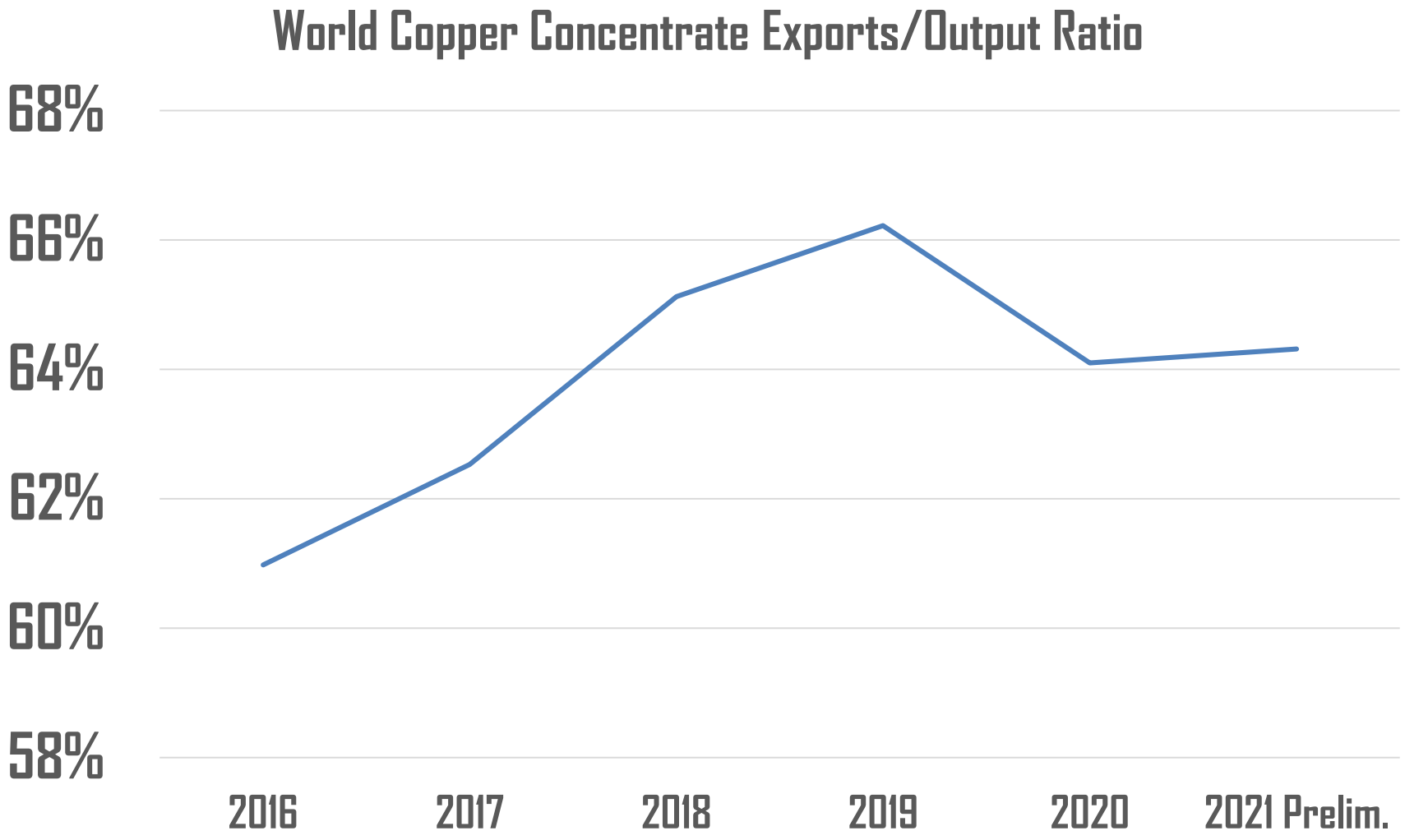
Global production of concentrates up in 2021 over 17 Mt-Cu per year for first time: on China, Peru Recovery and ROW supply.



Massive contraction in copper content in global exports of copper concentrates in 2020...followed by record export volumes in 2021.

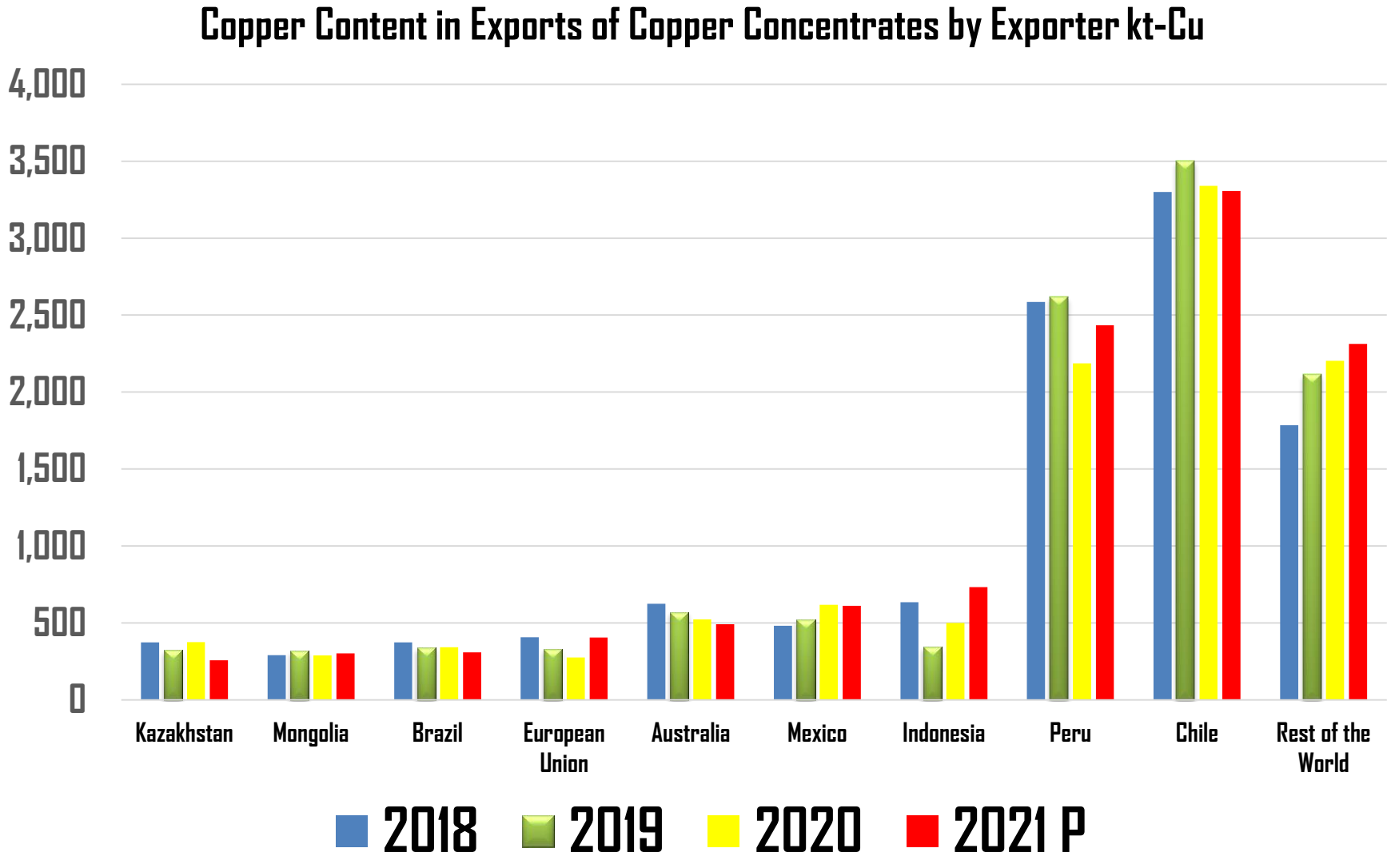


Share of global exports of concentrates in relation to output stagnated in 2020-2021 due to port restrictions and lockdowns.



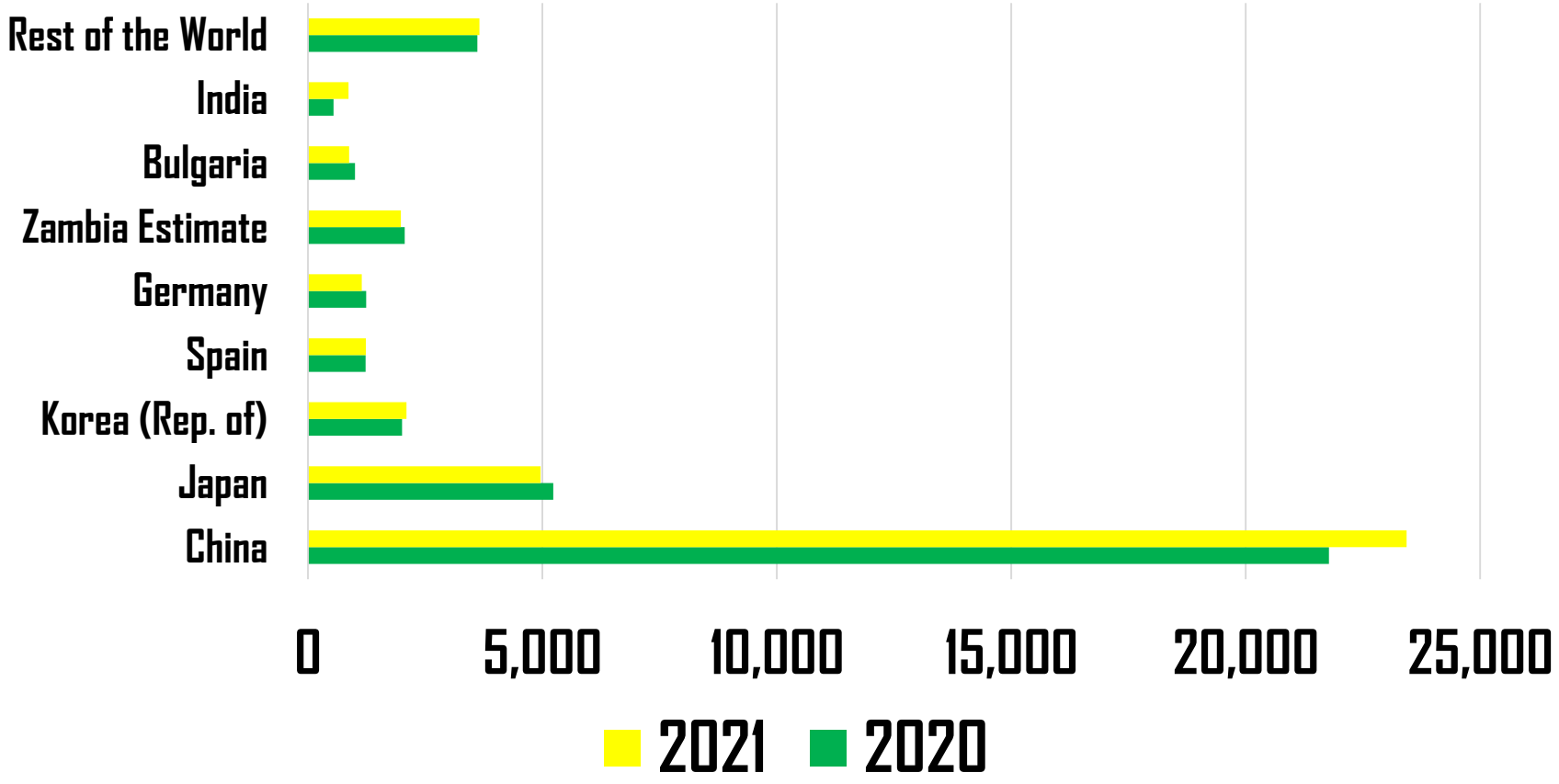
Still far from peak concentrate exports from Chile and Peru in 2021,

Indonesian recovery and advances in non traditional exporters.

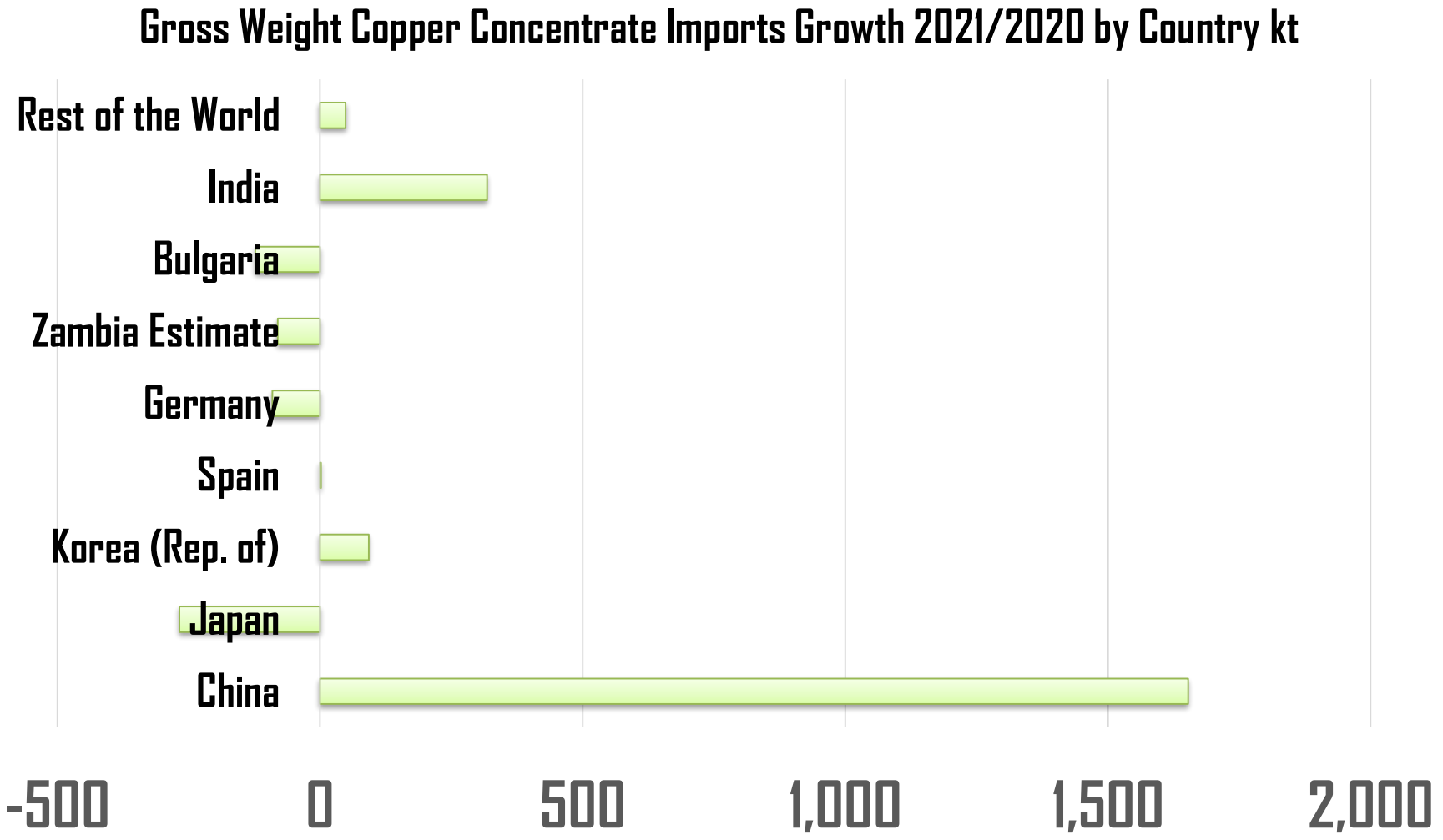


Significant annual growth of >4% in global imports of copper concentrates confirmed for 2021, as Chinese, Indian and Korean imports recovered.

Reported Gross Weight Imports of Copper Concentrates in kt gross weight, preliminary 2021 data,

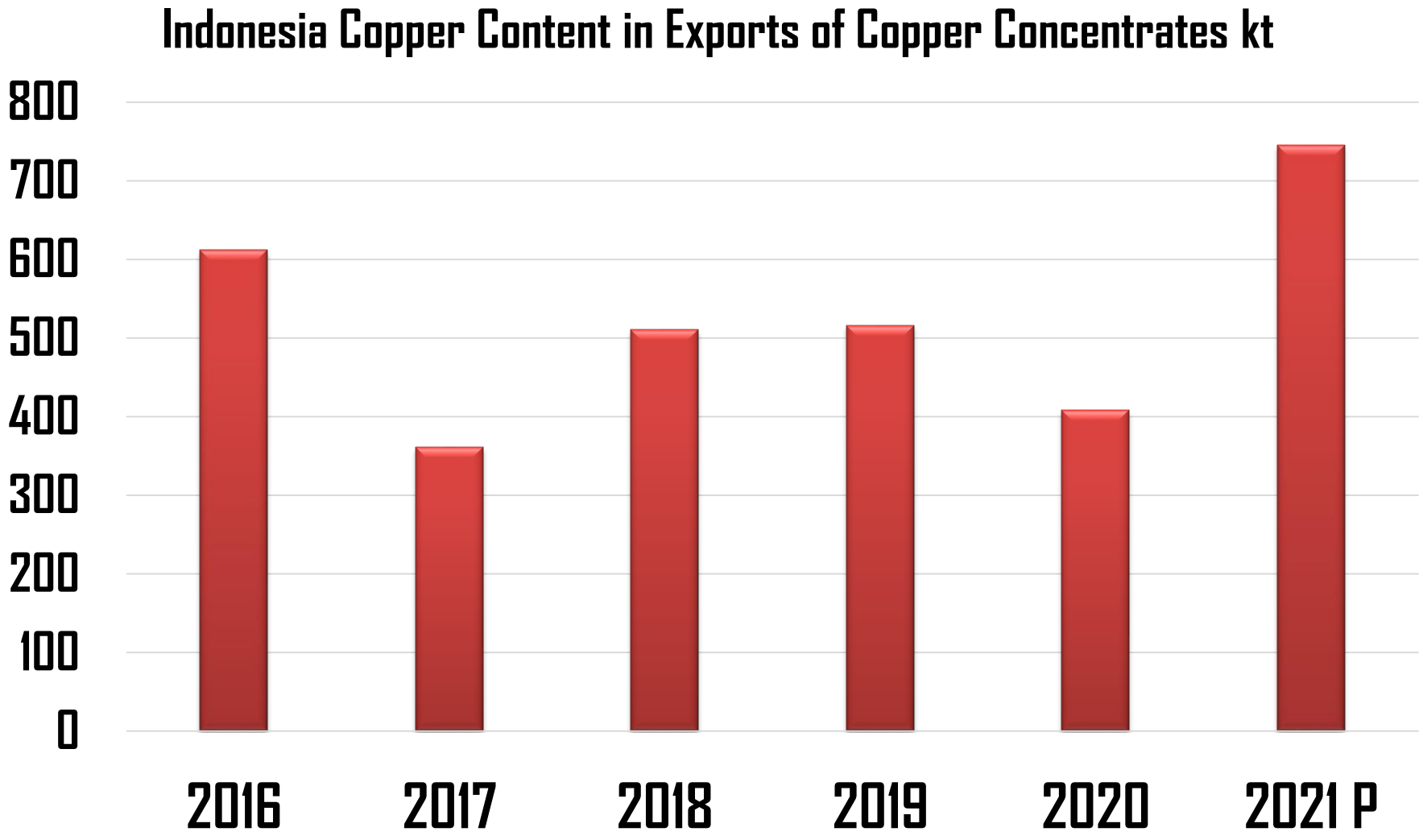


European and Japanese copper concentrate imports in 2021 below 2020, versus China, India and the Korean Republic imports.

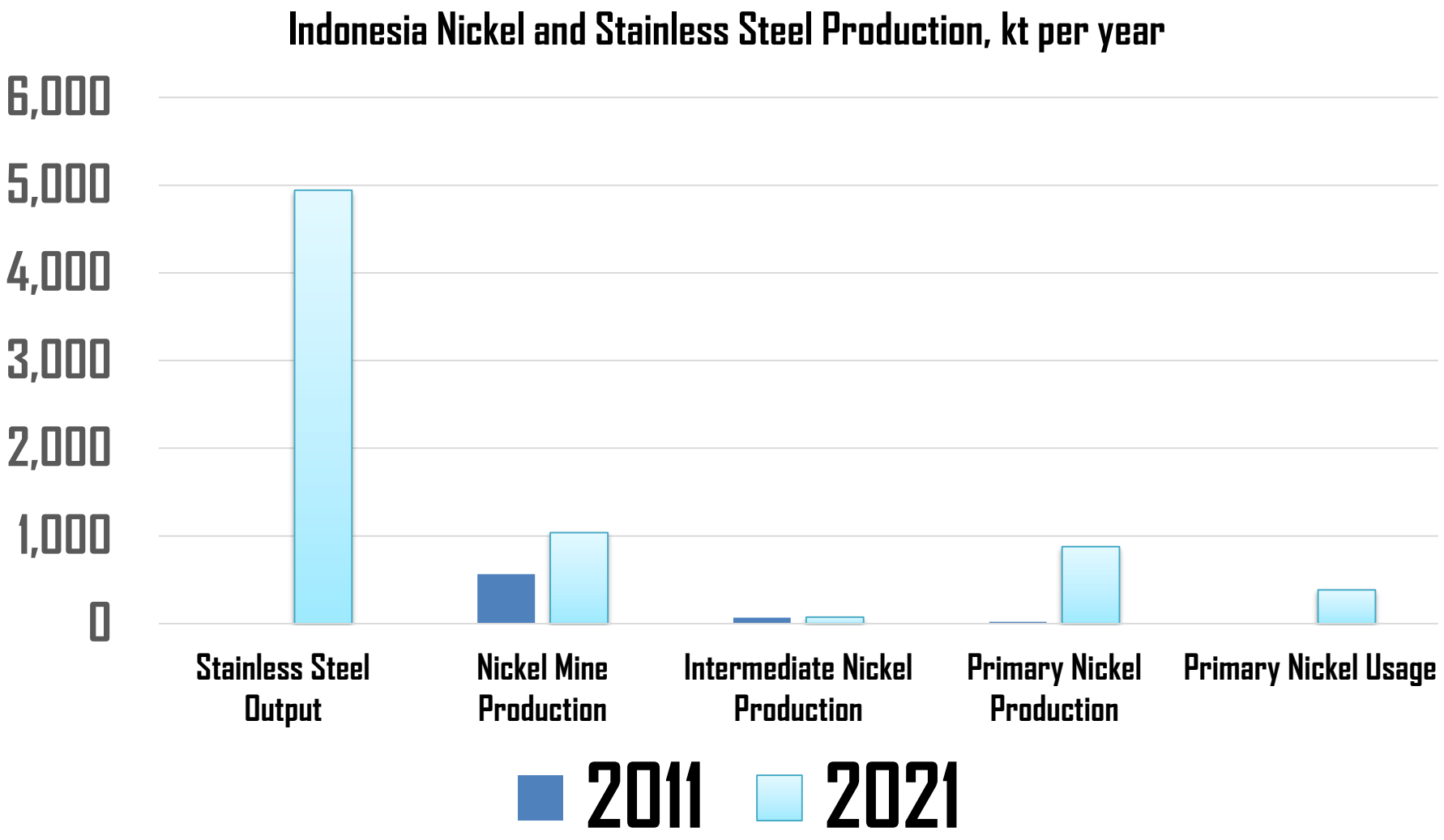


Indonesia copper in concentrates exported: strong 2021 recovery.

Around 2025-2026 smelters under construction in Indonesia might process all copper concentrates currently exported.



Indonesia developed a successful stainless steel industry, based on foreign investments and Ni concentrate export bans.



Indonesia President: export controls on unprocessed minerals ahead.

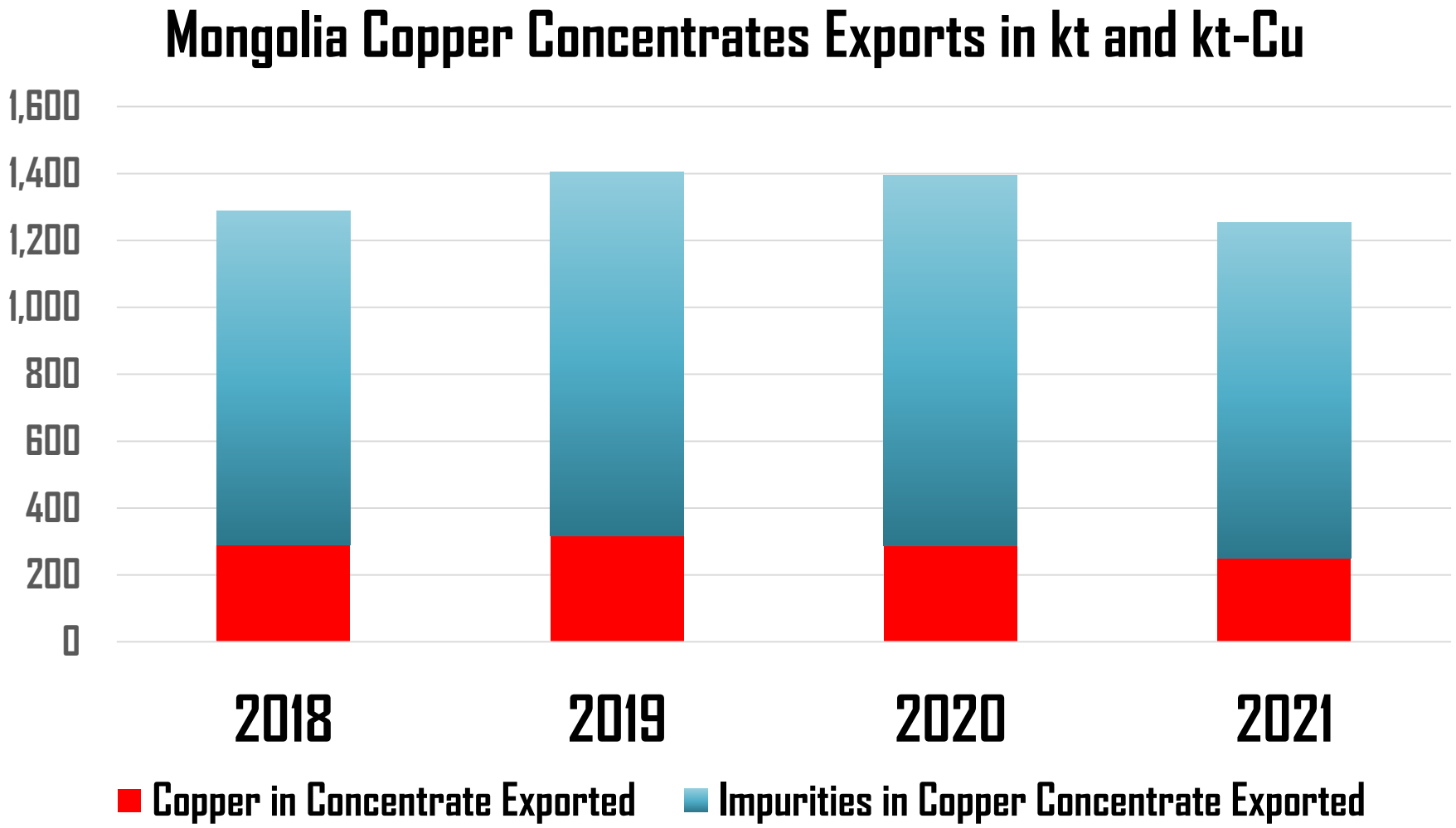
- *"We have always exported our raw material and we must stop it.*
- *We have discontinued nickel exports. Next year we will stop exporting bauxite.*
- ***After bauxite, we will stop exporting copper.***
- *After copper, we will stop exporting tin.*
- *The nickel case has been brought to the WTO. It is all right, we will face it.*

- ***If we produce finished goods, it will generate 10 times of added values.***
- ***If we stop exporting bauxite, exporting copper, exporting tin, exporting gold***
- ***and other raw material exports, we will get more.***

- *I fervently believe that* ***if we do this until 2023 and 2024****, our gross domestic product (GDP) in 2030*
- ***will triple".***

- **President Joko Widodo**
- **at the 7th Anniversary of the Indonesian Solidarity Party**
- **January 2022**

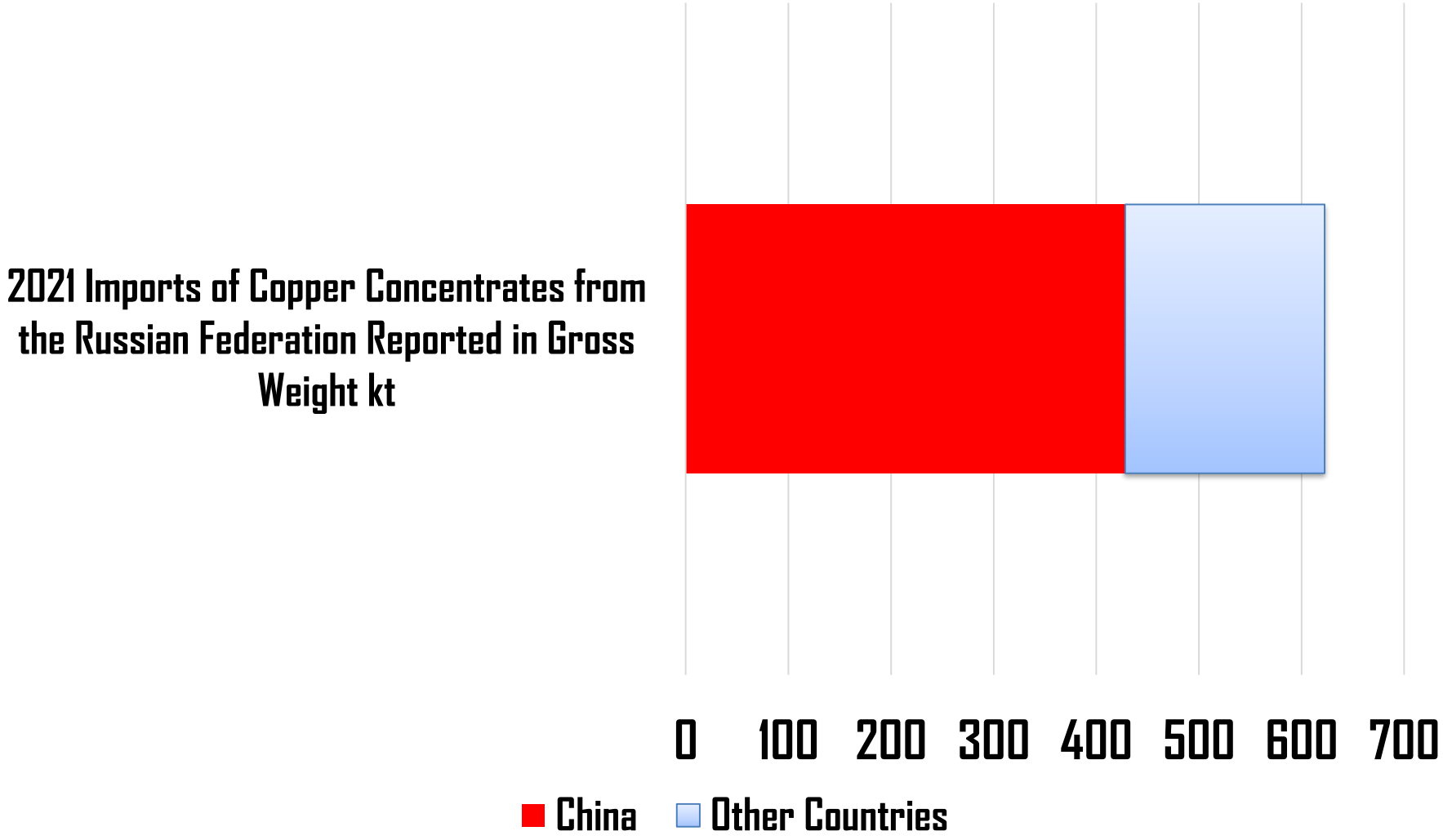
Mongolian exports of concentrates: stable and high arsenic, but slightly below 0.5% China import limit, so it is "clean".



Increase in Russian Federation copper concentrate exports 2020-2021:

Tominskoye copper mine start-up in April 2020 and Bystrinsky mine start-up in 2018

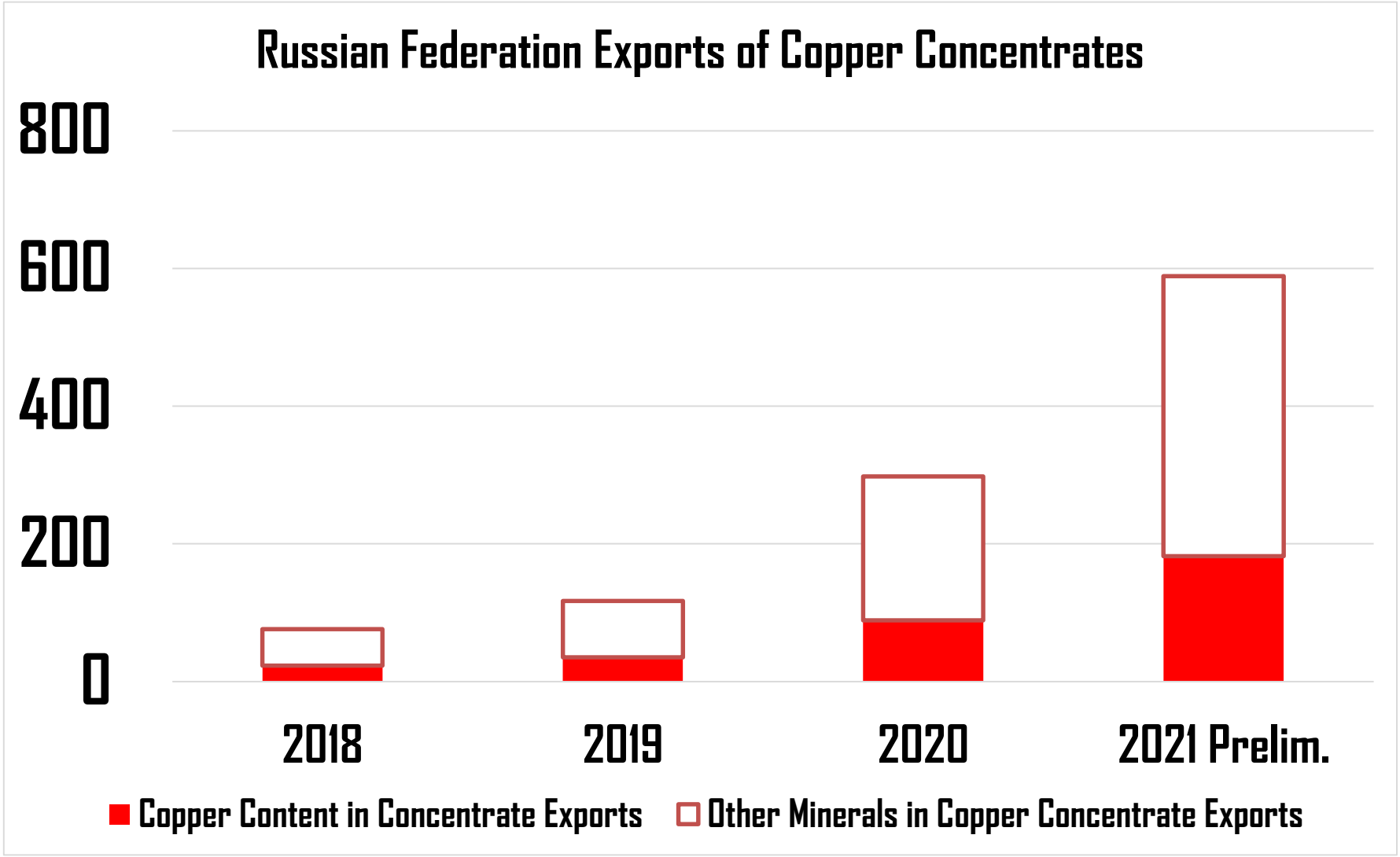
More exports in 2021 after Kola MMC Monchegorsk smelter stop to control air emissions.



Russian Federation: record copper concentrate exports in 2020-2021

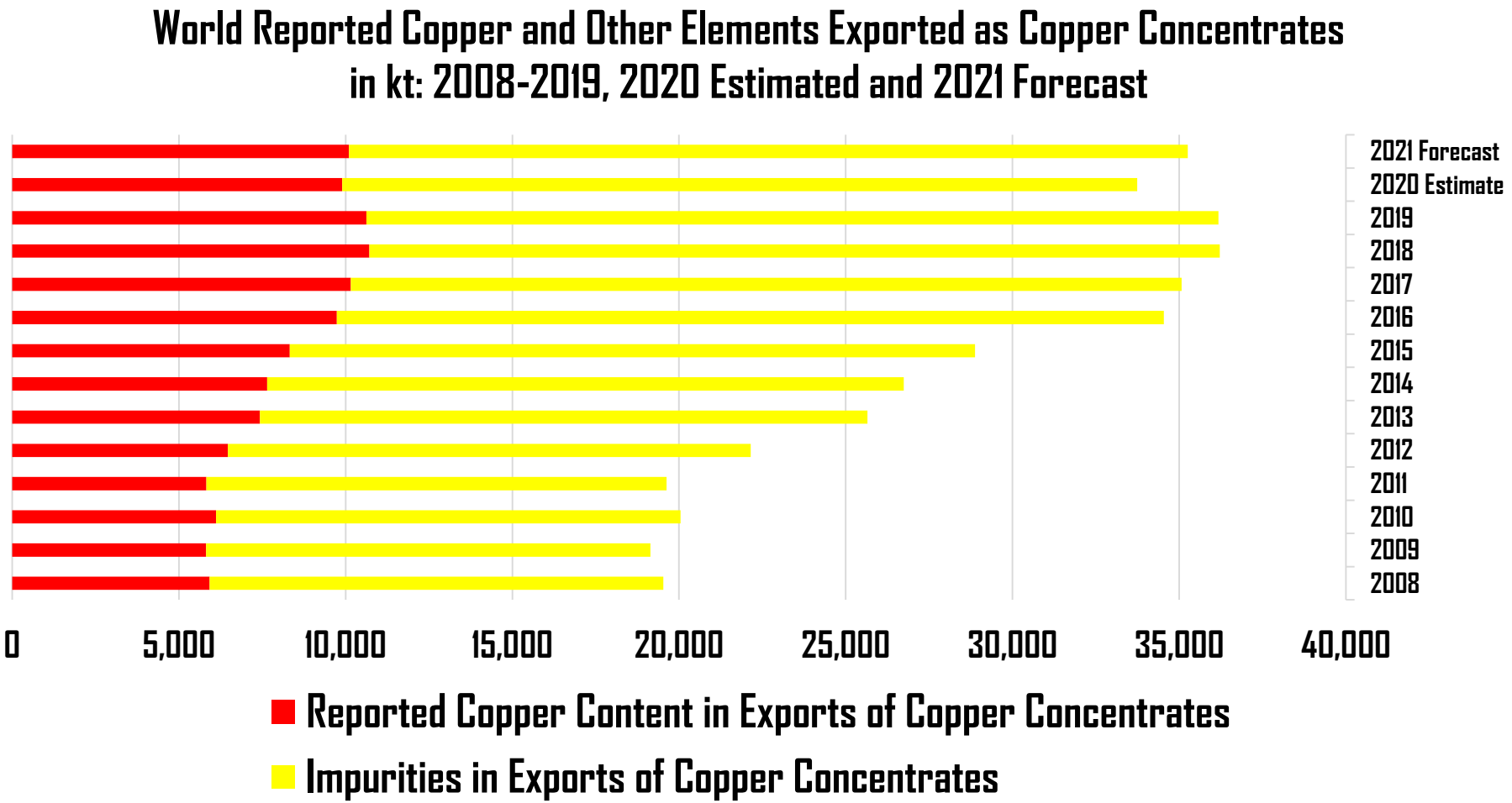
622.4 kt in 2021, most to Northern China smelters.

Udokan copper mine to be commissioned in 2022 will increase exports.



3. ICSG Research Advances on Arsenic in Copper Concentrates Output and Exports

Other minerals in exports of copper concentrates: growing faster than copper contents: data on 180 traded copper concentrates shows an average grade of 27% copper in recent years.

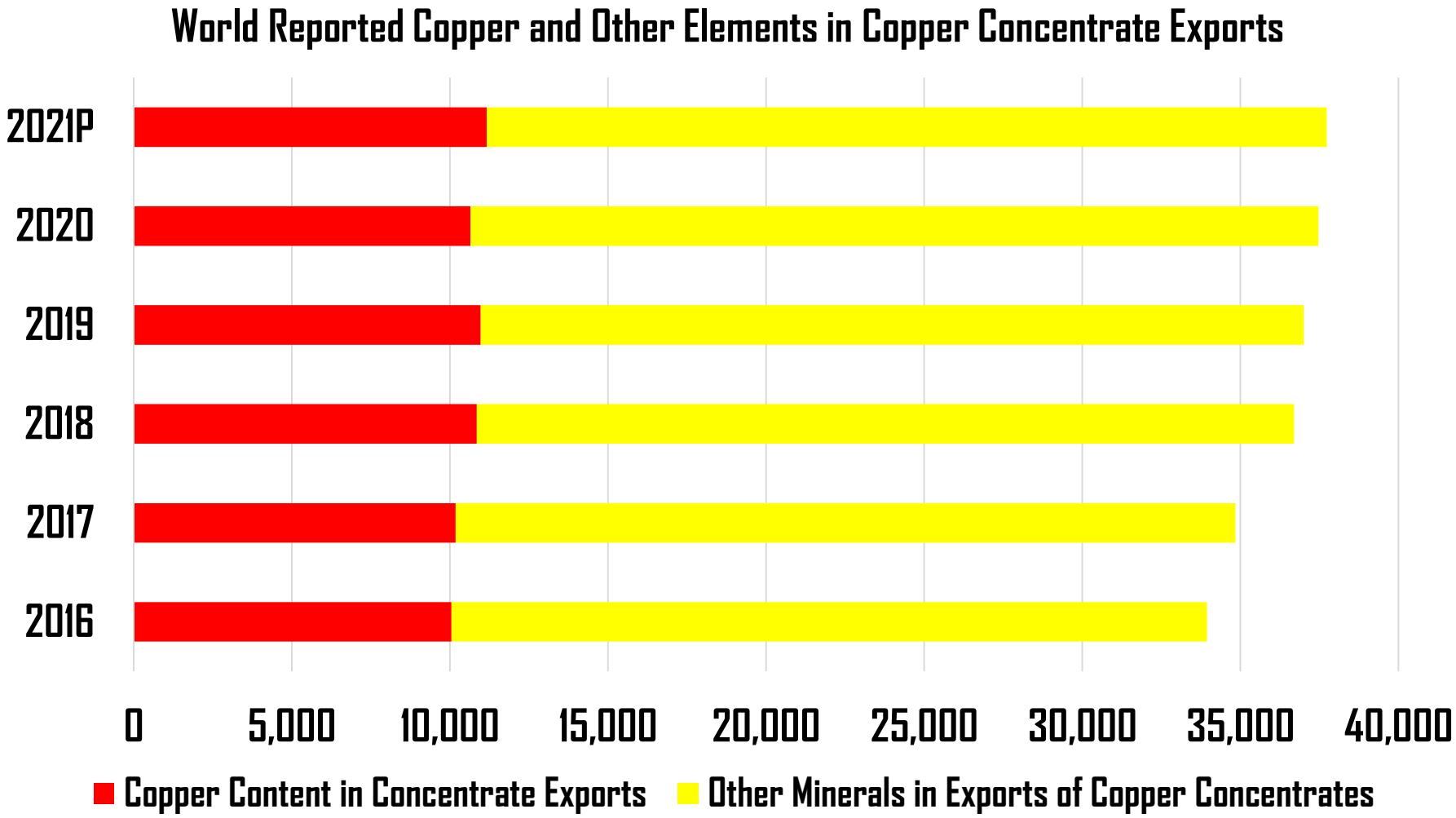


https://link.springer.com/content/pdf/10.1007%2Fs11837-020-04255-9.pdf

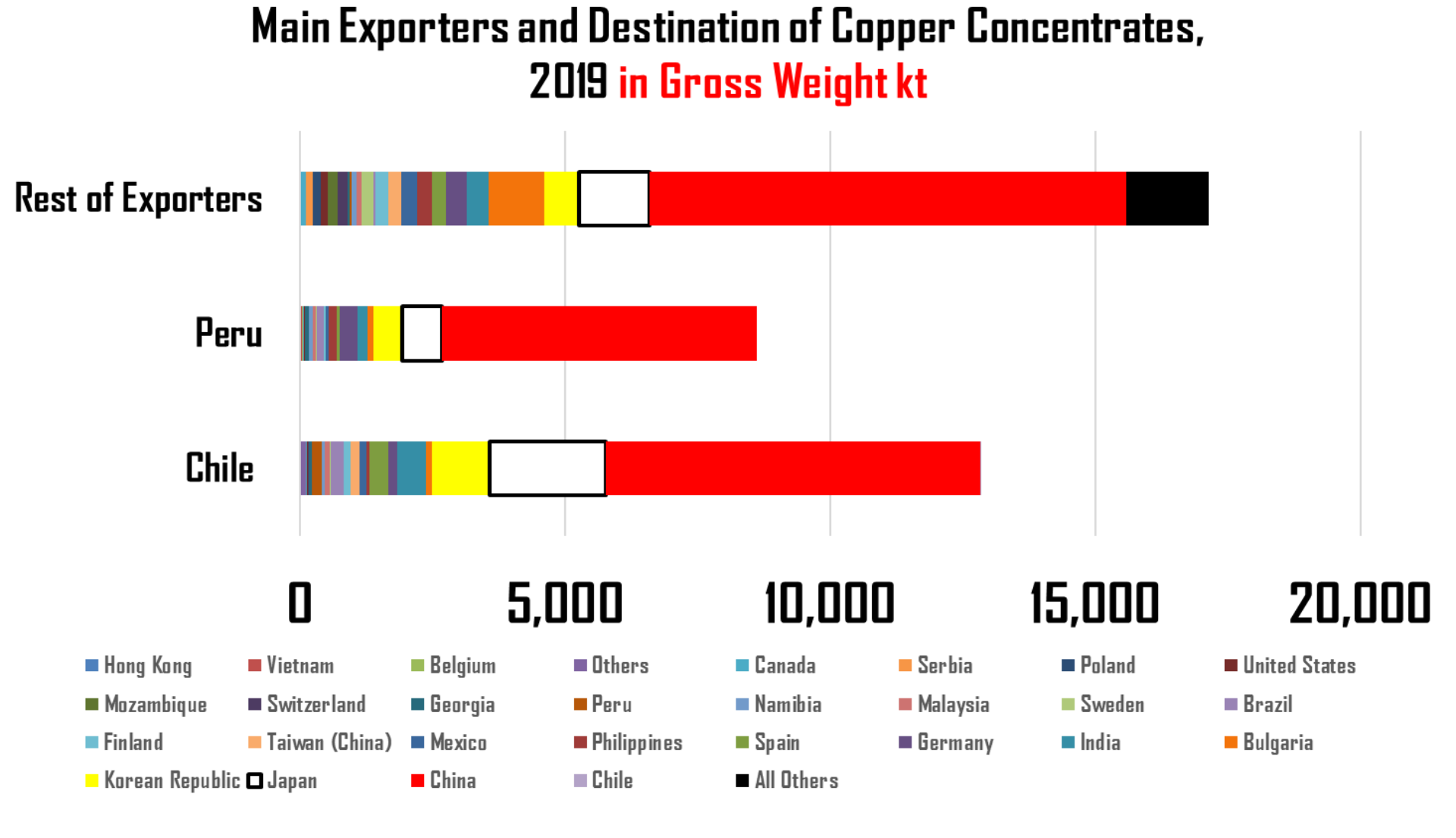
Latest update of global copper concentrates exports:

record gross weight export volumes in 2021, slightly more copper content.

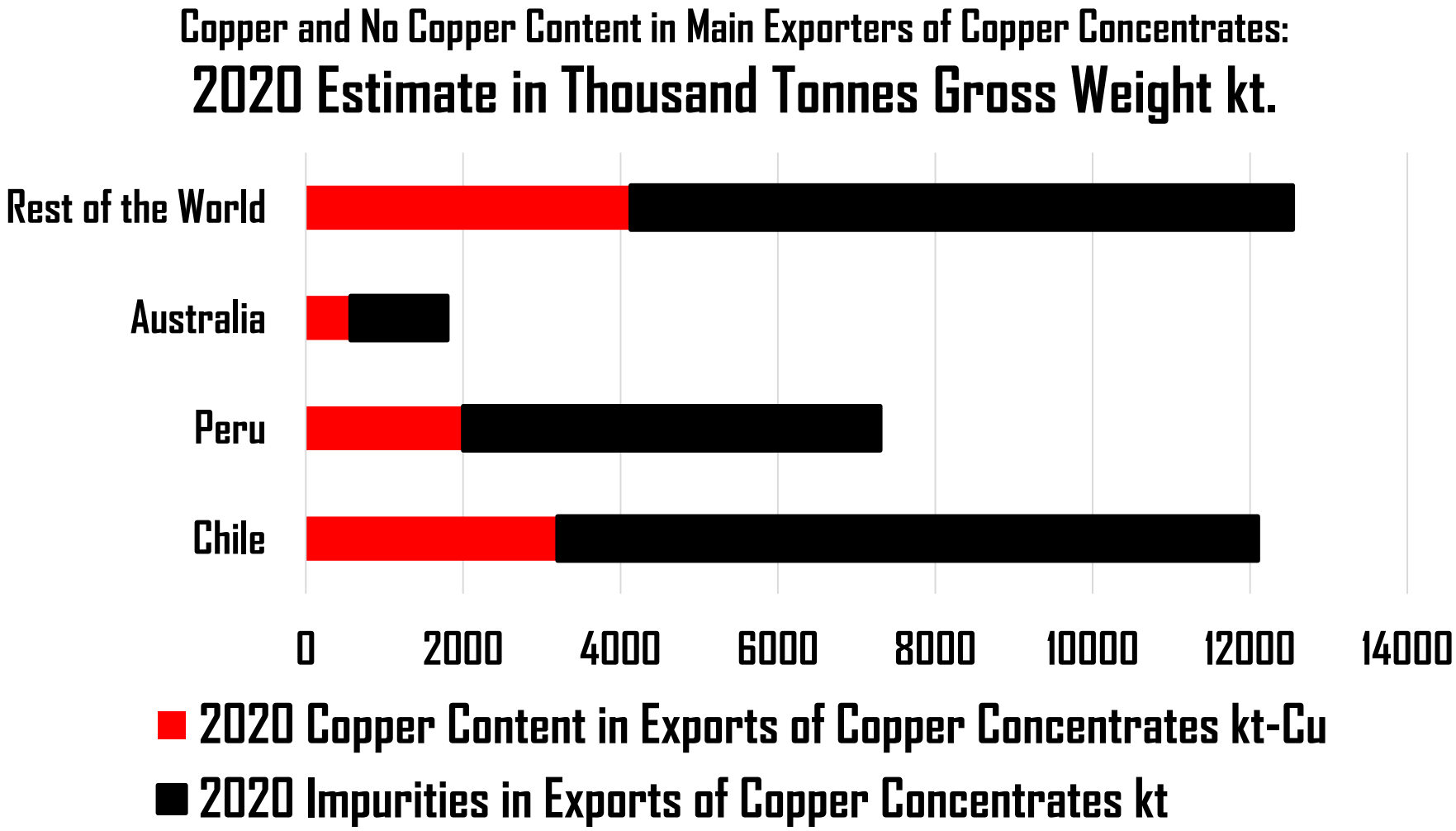
High chance of global copper content over reported in recent years.



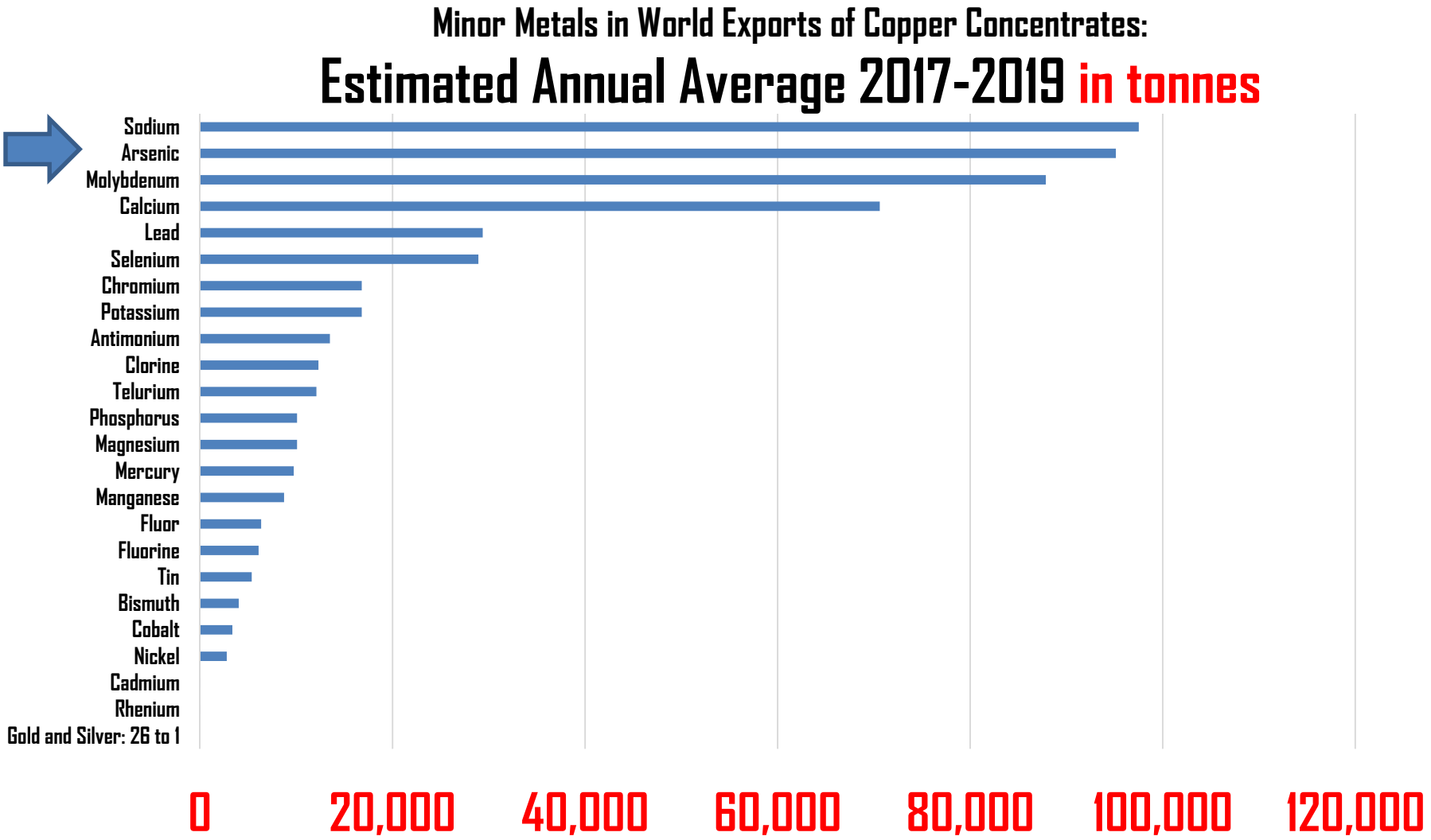
Smelters in China, Japan and Korean Republic: increasingly depend from blending and complex concentrate exports from Chile and Peru.



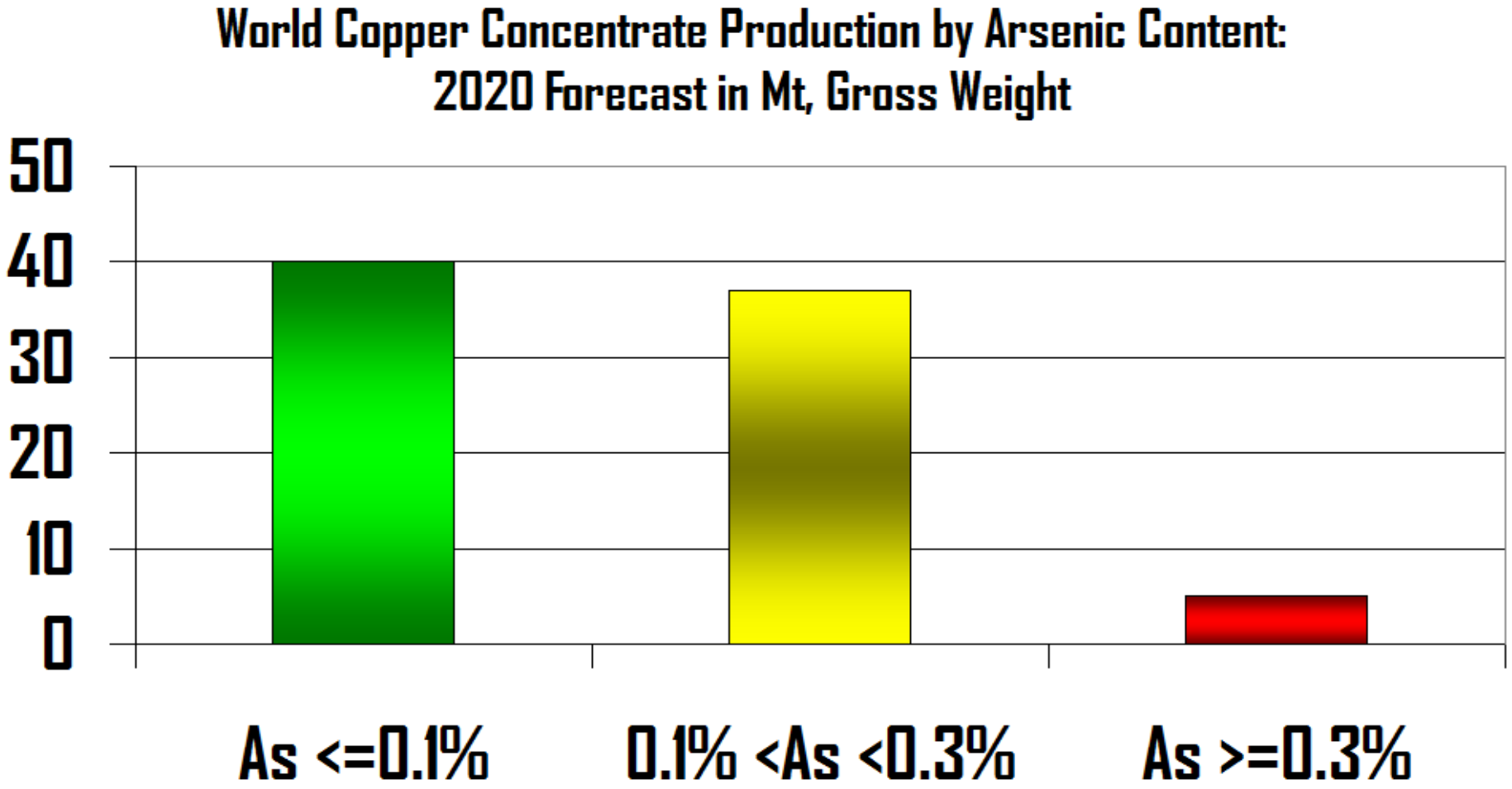
Other minerals in exports of copper concentrates in 2021: 26.6 Mt.
from Chile ~37%, Peru ~22%, Australia 5% and from rest of the world ~35%.



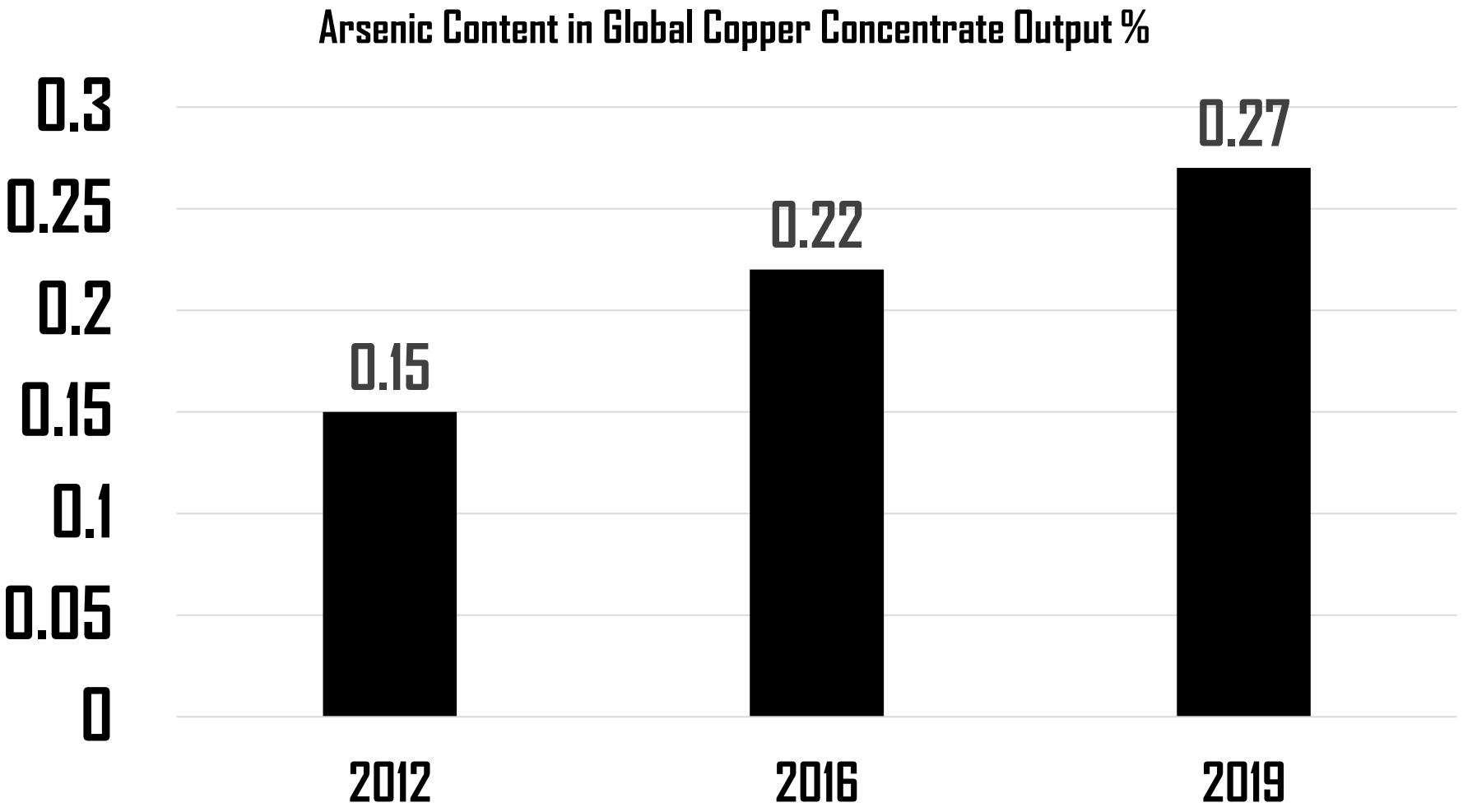
Important volumes of minor metals contained in global exports of copper concentrates traded internationally in recent years.



Most of the copper concentrates available in the global market has less than 0.3% Arsenic, still called "clean concentrates".



Increasing arsenic content in global output of copper concentrates: source of environmental regulations and more carefull industry monitoring, processing, extraction, estabilization and disposal.



Mineral composition ranking for global copper concentrate output over 62 Mt-Cu per year estimated with record Arsenic >200 kt in 2021.

Mineral Composition in World Copper Concentrates Output: Changes 2017-2020

Average Estimates Based on Information Collected from Mining Companies and Governments

Units in thousand tonnes kt

	2017	2018	2019	2020 Preliminary
Sulphur	19,078.4	19,975.4	19,862.8	20,027.2
Copper	16,285.0	16,667.0	16,573.0	16,585.0
Iron	14,799.1	15,418.5	15,269.5	15,395.9
Other Unreported Minerals	320.7	998.8	2,234.6	2,503.4
Silica	1,901.9	1,997.5	1,986.3	2,002.7
Alumina	1,367.0	1,061.2	931.1	813.6
Zinc	1,182.7	1,479.4	484.2	250.3
Sodium	172.4	181.0	180.0	181.5
Molybdenum	118.9	255.9	105.5	150.2
Arsenic	178.3	137.3	204.8	143.9
Mercury	16.0	16.9	20.5	137.7
Calcium	124.8	131.1	130.3	131.4
Lead	50.5	54.3	55.9	61.3
Selenium	51.1	53.7	53.4	53.8
Chlorine	23.8	18.7	24.8	31.3
Potassium	29.7	31.2	31.0	31.3
Chromium	29.7	31.2	31.0	31.3
Tellurium	21.4	22.5	22.3	22.5
Manganese	17.8	18.7	18.6	18.8
Phosphorus	17.8	18.7	18.6	18.8
Magnesium	15.5	16.2	16.1	16.3
Antimony	16.6	21.8	35.4	15.0
Fluorine	10.7	11.5	11.2	12.5
Tin	9.5	9.4	10.6	10.0
Bismuth	5.9	8.1	8.1	8.8
Cobalt	5.9	6.2	6.2	6.3
Nickel	4.9	5.2	5.2	5.2
Cadmium	0.4	0.4	0.4	0.4
Rhenium	0.1	0.1	0.1	0.1
Gold and Silver: 26 Rate	0.0002	0.0002	0.0002	0.0002
Others SiO2 Related Elements	3,577.5	3,775.0	3,739.7	3,918.4
Copper Concentrates Output in kt	59,434.3	62,423.2	62,071.2	62,584.9

Mineral composition of global copper concentrate exports, >60% of global output and >100 kt of Arsenic exported in 2021.

Identified Mineral Composition in World Copper Concentrate Exports: Changes 2017-2020

Average Estimates Based on Information Collected from Mining Companies and Governments

Units in thousand tonnes, gross weight kt

	2017	2018	2019	2020 Preliminary
Sulphur	10,471.0	10,969.1	10,874.9	9,087.0
Copper	8,937.9	9,152.3	9,073.7	7,525.2
Iron	8,122.4	8,466.8	8,360.1	6,985.6
Other Unreported Minerals	182.5	551.9	1,232.6	1,221.1
Silica	1,043.8	1,096.9	1,087.5	908.7
Alumina	750.3	582.7	509.8	369.2
Zinc	649.1	812.4	265.1	113.6
Sodium	94.6	99.4	98.6	82.4
Molybdenum	65.2	140.5	57.8	68.2
Arsenic	97.9	75.4	112.1	65.3
Mercury	8.8	9.3	11.2	62.5
Calcium	68.5	72.0	71.4	59.6
Lead	27.7	29.8	30.6	27.8
Selenium	28.1	29.5	29.2	24.4
Chlorine	13.0	10.3	13.6	14.2
Potassium	16.3	17.1	17.0	14.2
Chromium	16.3	17.1	17.0	14.2
Telurium	11.7	12.3	12.2	10.2
Manganese	9.8	10.3	10.2	8.5
Phosphorus	9.8	10.3	10.2	8.5
Magnesium	8.5	8.9	8.8	7.4
Antimony	9.1	12.0	19.4	6.8
Fluorine	5.9	6.3	6.1	5.7
Tin	5.2	5.1	5.8	4.5
Bismuth	3.3	4.5	4.4	4.0
Cobalt	3.3	3.4	3.4	2.8
Nickel	2.7	2.8	2.8	2.4
Cadmium	0.0002	0.0002	0.0002	0.0002
Rhenium	0.00004	0.00004	0.00004	0.00003
Gold and Silver: 26 to 1	0.0000001	0.0000001	0.0000001	0.0000001
	-	-	-	-
Concentrate Exports Contents in kt	32,620.0	34,278.4	33,984.0	28,396.8
Concentrate Exports Untracked (kt)	3,734.0	4,175.6	4,593.0	3,837.9
	-	-		
Concentrate Exports Reported (kt)	36,354.0	38,454.0	38,577.0	32,234.7

More complex concentrates blended, instead of pre-treated: new Chinese blending plants to compete with existing blending operations.

Global Copper Concentrates Blending Facilities Before 2021

thousand tonnes per kt

Country	Port/City	Blending Capacity	Copper Content
Peru	Callao	1150	299
Mexico	Manzanillo	600	156
Chile	Antofagasta+Copiapo	600	156
Spain	Huelva	550	143
Taiwan China	Qwangyang	500	130
Malaysia	Port Klang	400	104
Georgia	Poti	400	104
Bulgaria	Varna	120	31
Emirates	Sahar	100	26
Netherlands	Moerdiskj	50	13
China	Daye+Sangmengxia+FanCHenDang	2500	650
China	Ningde	1000	260
China	Taichung	500	130
China	Shandong	300	78
China Before 2021		4,300	1,118
Rest of the World 2021		4,470	1,162

Several large-scale blending facilities commissioned in China in 2021.

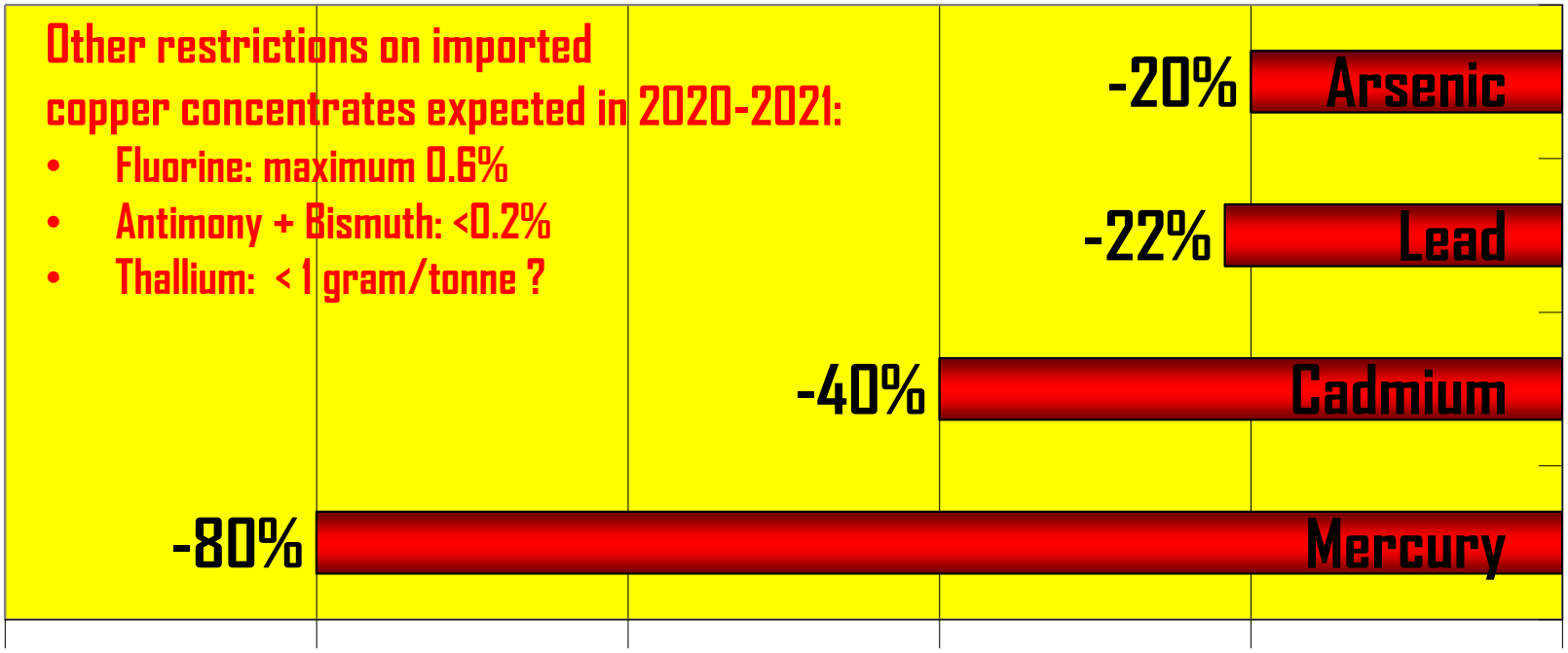
Zijin Mining new China concentrate blending facility with Minmetals. Plant in Lianyungang port of Jiangsu province approved in 2021.

In 2019 Glencore started a new copper concentrates blending facility in Taiwan (China).

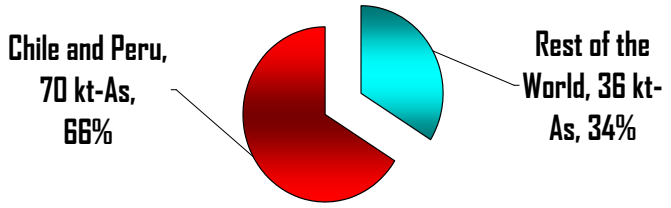
No new limits to minor metals in concentrates imports in China in 2021.

Permits to process complex concentrates and blending plants in China will keep arsenic flows to Chinese smelters and hazardous waste disposal places in China.

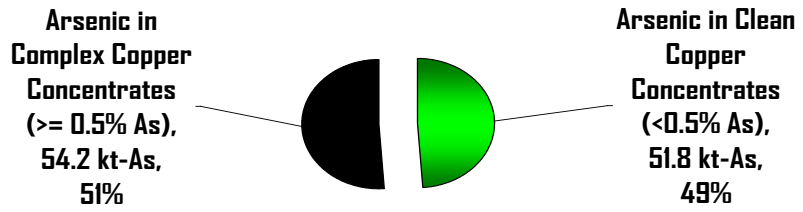
New Limits Proposed in 2019 to Imports of Copper Concentrates to China (% Versus Existing Limits)



Arsenic in 2016 Global Copper Concentrates Supply Already Treated (kt-As)

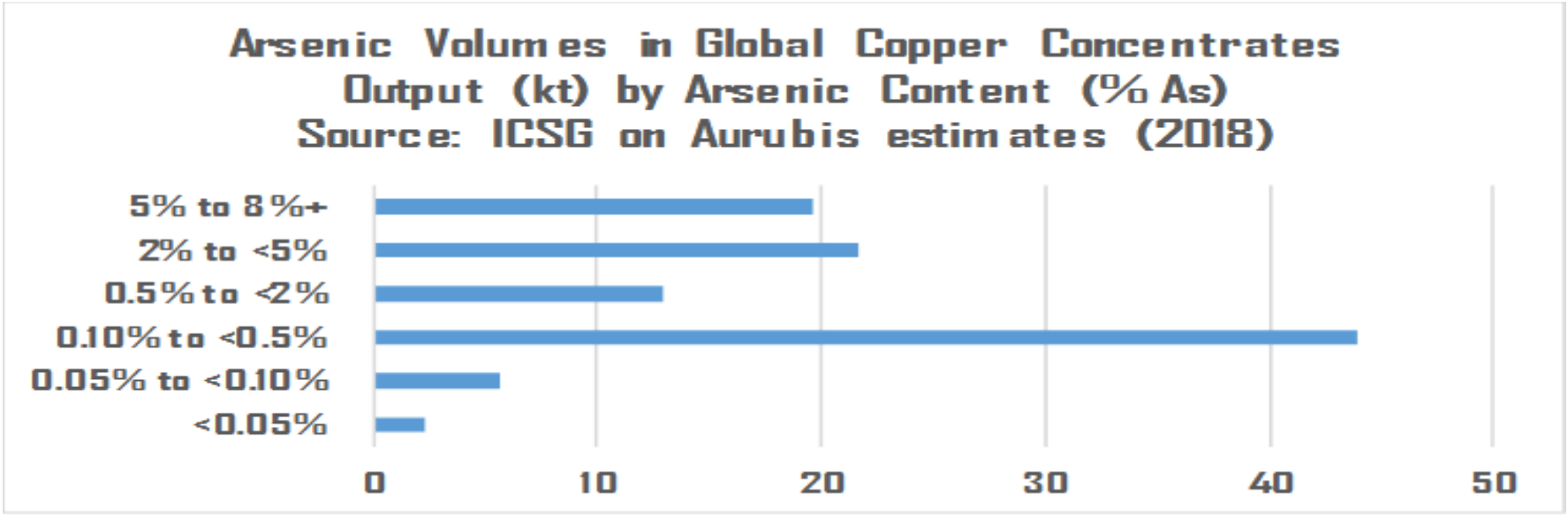


Arsenic Distribution in Clean and Complex Copper Concentrates Already Treated in 2016 (kt-As)



Half of copper concentrate output complied with China´s Arsenic limits.

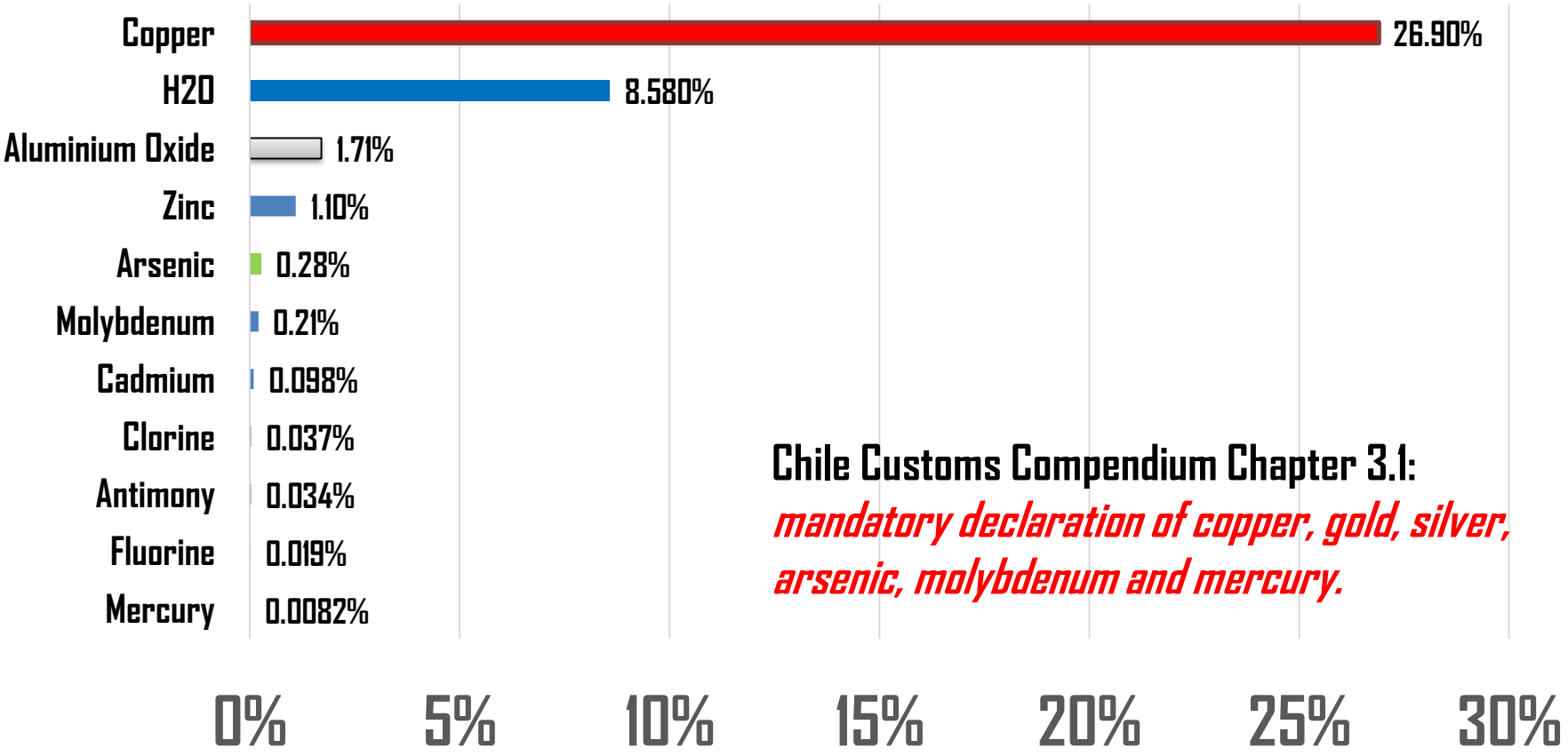
If the limit was tightened, blenders might not source enough "clean" concentrate.



4. Changes in Arsenic in Mineral Composition of Copper Concentrates Exported from Chile

Chile copper concentrates exporters reported only 39% of the total composition to Chile Customs in 2017-2019.

Chile: Mineral Content Reported in Copper Concentrates Exports Reported to Customs. % Weighted Average 2017-2019.



Chile Customs Compendium Chapter 3.1:

mandatory declaration of copper, gold, silver, arsenic, molybdenum and mercury.

Copper content exported by Chile keep falling (<26 %Cu in 2021).

Chile concentrates export record >12.8 Mt in 2019, then 12.2 Mt on lockdowns.

In 2021 Chile struggled to achieve <12.2 Mt exported on lower ore grades.

Chile Mineral Content in Exports of Copper Concentrates 2017-2019

Annual Weighted Averages as Percentage of Exports Reported %

Source: COCHILCO 2021 based on Chile Customs Data

	2017	2018	2019
Copper	27.4	26.9	26.7
Arsenic	0.30	0.22	0.33
Molybdenum	0.2	0.41	0.17
Alumina	2.3	1.7	1.5
Chlorine	0.04	0.03	0.04
Antimonium	0.028	0.035	0.057
Mercury	0.027	0.027	0.033
Zinc	1.99	2.37	0.78
Fluorine	0.02	0.01	0.027
Gold and Silver	0.00098	0.00093	0.00088
Sulphur	32	32	32
Iron	25	25	25
Other	11	11	13

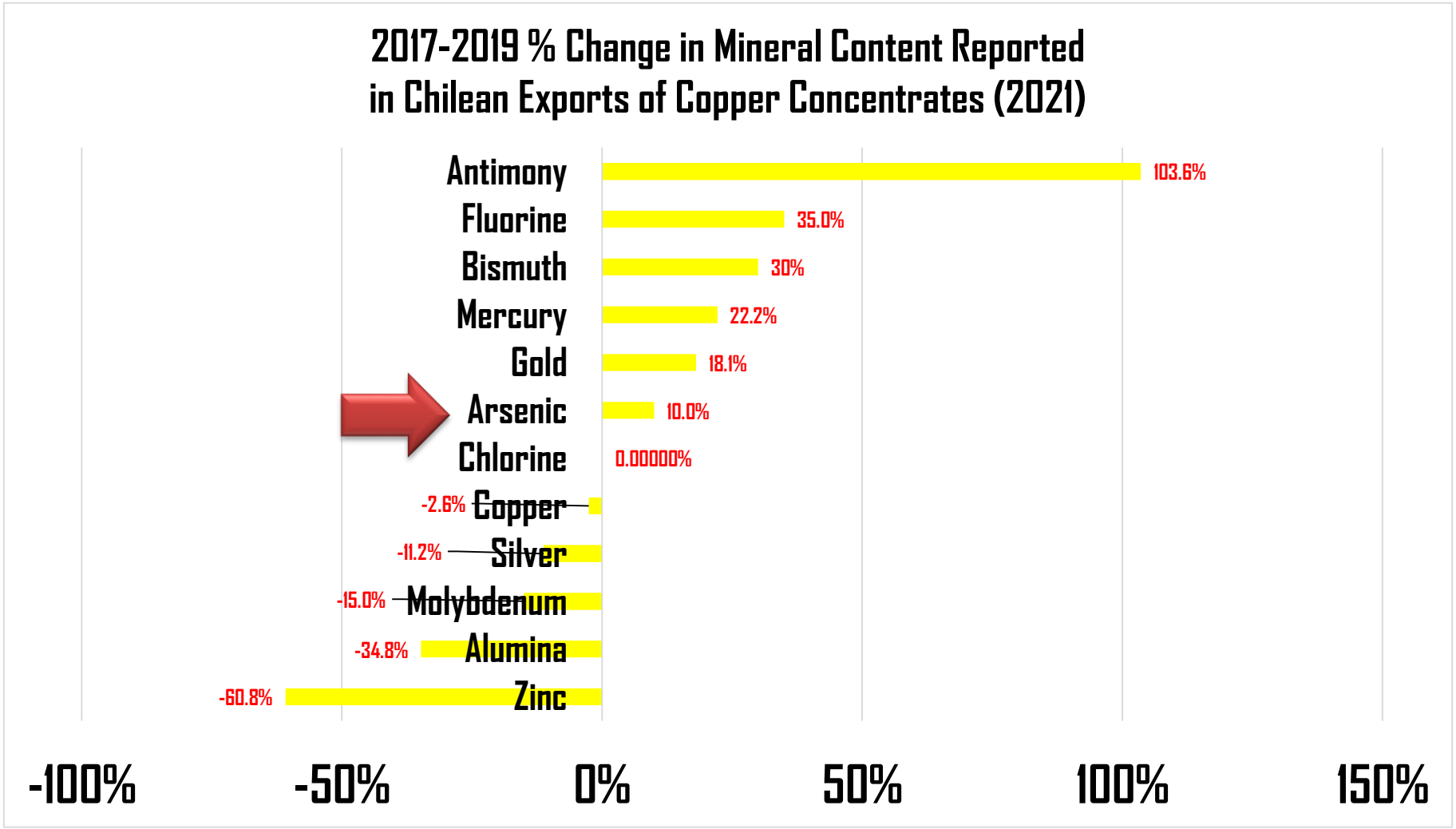
The average content of some hazardous minerals in copper concentrate exports reported by Chile increased in recent years.

Chile: Mineral Content Trend in Exports of Copper Concentrates 2017-2019

% weighted average reported, except gold and silver in grams per tonne

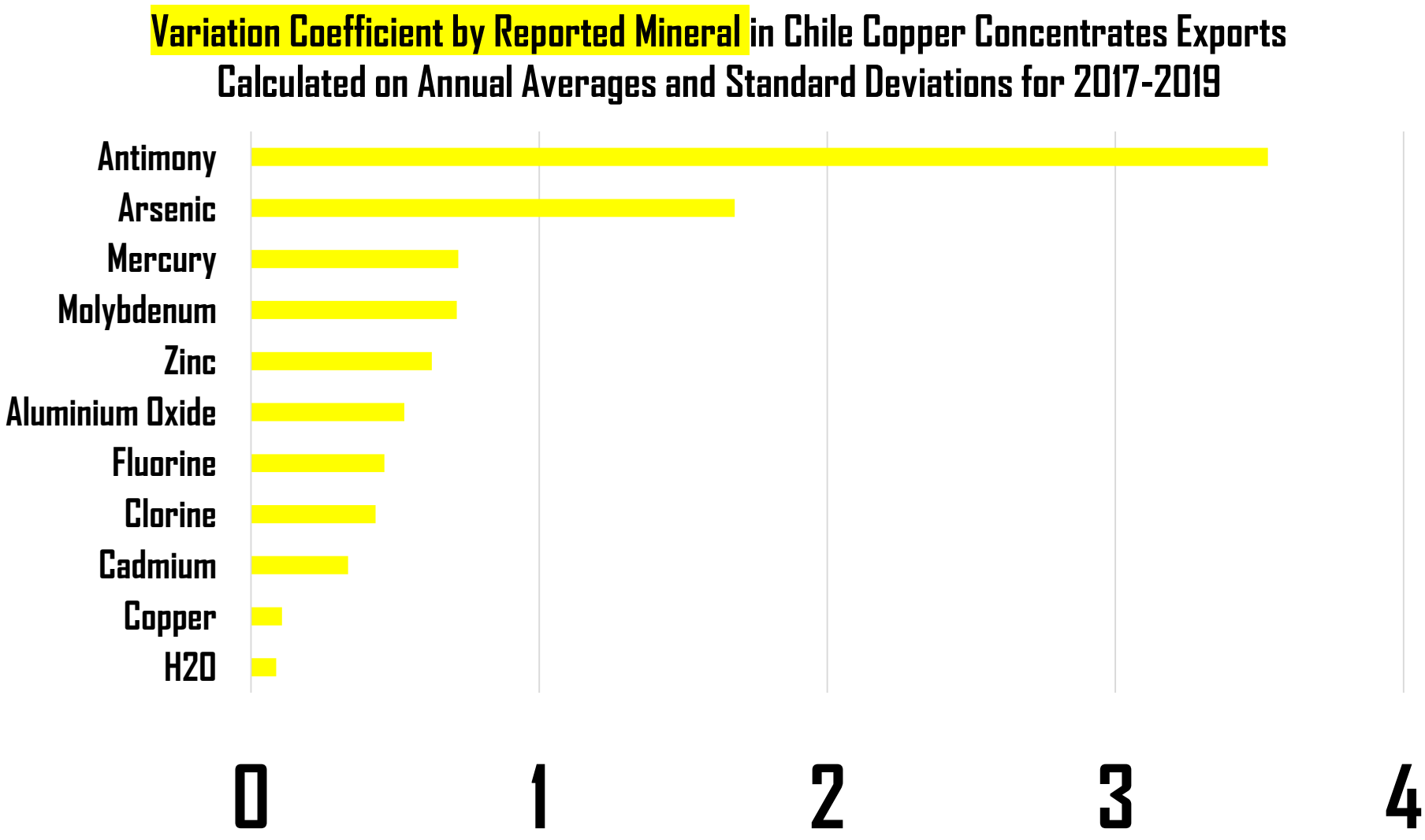
	2017	2018	2019	% Growth 2017-2019
Antimony	0.028	0.035	0.057	103.6%
Fluorine	0.02	0.01	0.027	35.0%
Mercury	0.027	0.027	0.033	22.2%
Arsenic	0.30	0.22	0.33	10.0%
Chlorine	0.04	0.03	0.04	0.0%
Copper	27.4	26.9	26.7	-2.6%
Molybdenum	0.2	0.41	0.17	-15.0%
Alumina	2.3	1.7	1.5	-34.8%
Zinc	1.99	2.37	0.78	-60.8%
Gold	2.1	2.37	2.48	18.1%
Silver	96.2	90.8	85.4	-11.2%
% of Exports Reported	32.3	31.7	29.6	-8.3%

The mineral composition of Chile exports of copper concentrates changed fast in 2017 – 2019 and will keep changing in the future.



Source: ICSG based on COCHILCO analysis of Chile Customs Bureau Statistics (2021).

Large differences in the average contents of Arsenic in exports of Chilean copper concentrates versus other elements.

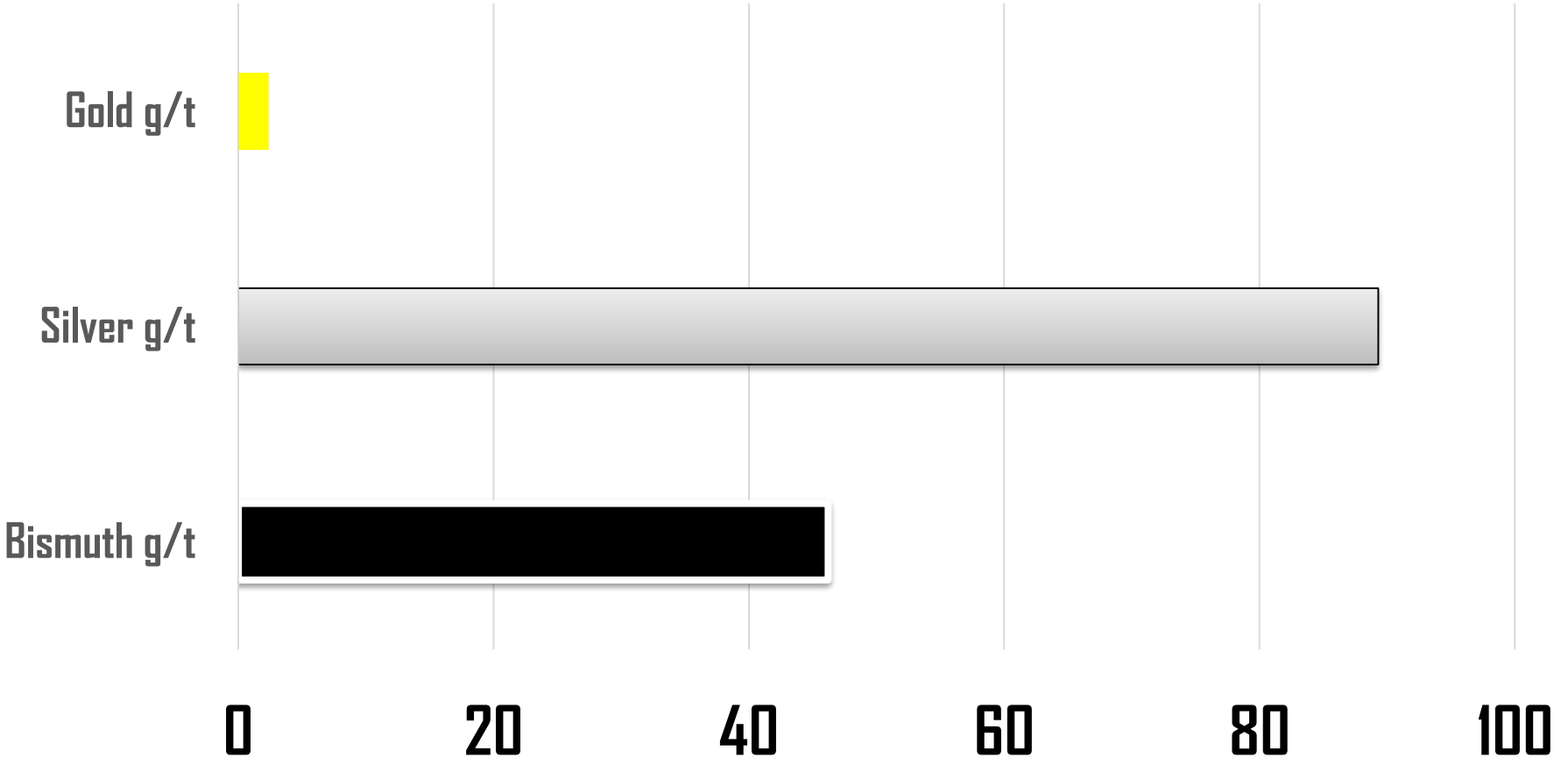


Silver and gold content in Chilean Cu concentrates exported are significant.

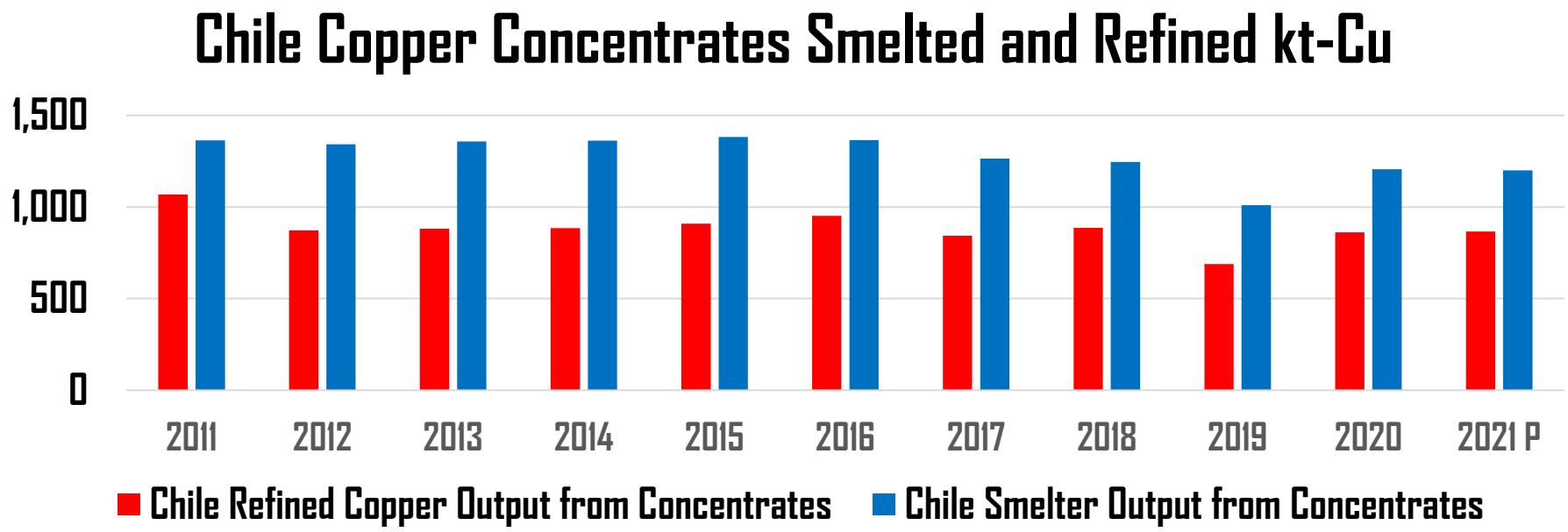
High silver and high gold concentrates not reported as "copper concentrate" by importers causing under-reporting of copper and As in some importer countries.

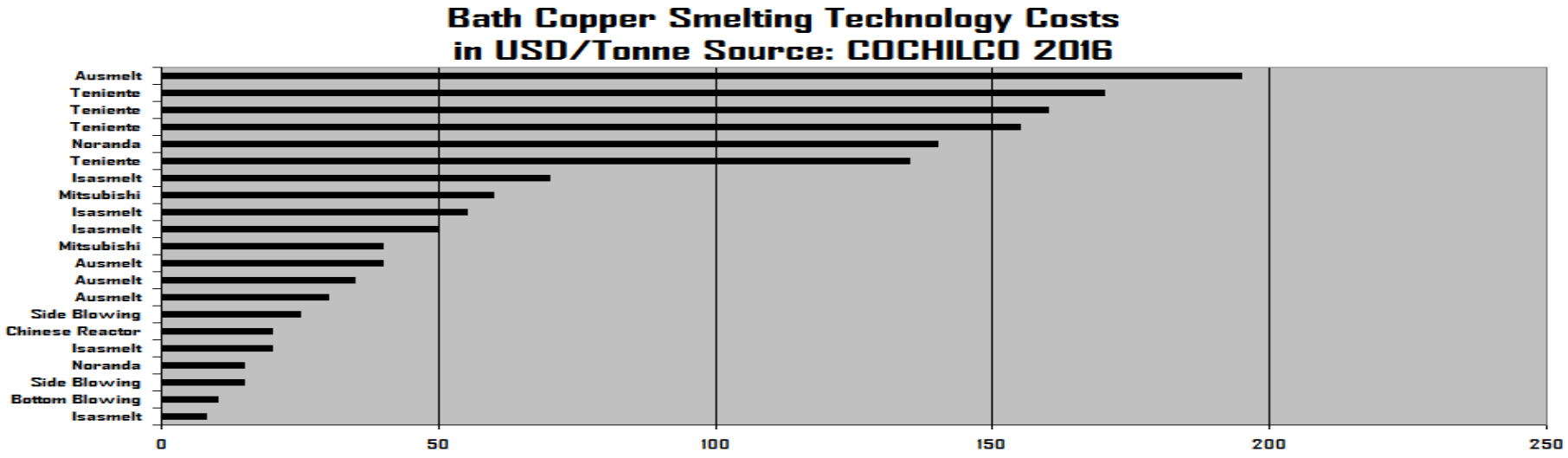
Dealing with bismuth will remain a challenge for copper smelters.

Average 2017-2019 Content of Precious Metals in Exports of Copper Concentrates from Chile grams/tonne



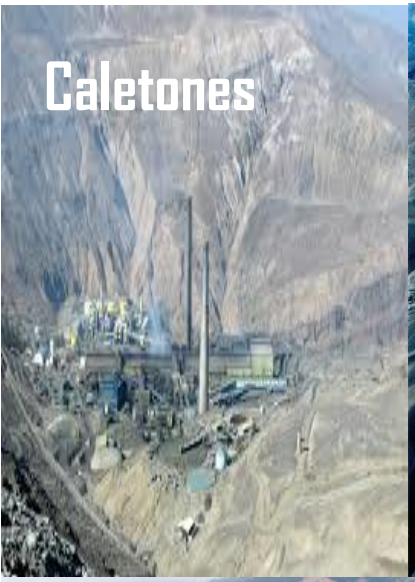
Chile mine supply complexity is increasing, so smelters process high As. Domestic value added output stagnated on high smelting costs.

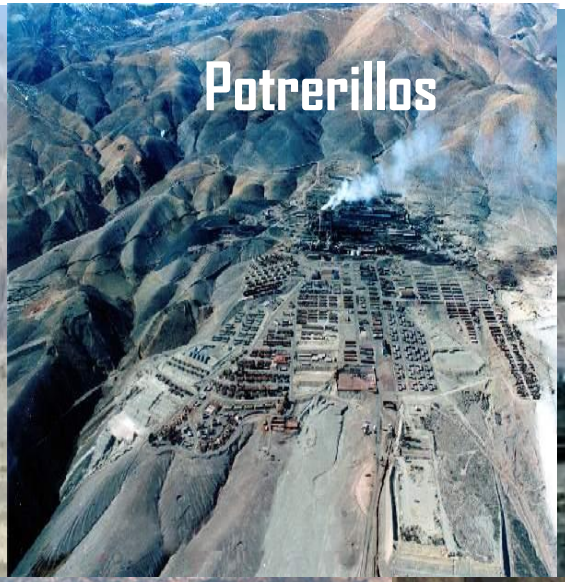




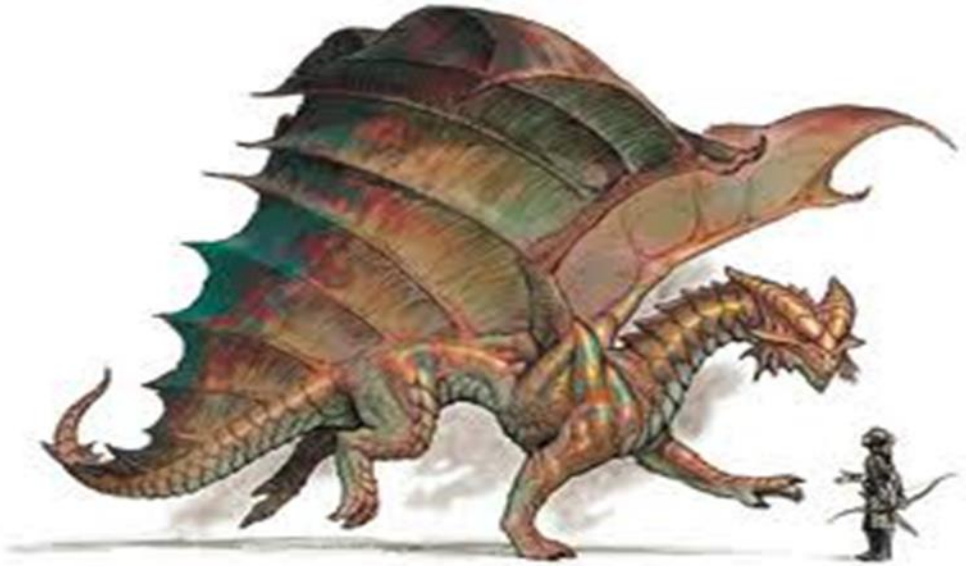
Chile smelter technologies: end of pipe upgrades commissioned in 2019.

Paipote copper smelter project: only capacity expansion in Chile not confirmed yet.

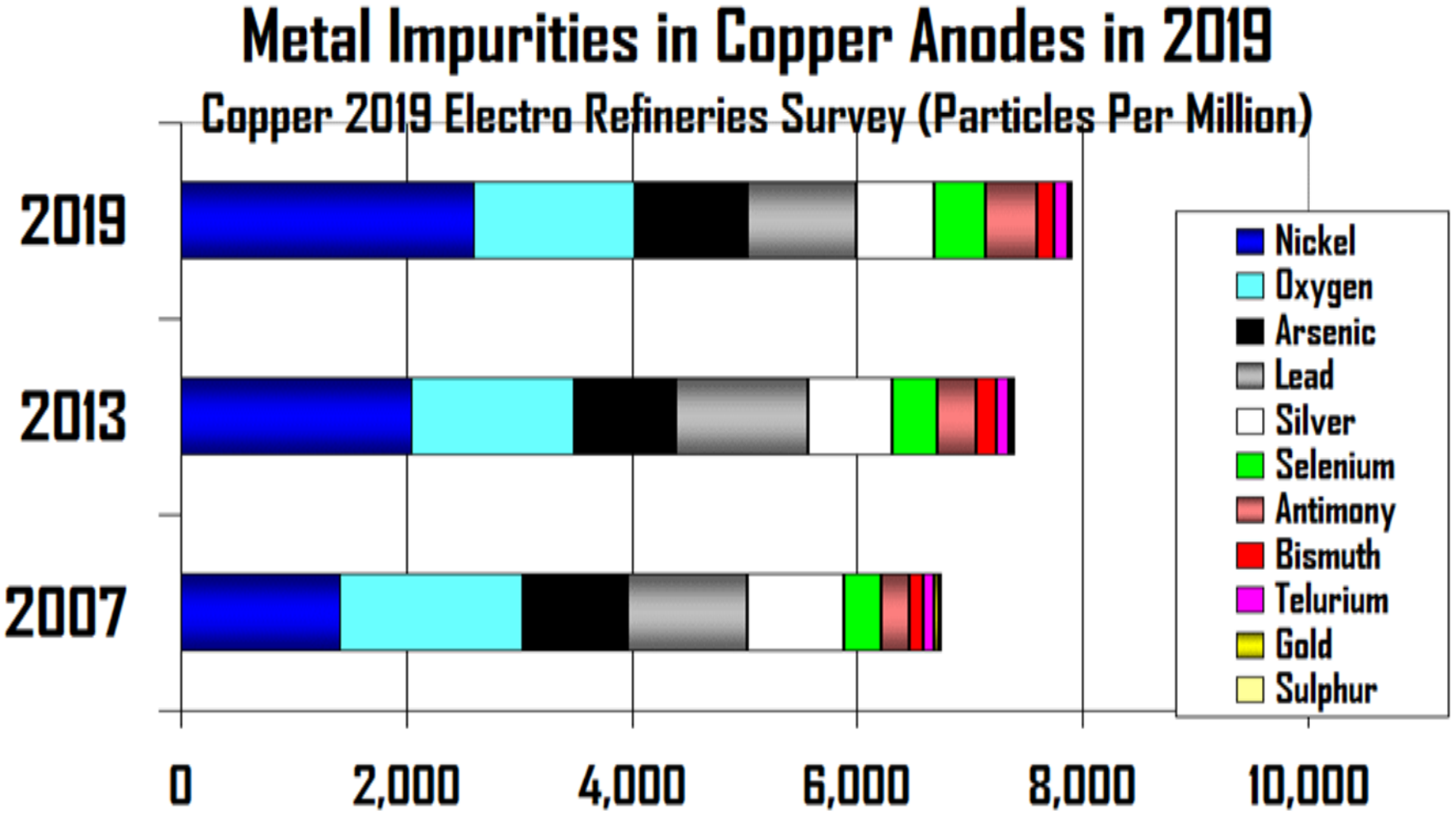




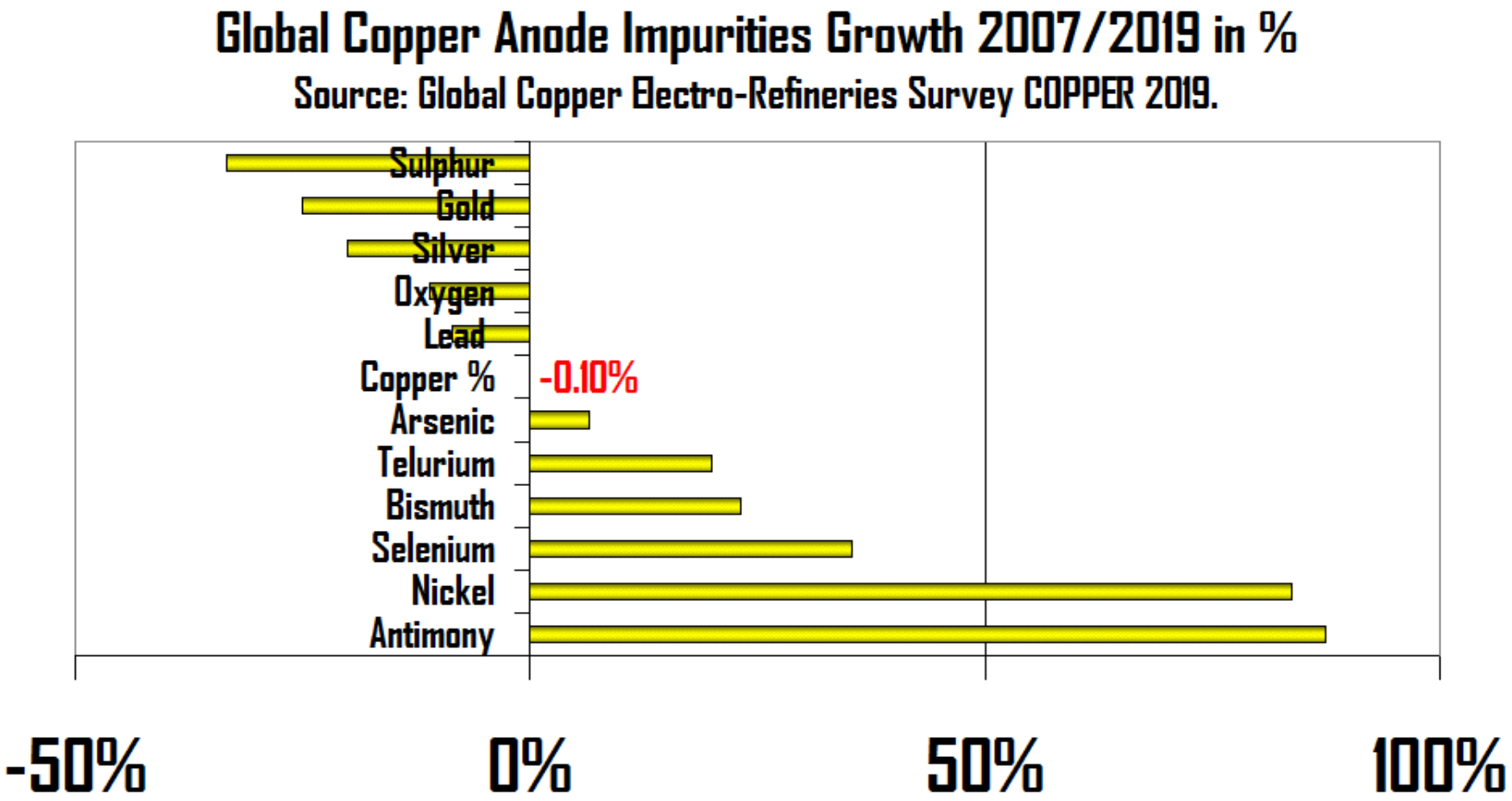
5. Impact of More Arsenic in Copper Concentrates And Response of Copper Smelters and Refineries



Copper concentrate complexity increased in 2007-2021, so minor metal content in smelter anodes kept growing.

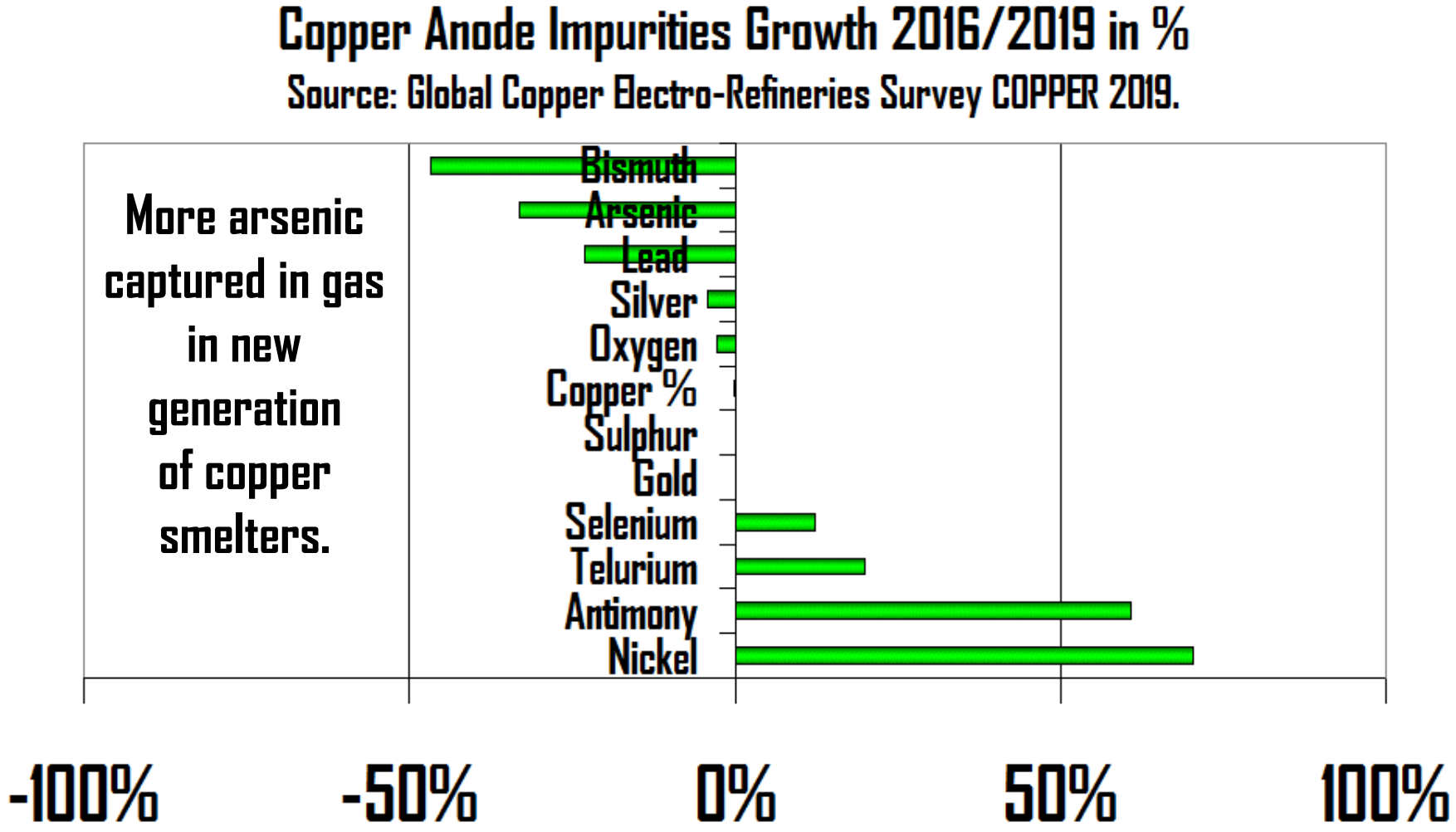


Arsenic and other minor metals content in copper anodes: increasing in the last 14 years before 2022.

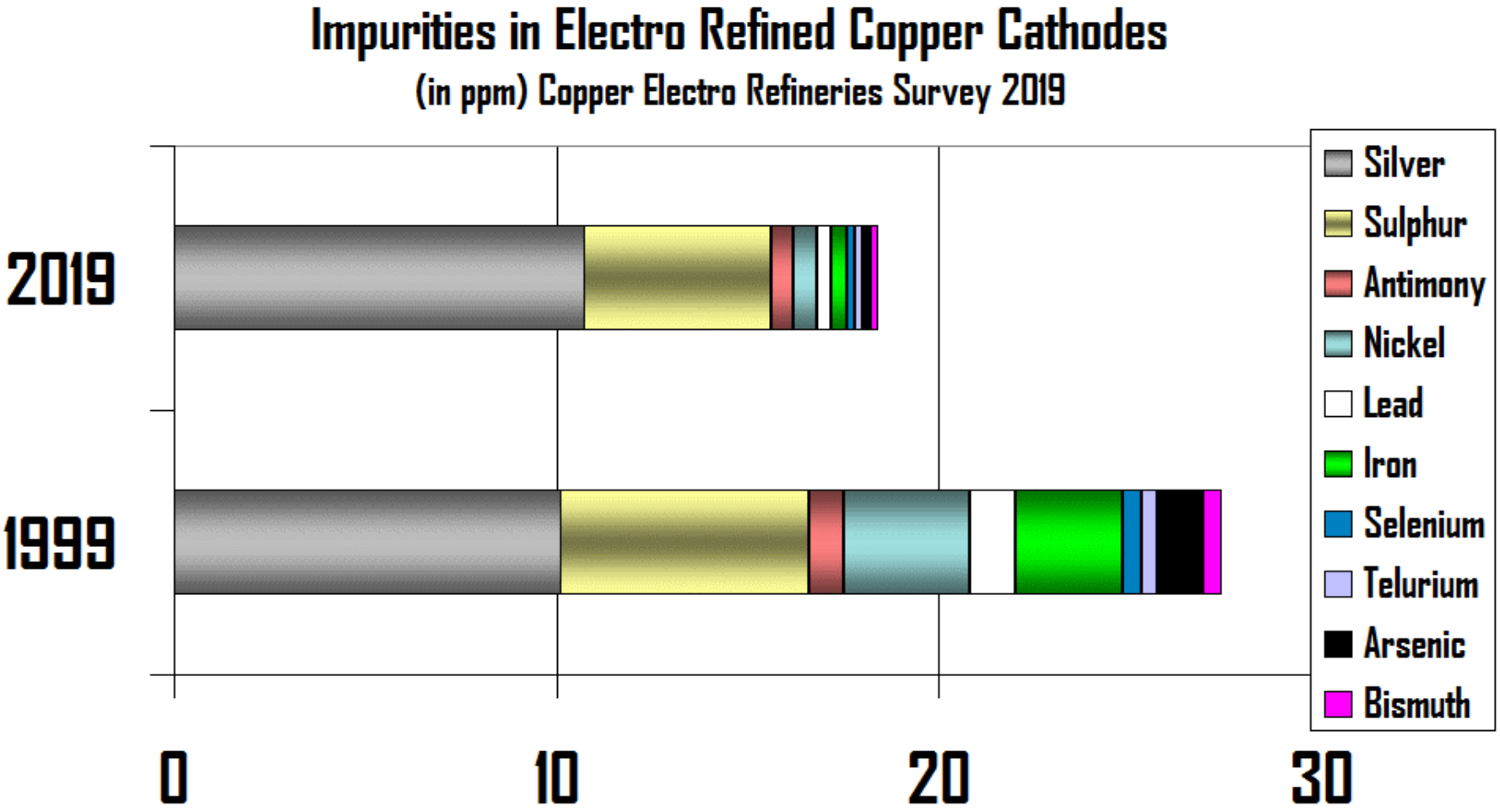


In 2016-2021, less arsenic in copper anodes,

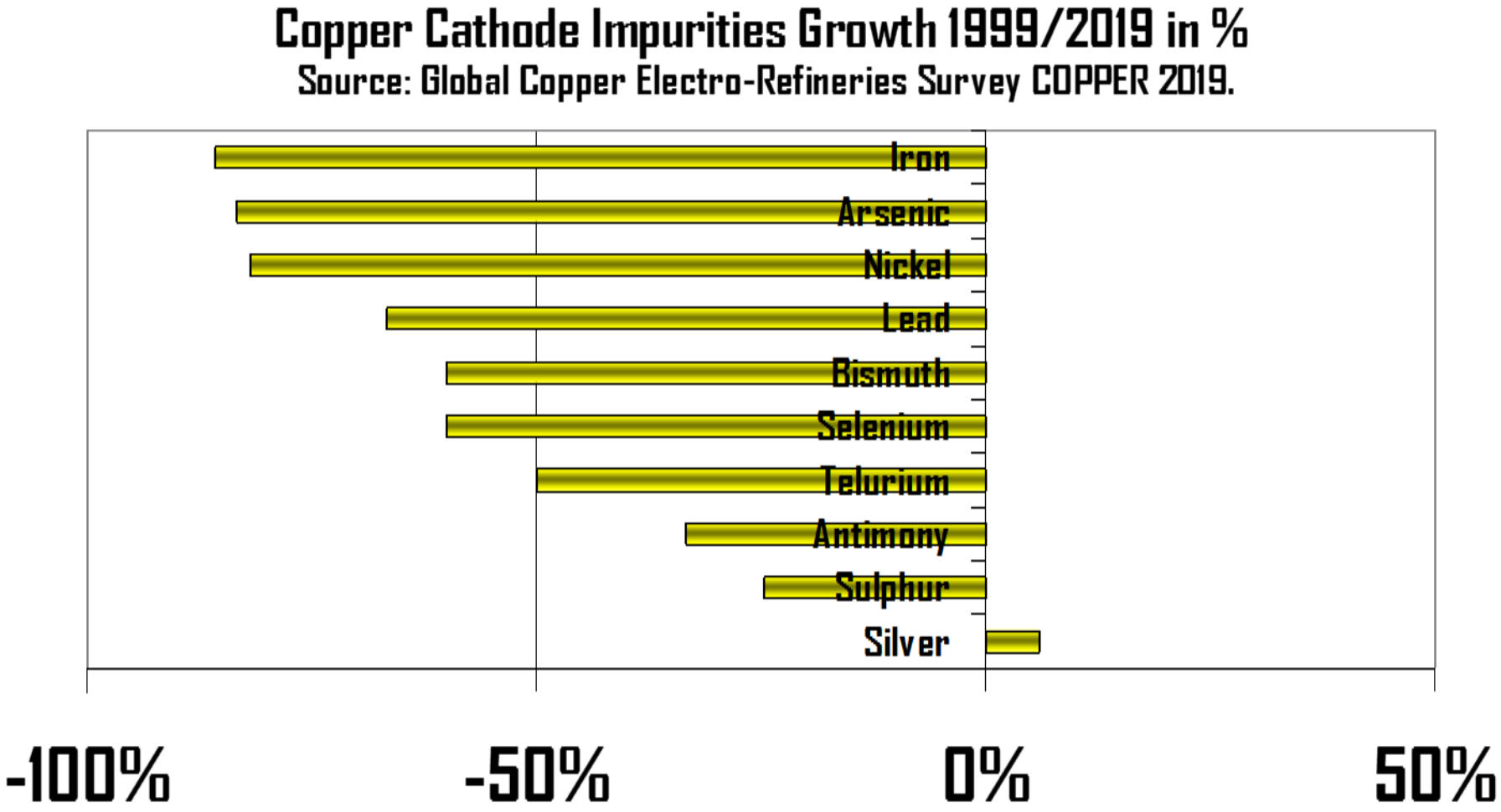
but contents of Ni, Sb, Se and Te kept growing.



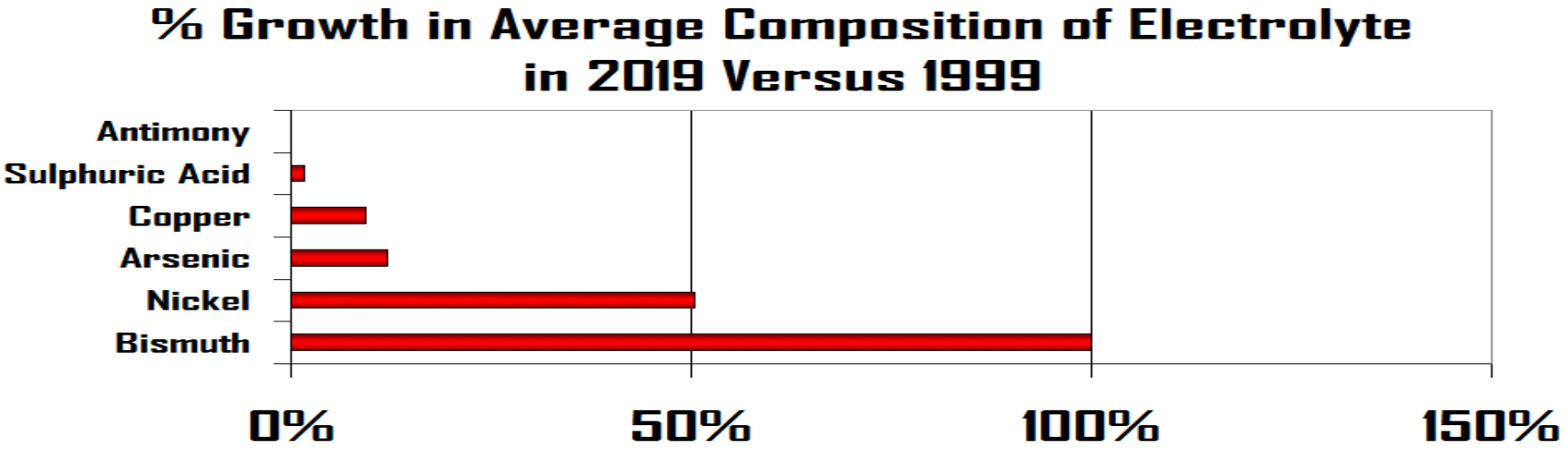
Minor minor metals reduction in copper electro-refineries: efficiency gains in the last 20 years.

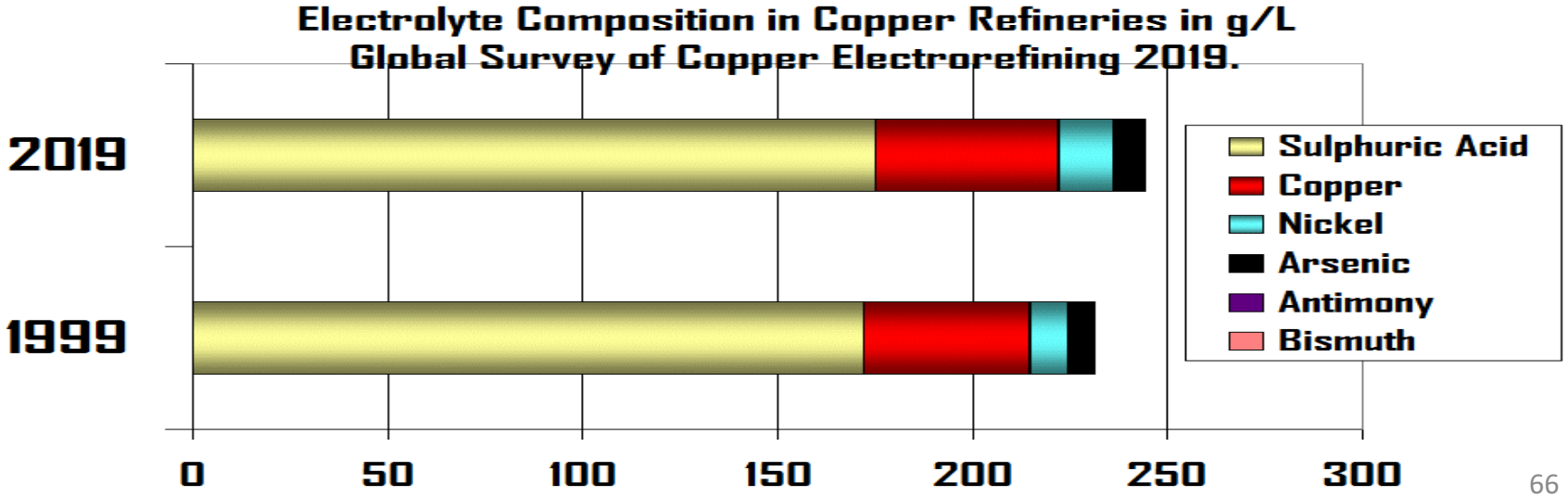


Electrolytic refineries increased efficiency and successfully reduced minor metals in cathodes.

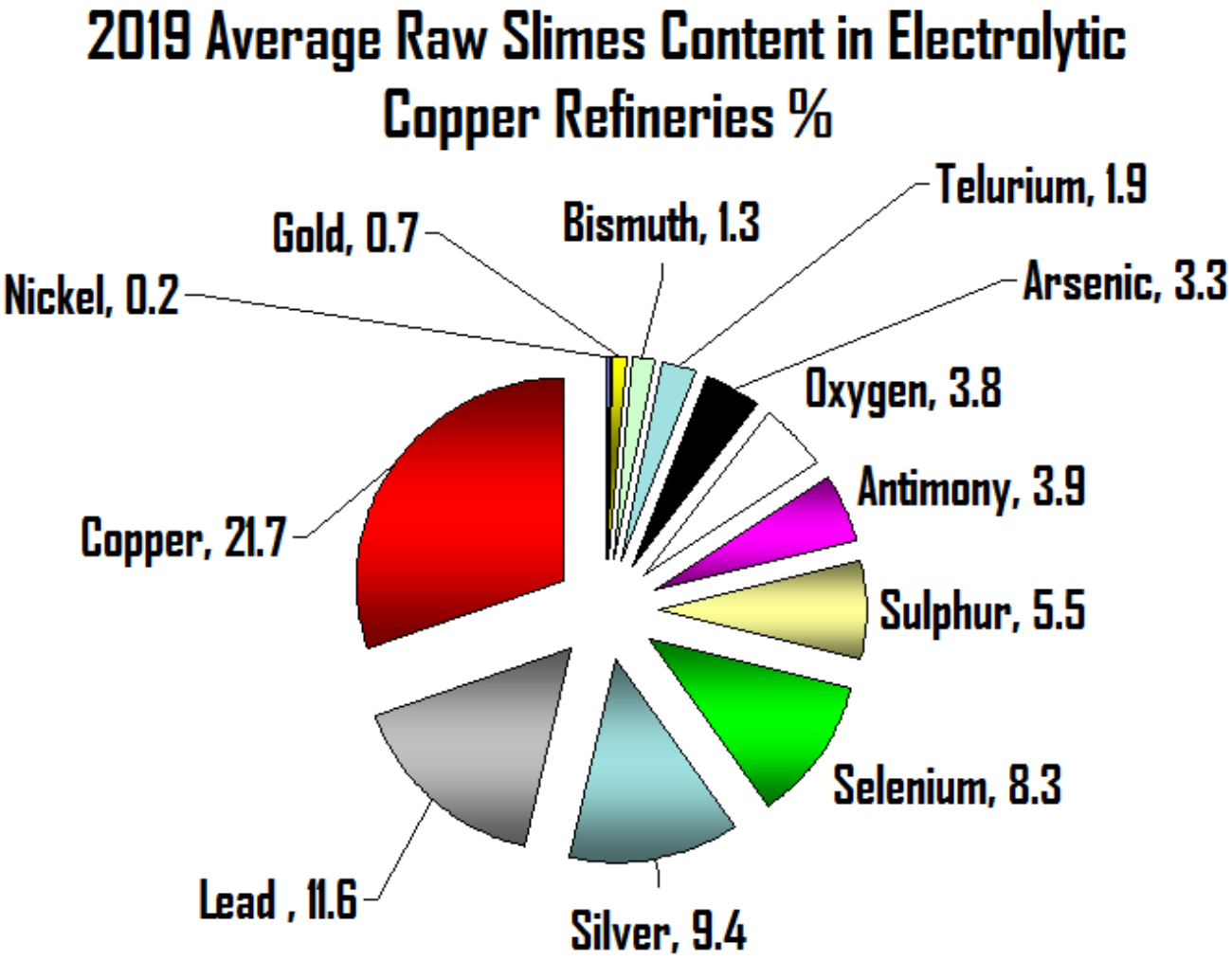


More Arsenic, Ni and Bi appearing now in electrolytic copper refineries electrolite.

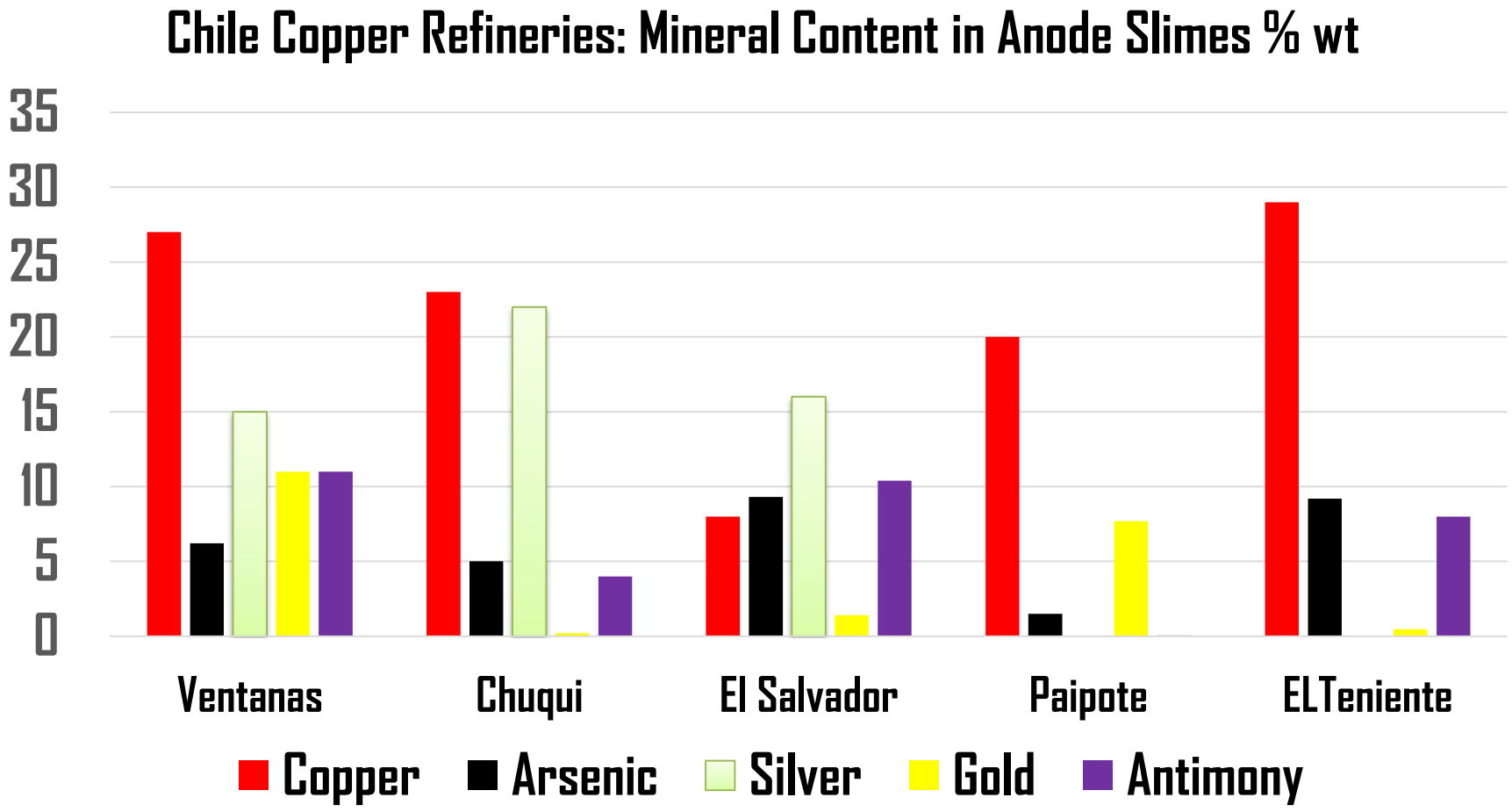




However, anode slimes composition in electro-refineries remains the same versus 2003.



Role of governments in strengthening policies of precious metals recovering from anode slimes in electro-refineries?

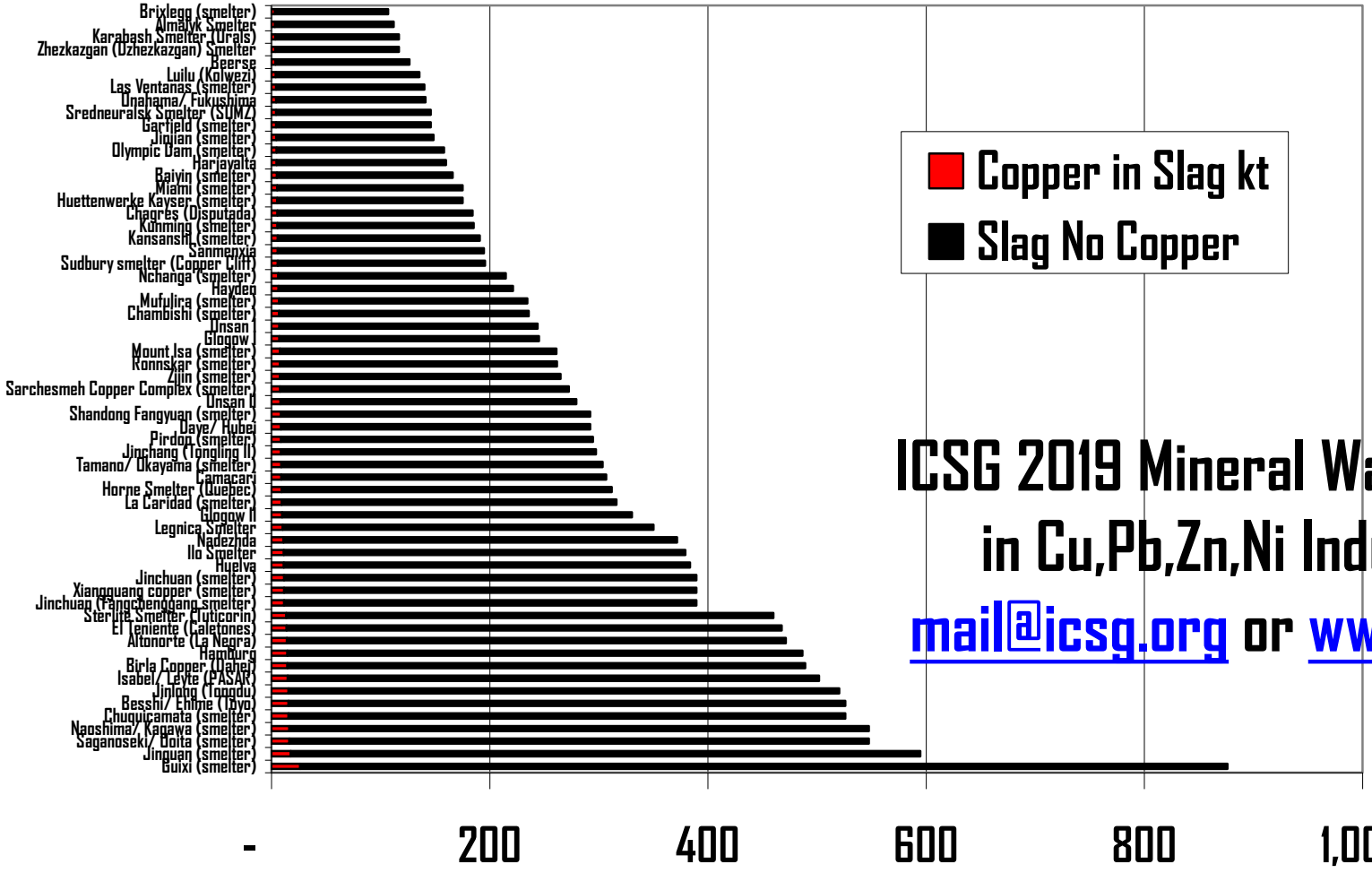


https://www.researchgate.net/publication/358670677_Chemical_Composition_Data_of_the_Main_Stages_of_Copper_Production_from_Sulfide_Minerals_in_Chile_A_Review_to_Assist_Circular_Economy_Studies

Arsenic in copper smelters slag: issue of concern for the industry.

~650 kt-Cu per year potential copper recovery from smelter slags.

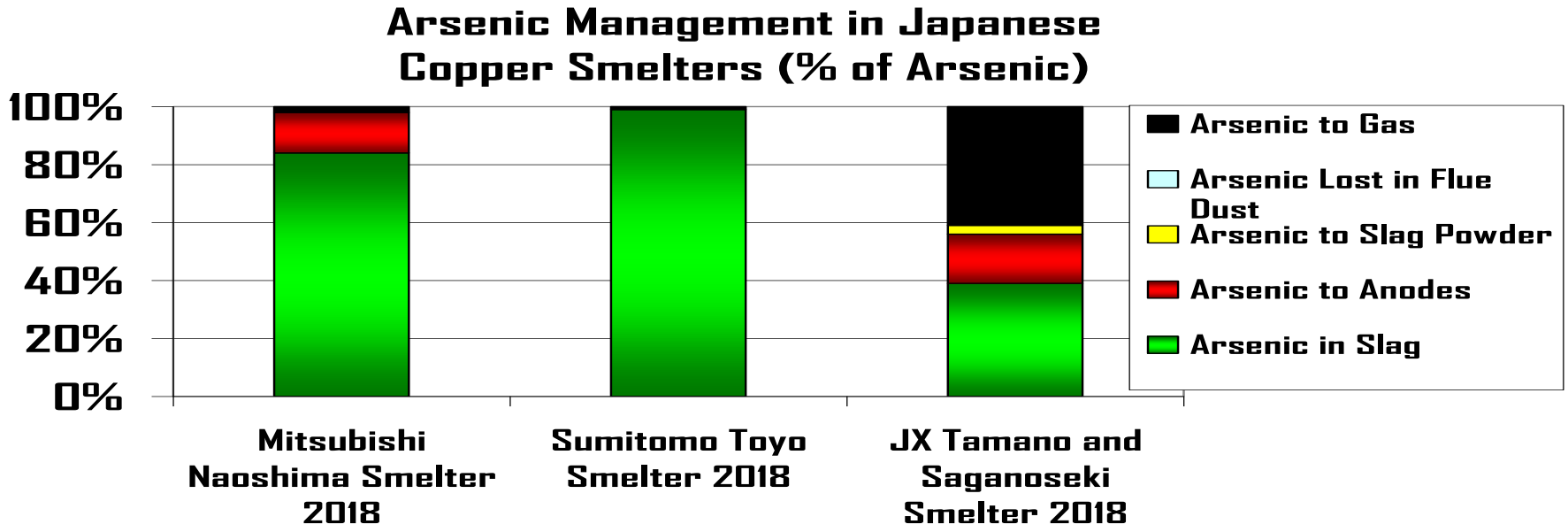
Solid Waste and Copper Content in Slag from Top Copper Smelters
> 100 kt of Slag per Year



ICSG 2019 Mineral Waste Report in Cu,Pb,Zn,Ni Industries:

mail@icsg.org or www.icsg.org

More arsenic was treated by smelters in Japan before 2019:
slag rejected as fill material in construction and infrastructure



Japan standard for arsenic in slag to be sold for general uses:

150 mg/
As per Kg of slag

Japan standard for disolution of arsenic in slag to be sold for general uses:

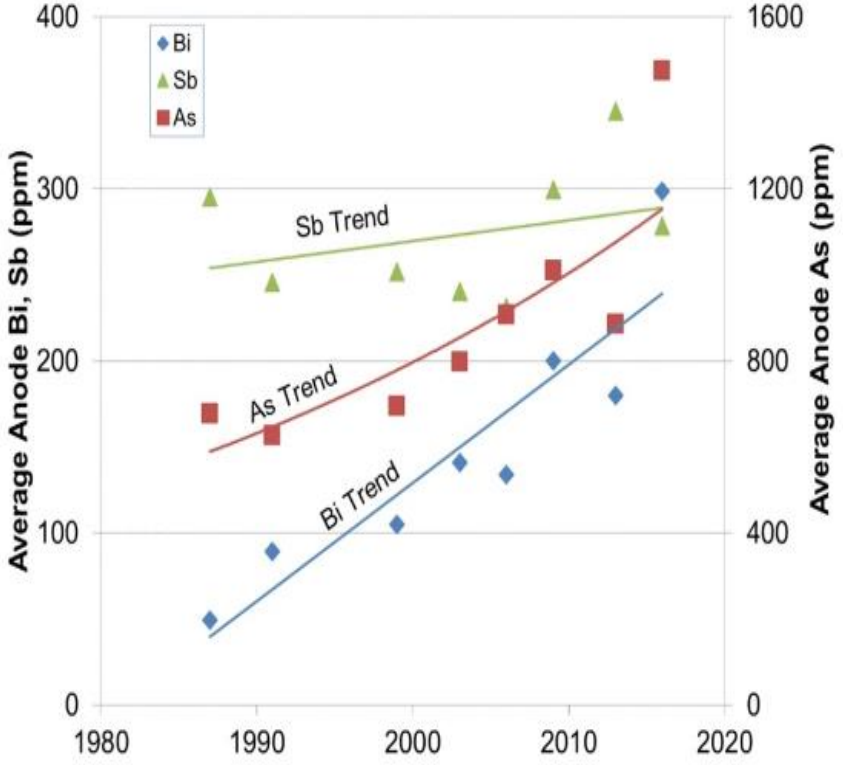
0.01 mg/lt
As per Kg of slag

Japan standard for arsenic disolution in slag to be used in seashore applications:

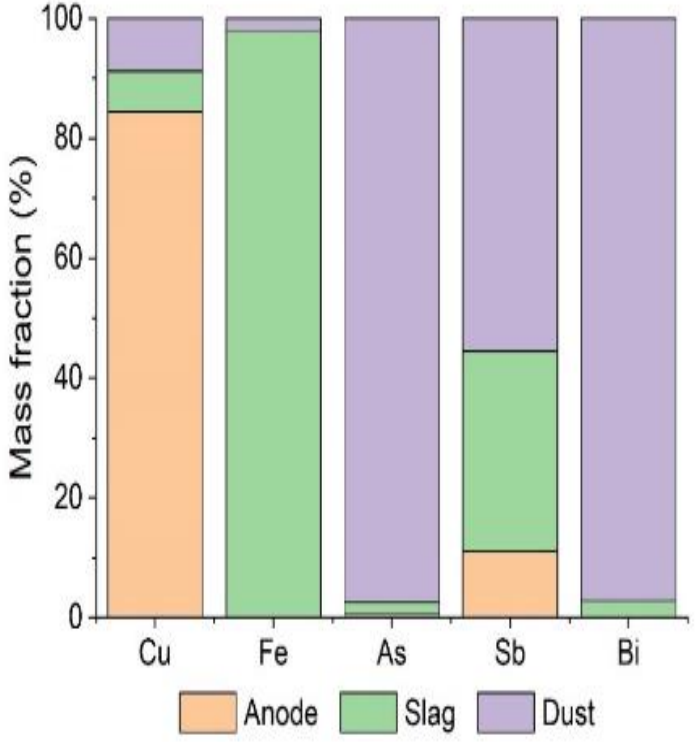
0.03 mg/lt
As per Kg of slag

Chilean copper anodes: most of the arsenic captured in smelter dust but still high significant in the slag, as in Japan.

Arsenic and other minor metals composition in Chilean copper anodes: 30 years trend.



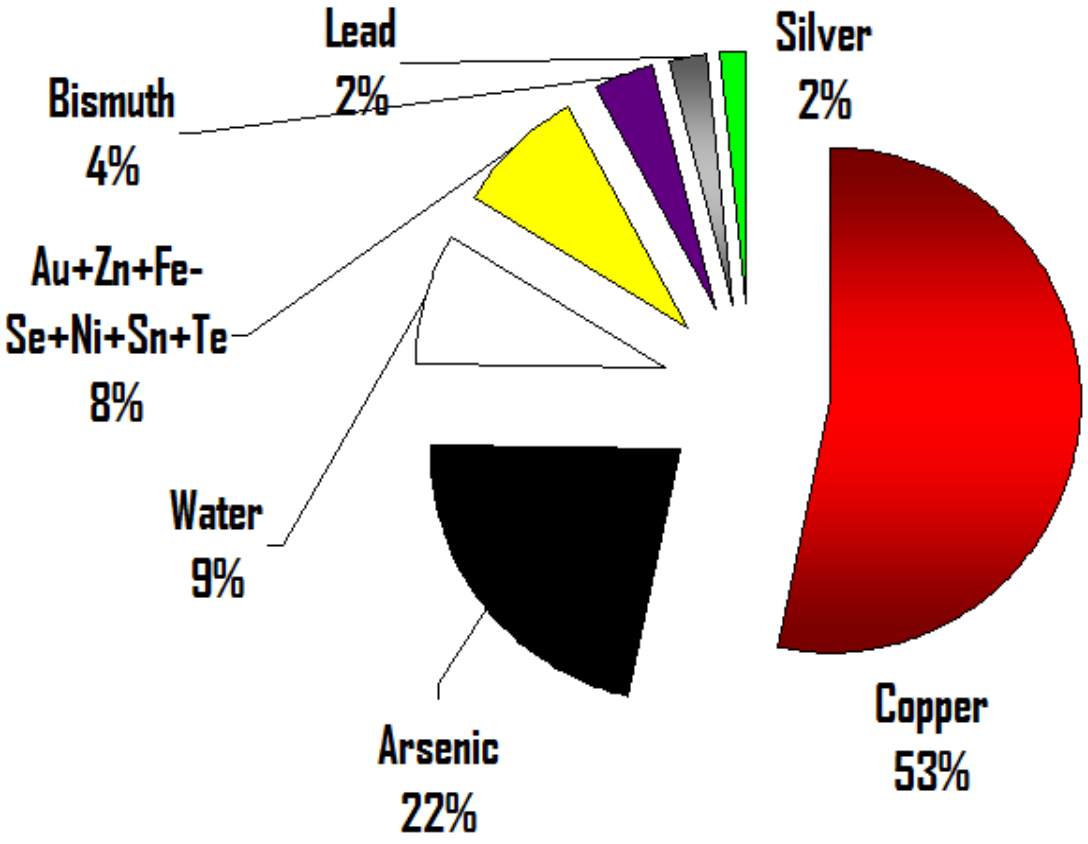
Chuquicamata copper smelter:
most of As in the dust of the S2H04 plant.
Some As in the slag. Small volumes in anodes.



https://www.researchgate.net/publication/358670677_Chemical_Composition_Data_of_the_Main_Stages_of_Copper_Production_from_Sulfide_Minerals_in_Chile_A_Review_to_Assist_Circular_Economy_Studies

Flash smelters keep re-circulating arsenic-rich solid waste to furnace to recover copper, increasing risks and polluting slag.

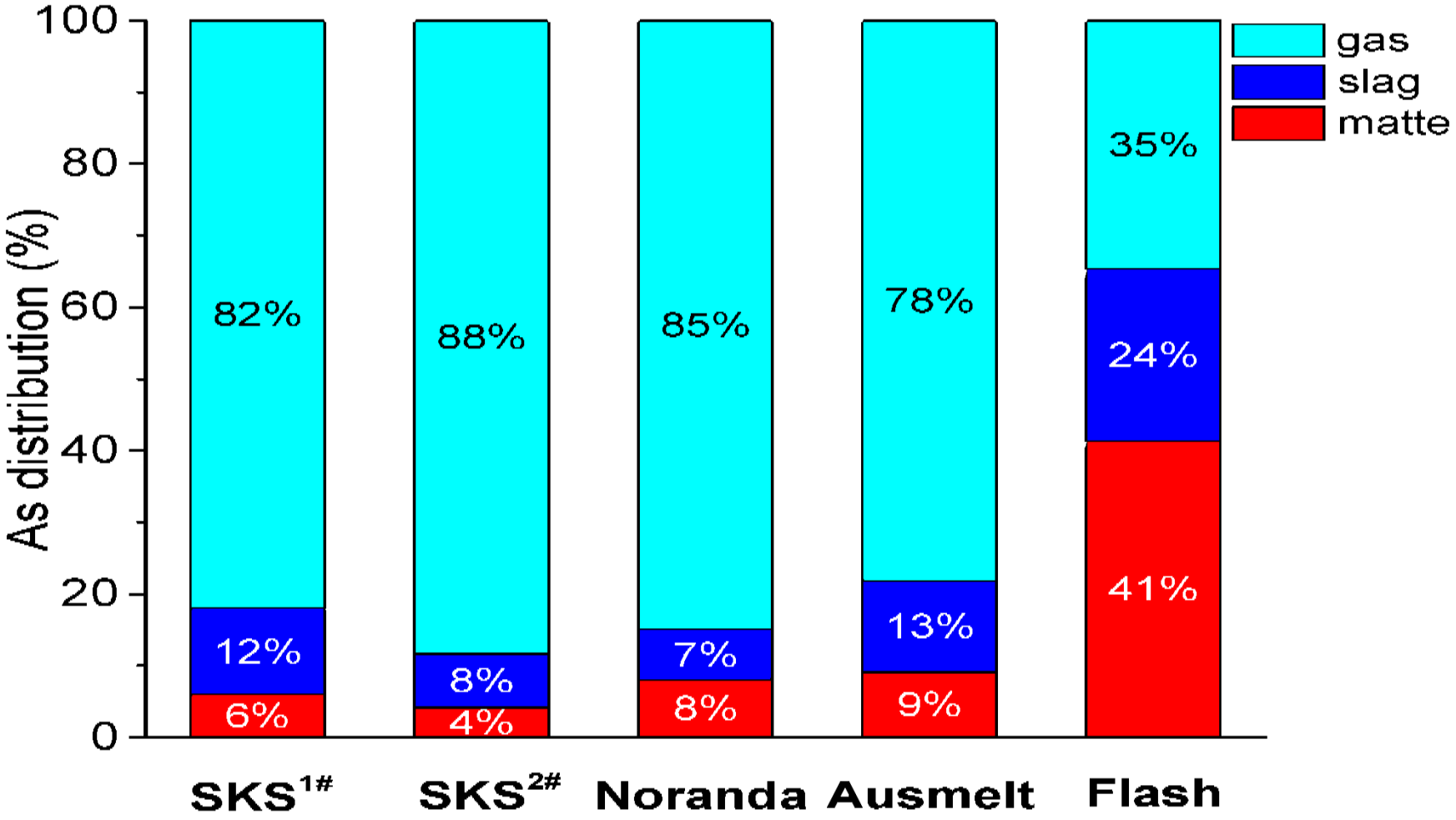
Elements Recovered in the Sulphide Precipitation Plant of a Flash Copper Smelter in China (2017) %



Source: BGRIMM EMC 2017

In bottom and side blown smelters, up to 88% of Arsenic goes to gas.

No dust is re-circulated, arsenic is collected, recovering more valuable metals.



A new generation of Chinese smelters are processing all waste together in high pressure leaching furnaces.

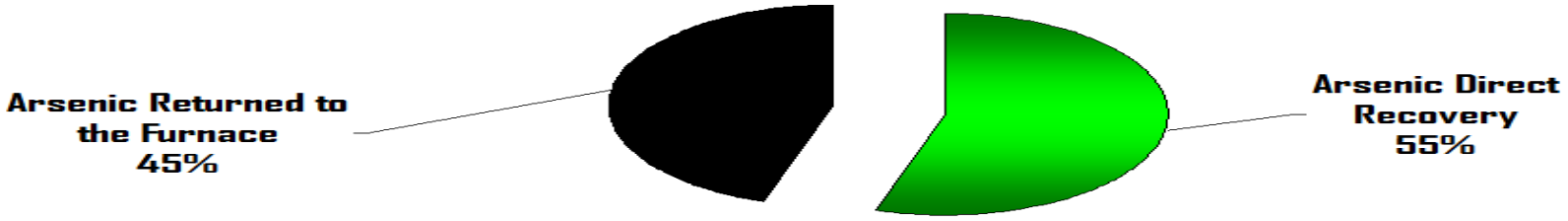
Arsenic sulphide pressure leaching operating in Guixi smelter from 2008.

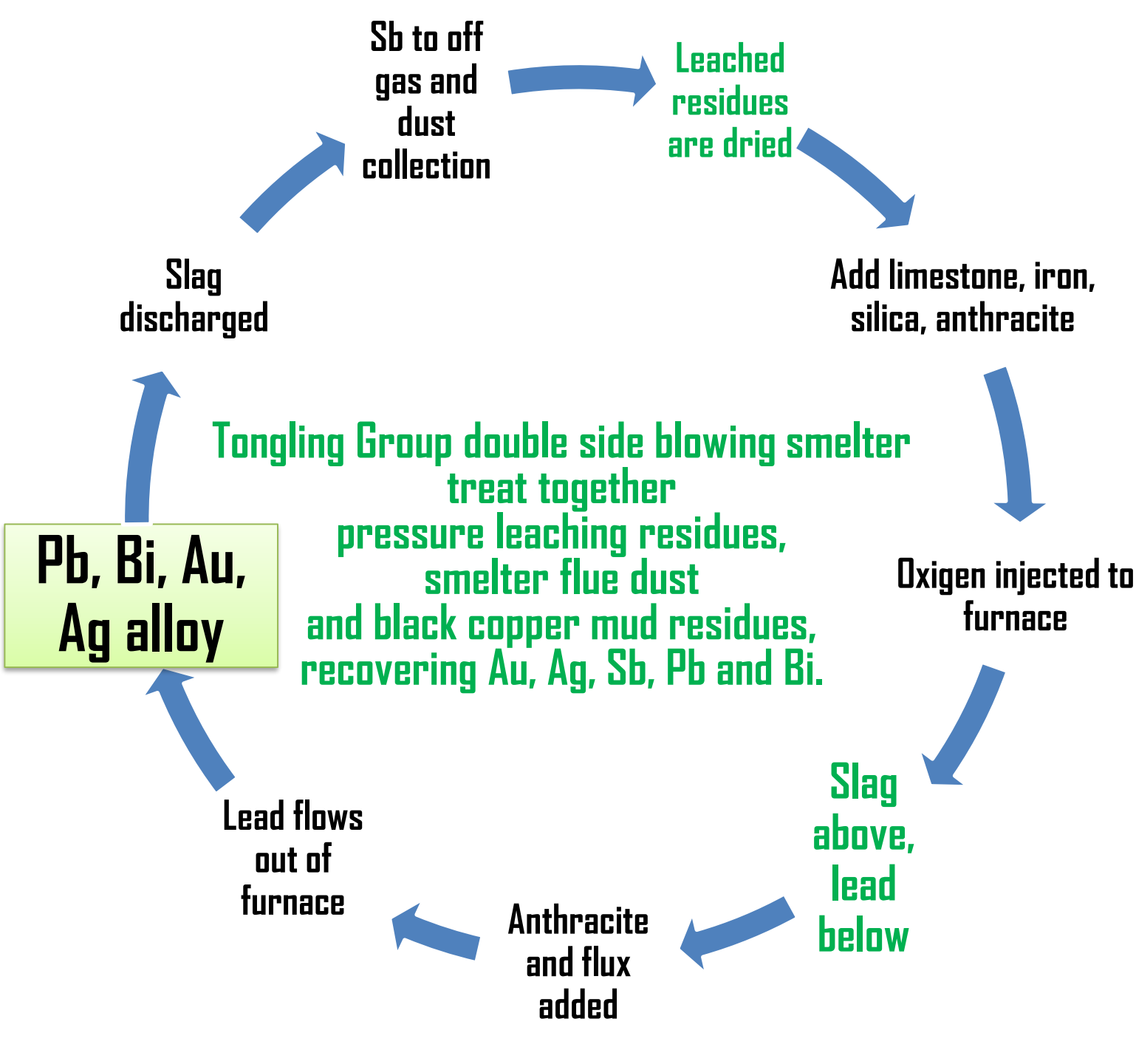
Arsenic leaching ratio: 95%

Copper leaching ratio: 95%

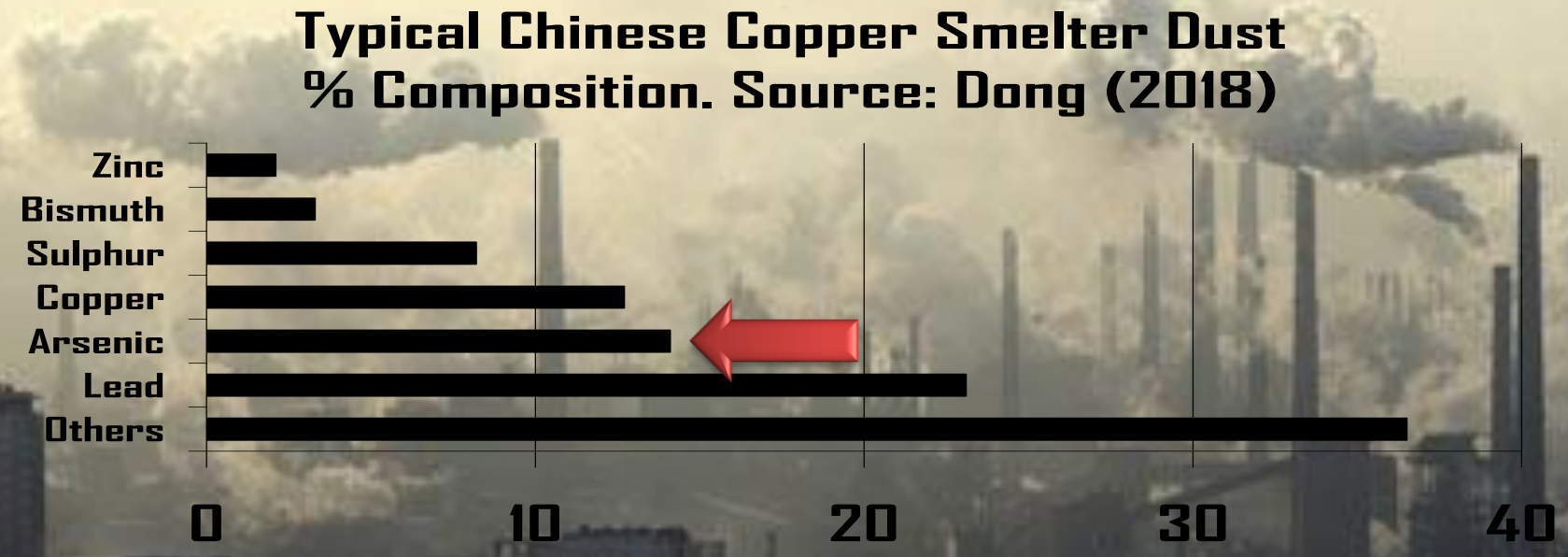
Rhenium leaching ratio: >98%

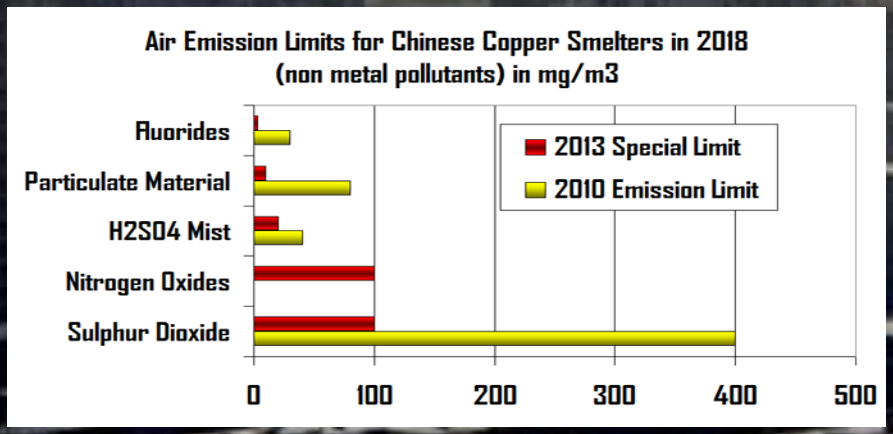
Arsenic Trioxide Production from Japan Copper Sulphate Process Results in China Guixi Smelter (BGRIMM 2017)

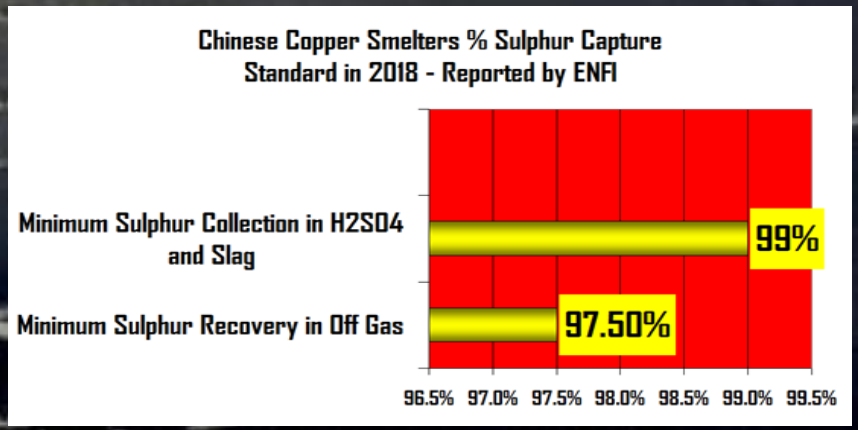



Sb to off gas and dust collection
Leached residues are dried
Add limestone, iron, silica, anthracite
Oxigen injected to furnace
Slag above, lead below
Anthracite and flux added
Lead flows out of furnace
Slag discharged
Pb, Bi, Au, Ag alloy
Tongling Group double side blowing smelter treat together pressure leaching residues, smelter flue dust and black copper mud residues, recovering Au, Ag, Sb, Pb and Bi.

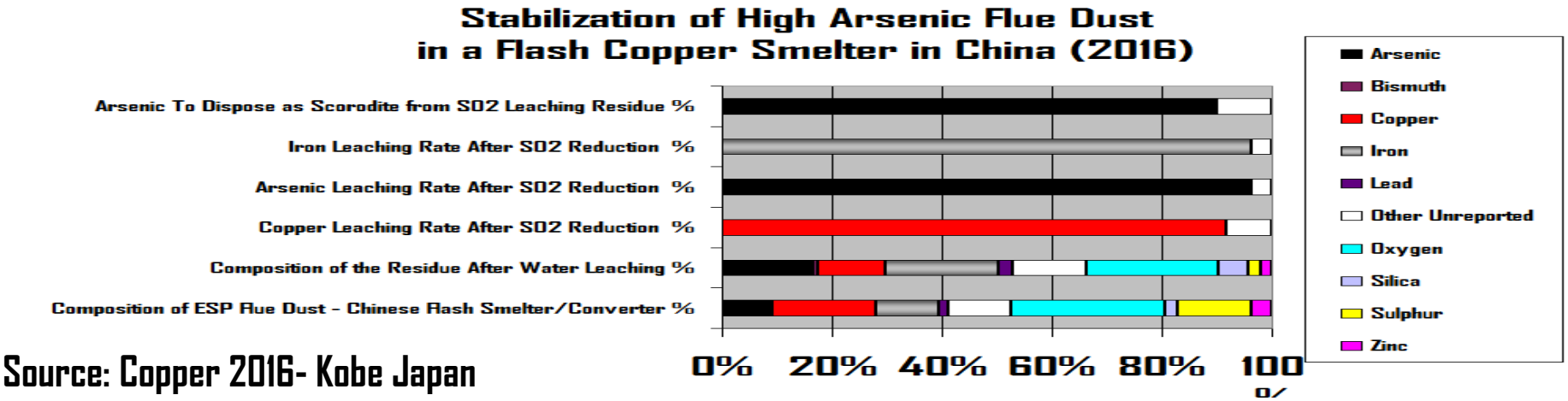
Chinese copper smelters processed >100 kt of Arsenic/year to produce 8.2 Mt-Cu of copper anodes in 2021.



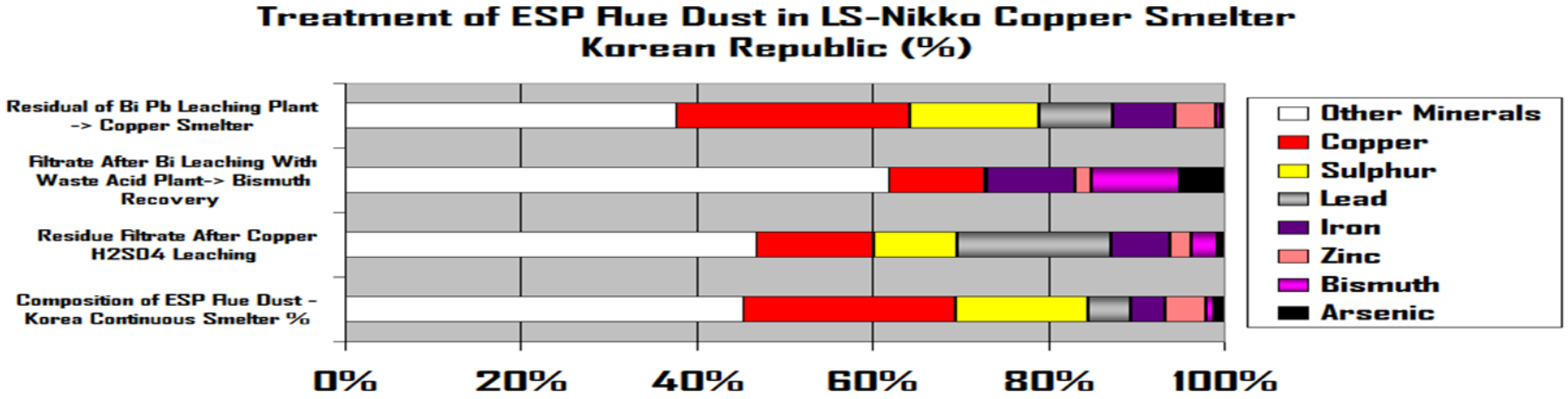




More smelters in China are disposing Arsenic as Scorodite now. More smelter flue dust to be processed in-house in 2020-2025.

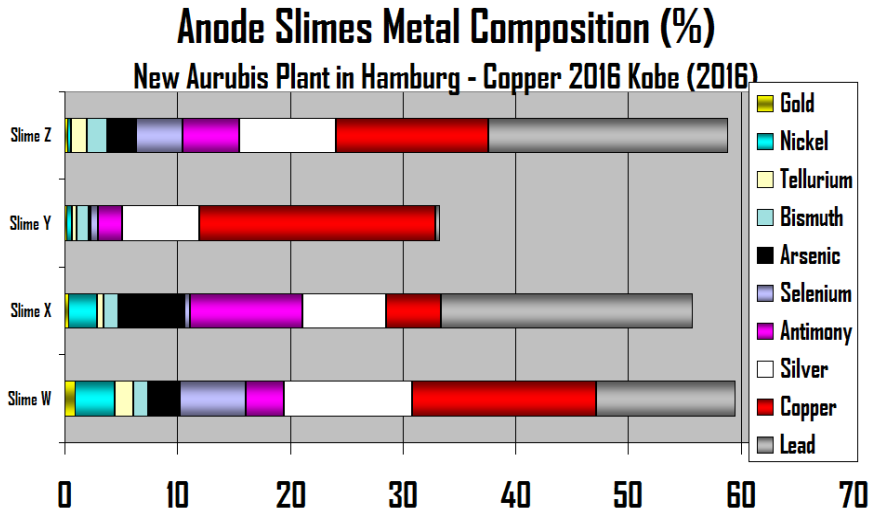


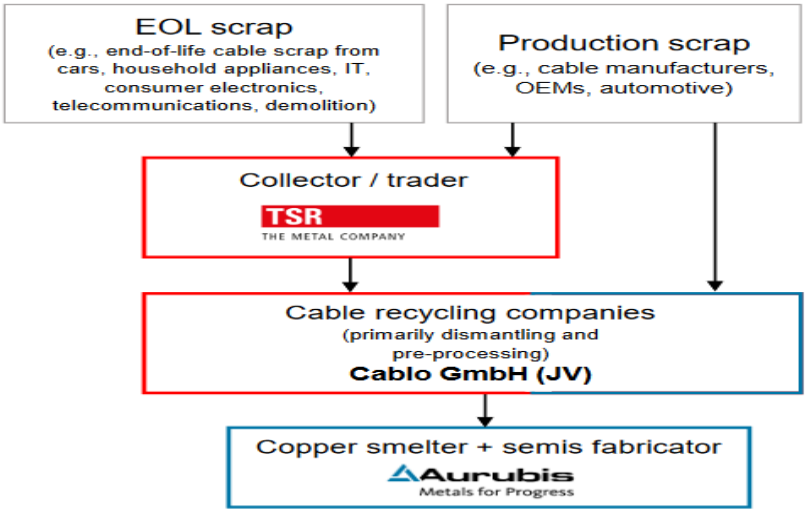
Source: Copper 2016- Kobe Japan



Korean Republic smelter using waste acid to recover bismuth from flue dust, then residuals are re-circulated.

European smelters increased capacity to recover by-products and capture hazardous wastes.
In 2020-2021 they refocused in copper recycling investments in Europe and in North America. But the scrap supply is limited.





Press Release

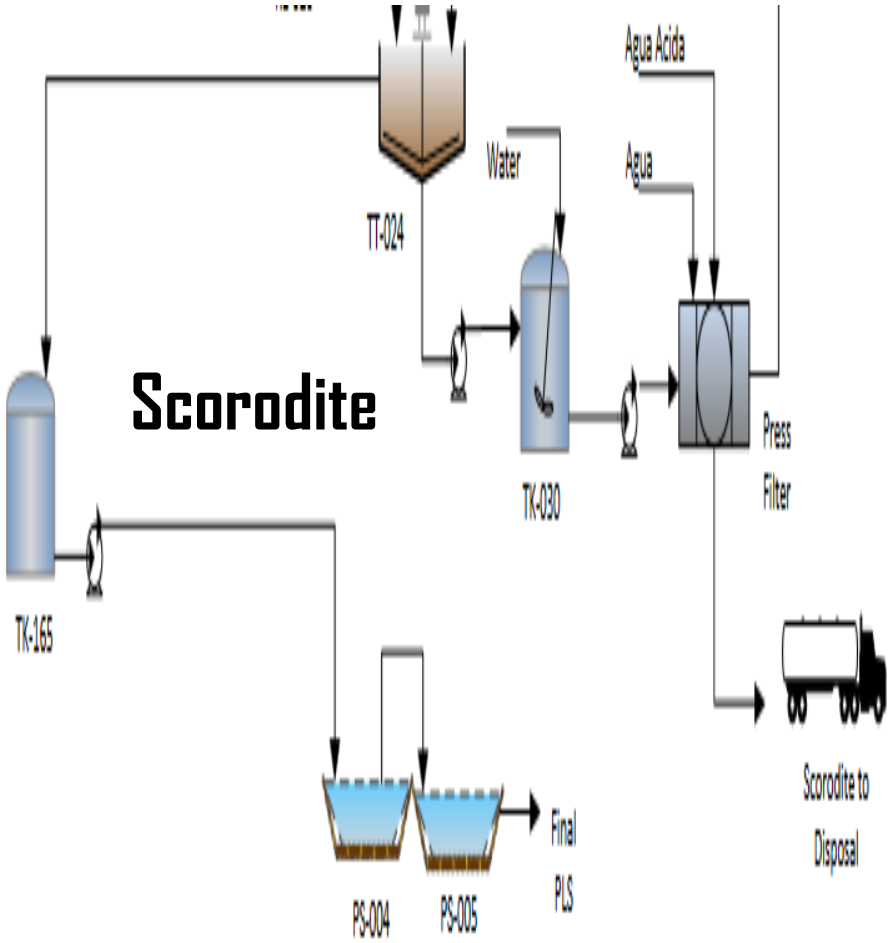
Aurubis builds recycling plant in the US and sets its sights on sustainable growth

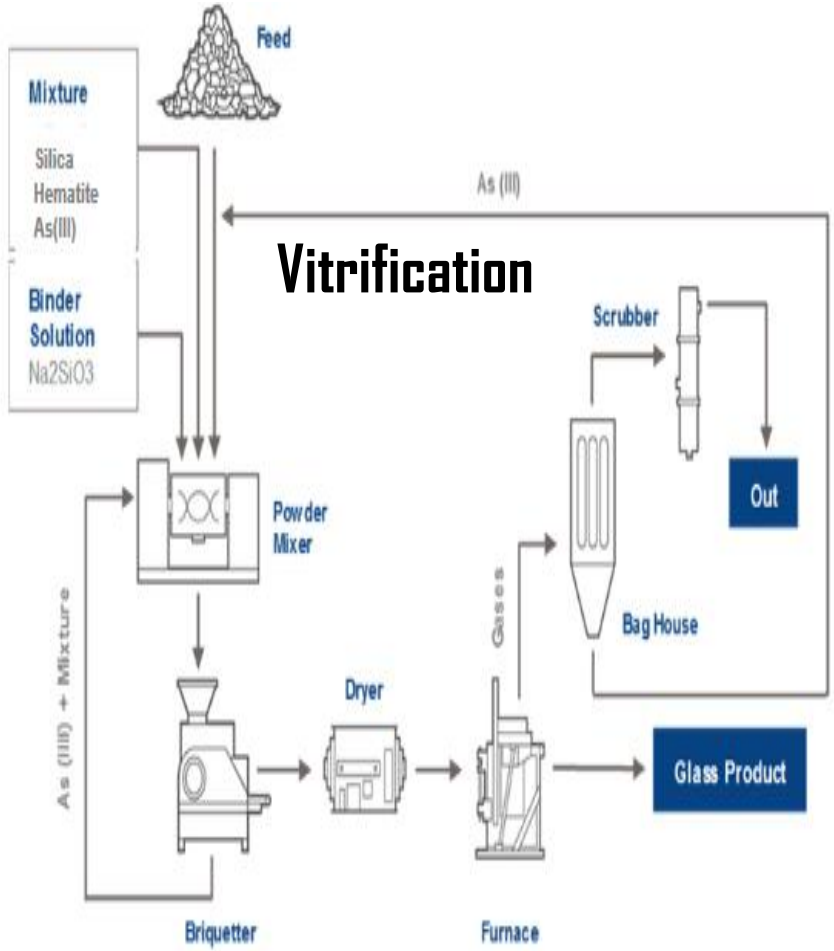
Hamburg | Wednesday, November 10, 2021

Aurubis
Metals for Progress

METALLO
THE FURNACE OF INNOVATION

Arsenic from acid plants flue dust, is now disposed as stable residue thanks to Professor Demopoulos and others. The new challenge is removing Arsenic in mines, concentrators, smelters and mine tailings.

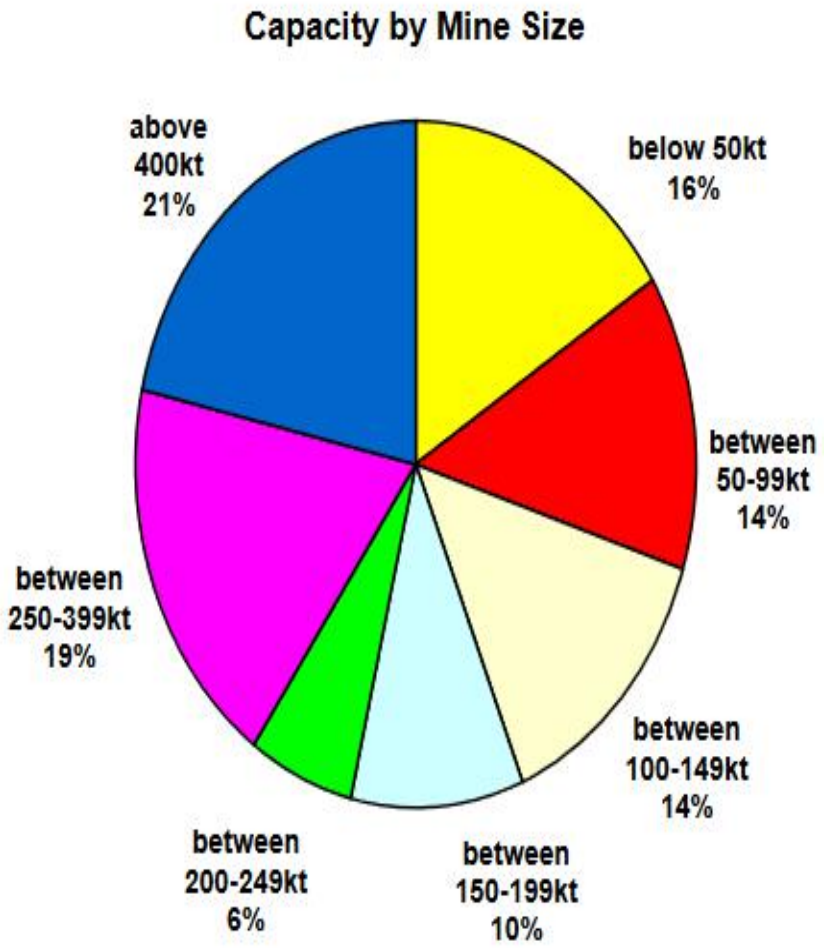


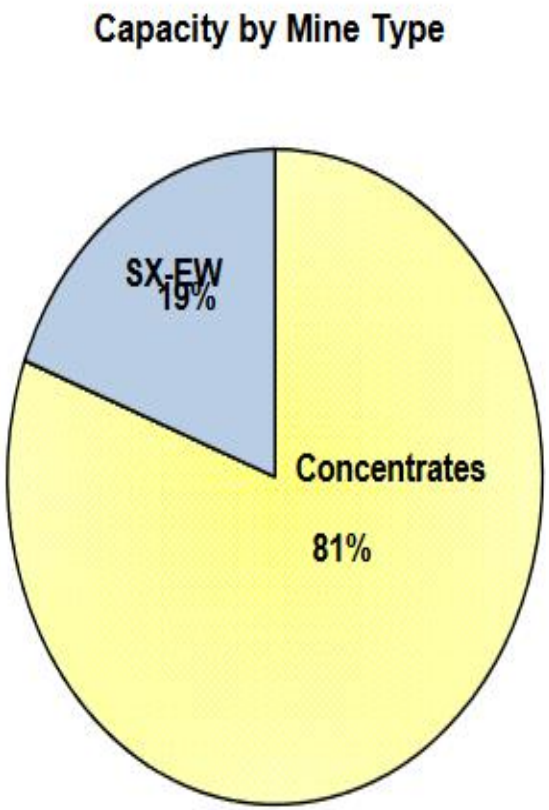


Source: Trends and Treatment of Arsenic in Copper Mining . COPPER 2019 Vancouver, Canada.

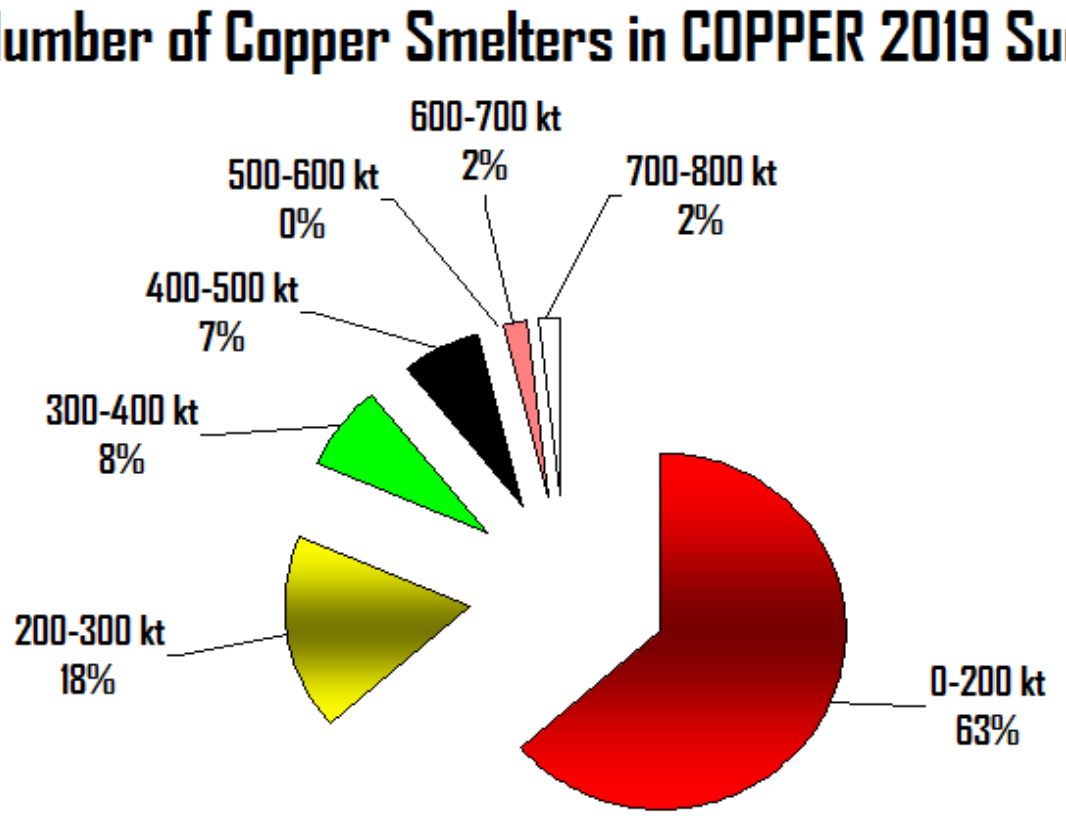
6. Copper Mines, Smelters and Refineries Capacity and Technology Challenges 2022-2030

Global copper mine capacity to produce concentrate: 81% of mine capacity.
Copper mine capacity >200 kt/year: 46% of world capacity in 2021.





Small economies of scale observed in most of copper smelters operational outside China.



Source: 2019 Copper Smelting Survey. COPPER 2019
Vancouver, Canada.

Outside China, copper smelters have survived on strategic advantages: proximity of mines, arsenic treatment, scrap use or ownership.

Upstream Integration

- Strategic acquisitions

Alternative Raw Materials

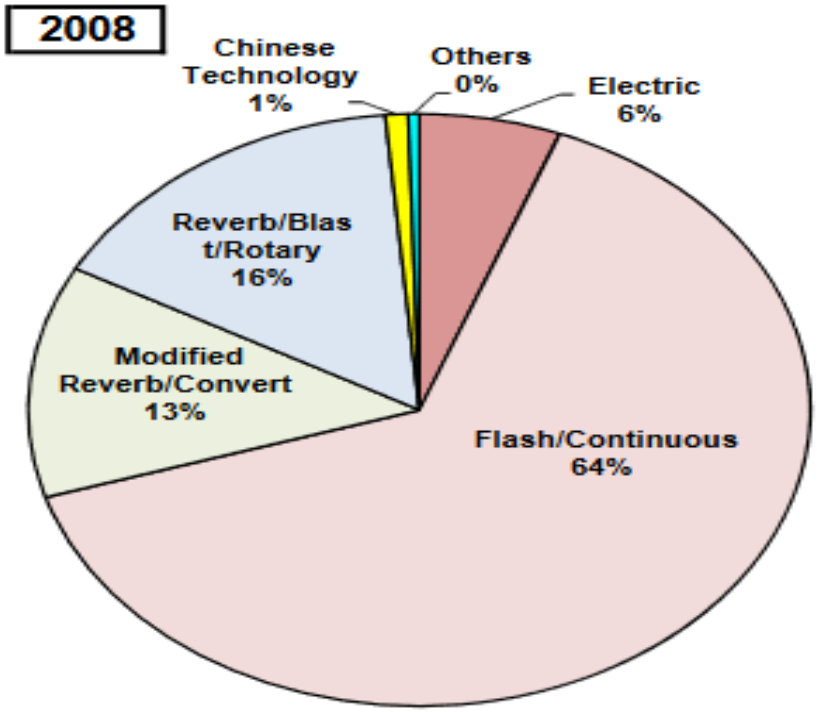
- Complex concentrates
- Secondary materials

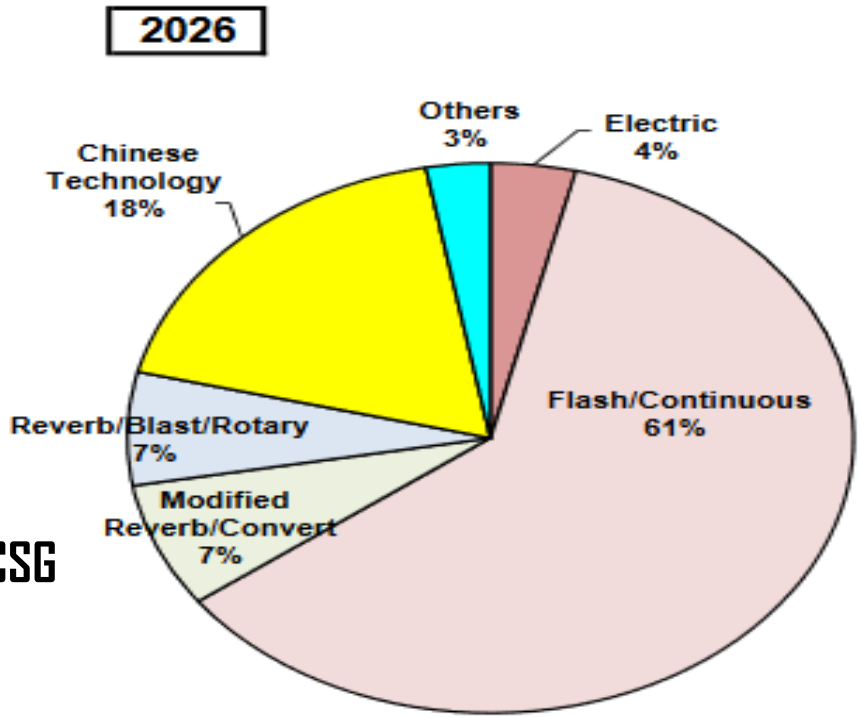
Geographical Location

- Proximity to mines
- Government policy downstream value
- Government policy emissions

Source: Open Mineral at ICSG Session 2021

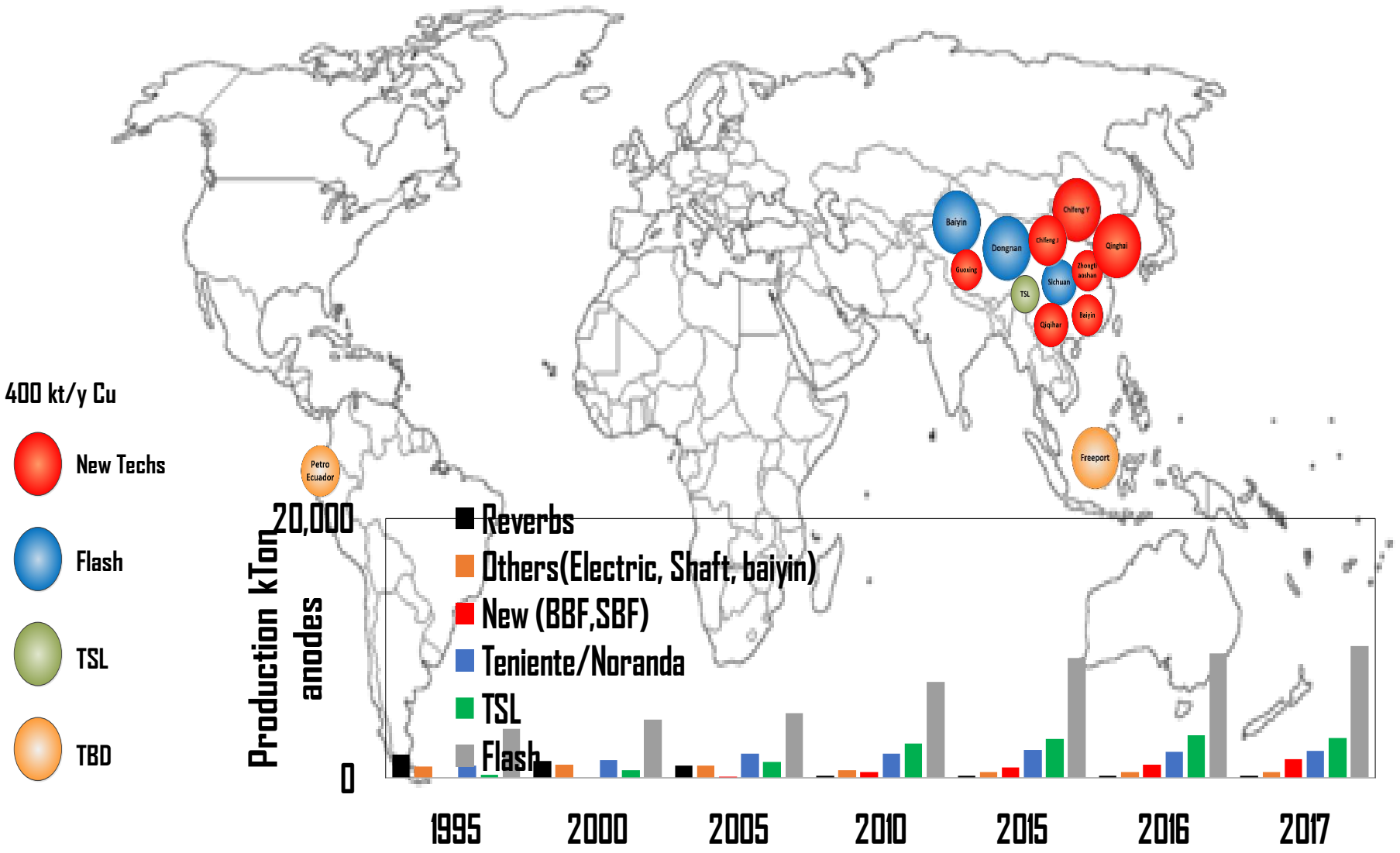
A significant change in copper smelter technology observed in the new generation of copper smelting capacity 2008-2026*.





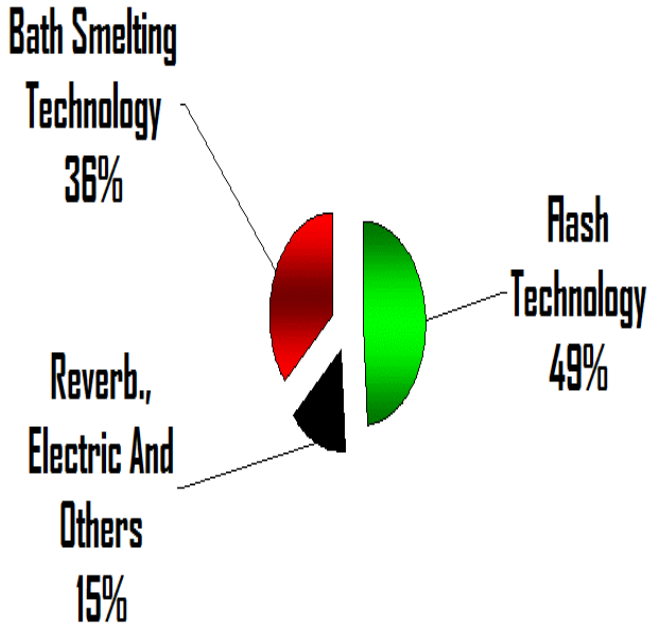
* See detailed technology information in ICSG Directory of Copper Mines and Plants January 2022 Edition.

Flash still the industry standard, but new smelters scales are larger with cleaner high oxygen blowing and all in China.

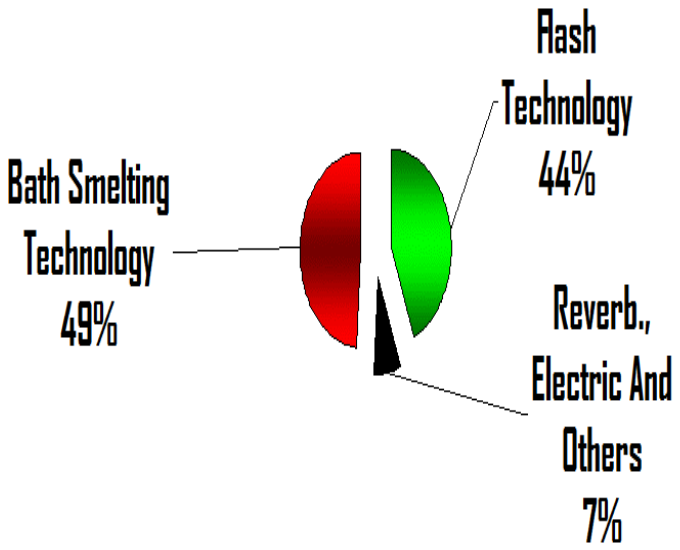


New bath technologies in concentrate smelters replacing traditional and outdated technologies.

2003 World Copper Smelter Production by Technology %



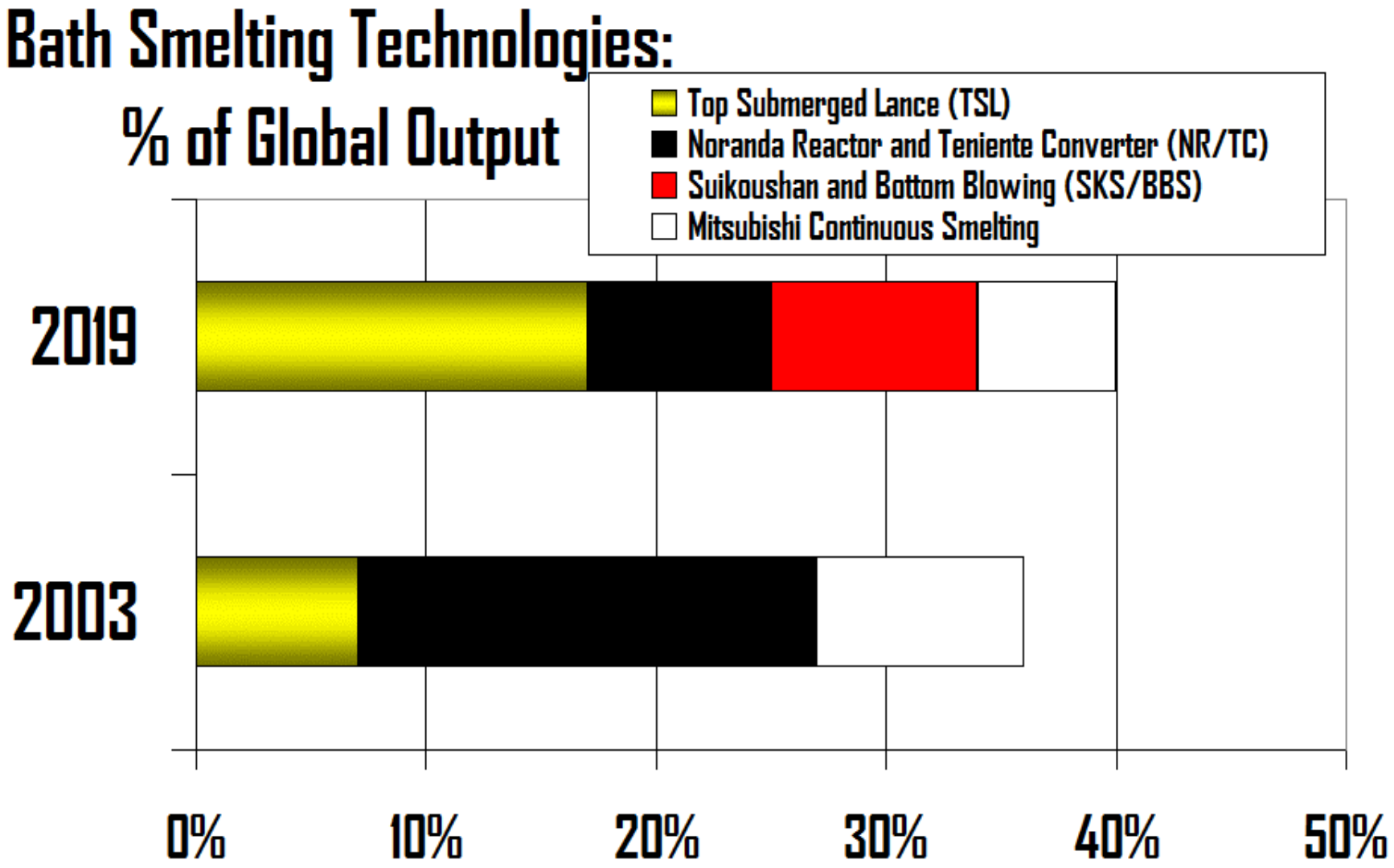
2019 World Copper Smelter Production by Technology %



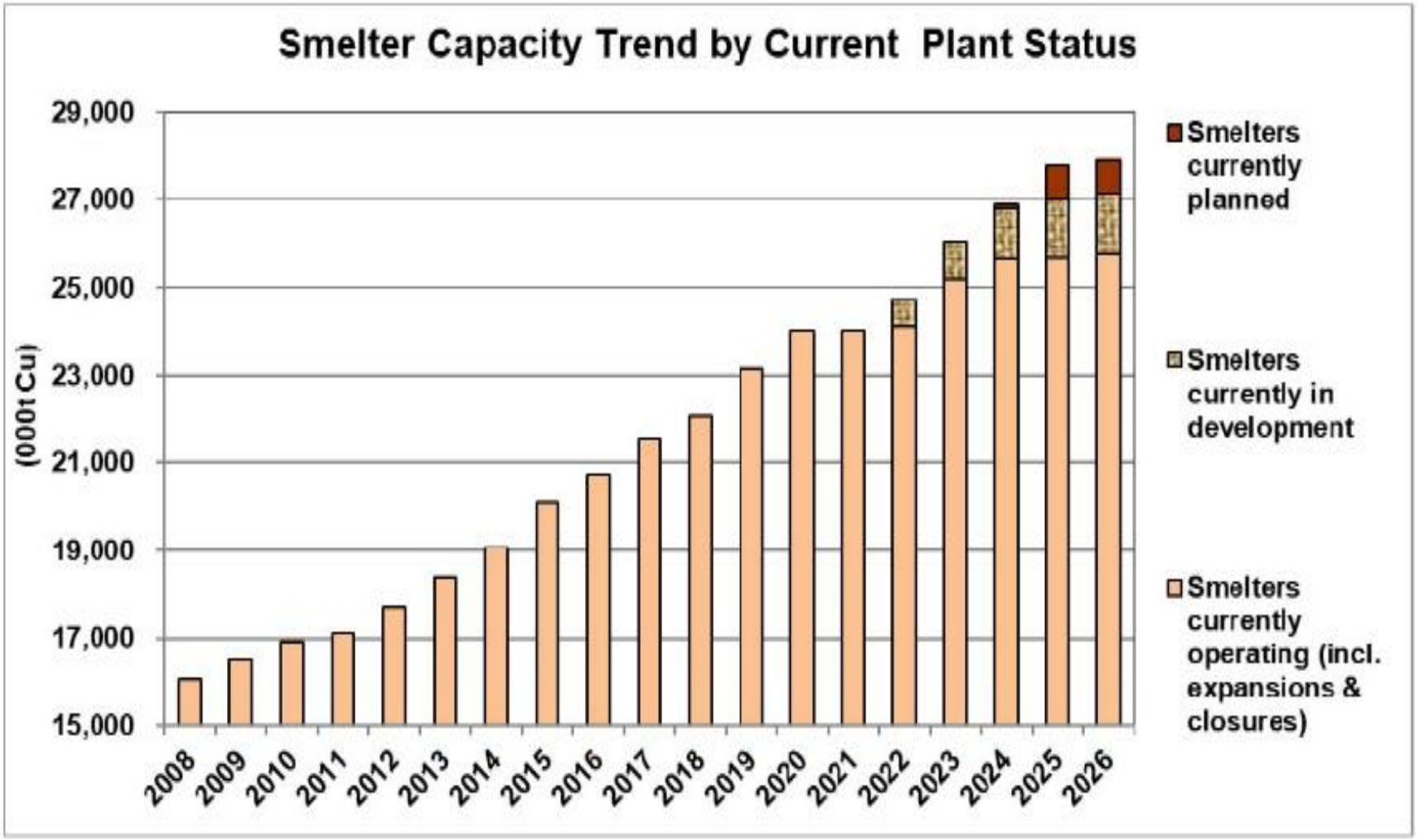
Source: 2019 Copper Smelting Survey. COPPER 2019 Vancouver, Canada.

Bath smelting technologies took more smelter market share.

Noranda Reactor/Teniente Converer replaced by Top Submerged Lance Technology

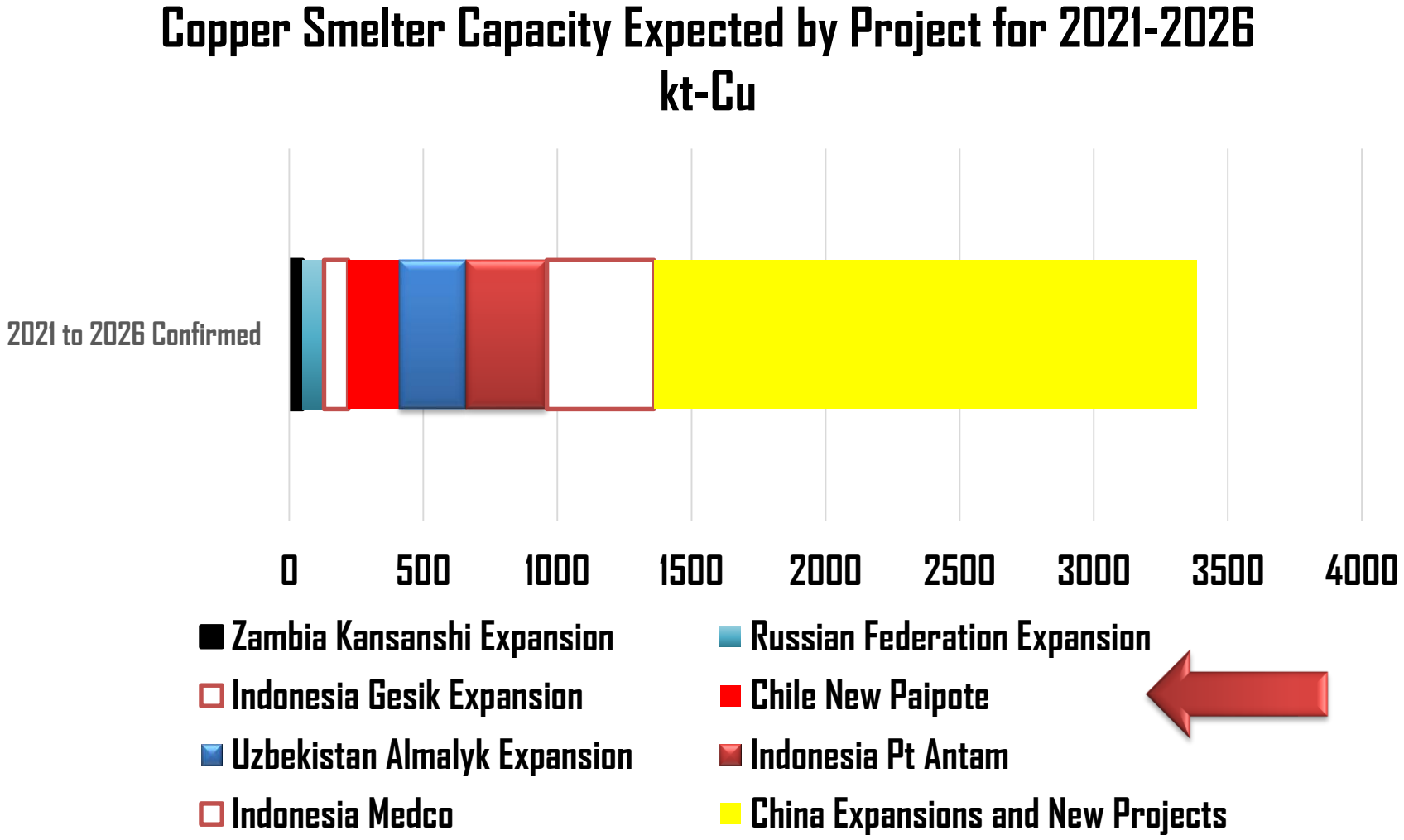


Massive global copper smelter capacity expansions expected in 2022-2026 on new smelters and expansions in China, Indonesia, Uzbekistan, Iran, Russian Fed., South Africa, United States (scrap), Zambia and Serbia.

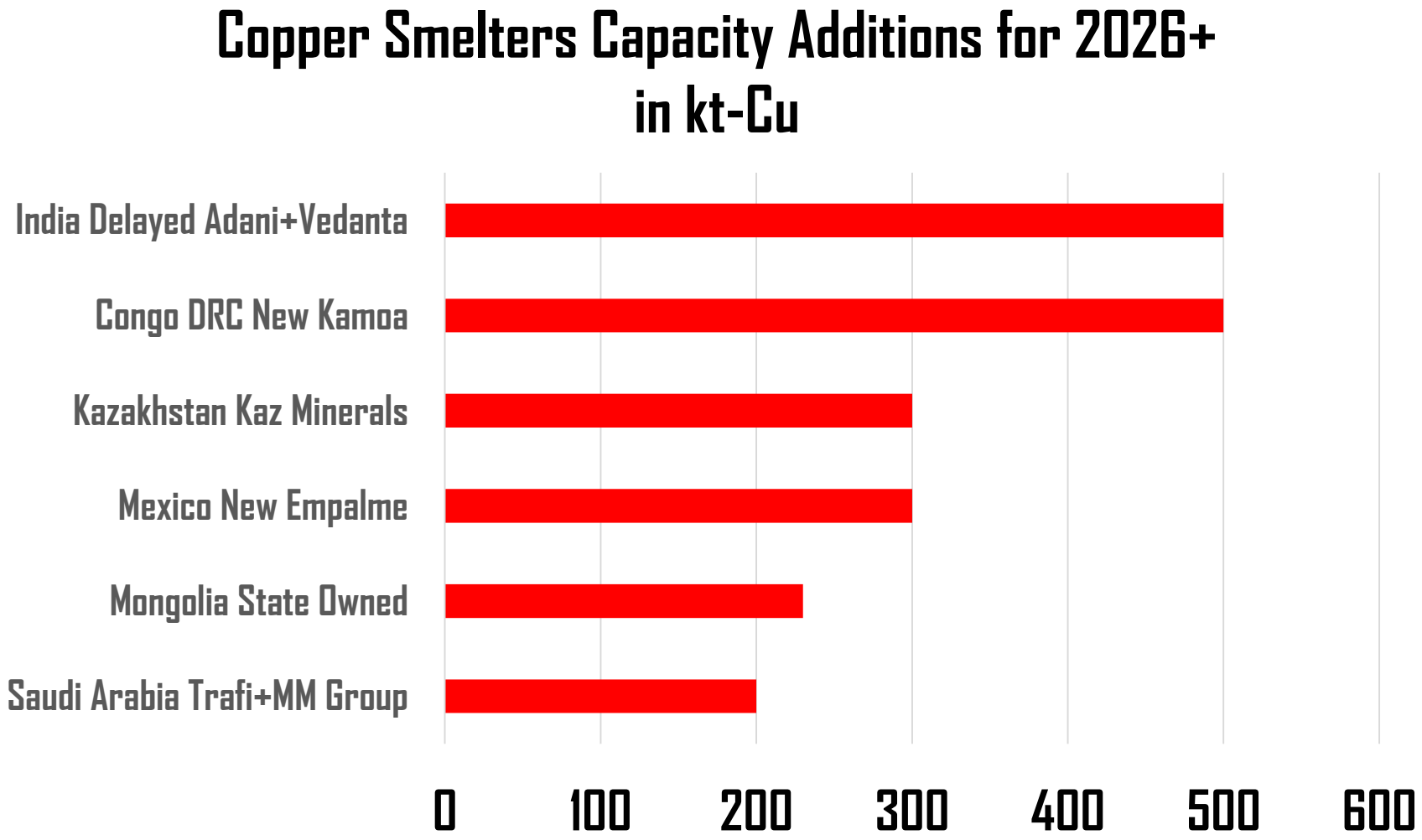


Global Copper Smelter Capacity Pipeline 2021-2026,

some probability of commissioning: ~3.4 Mt-Cu of new capacity.



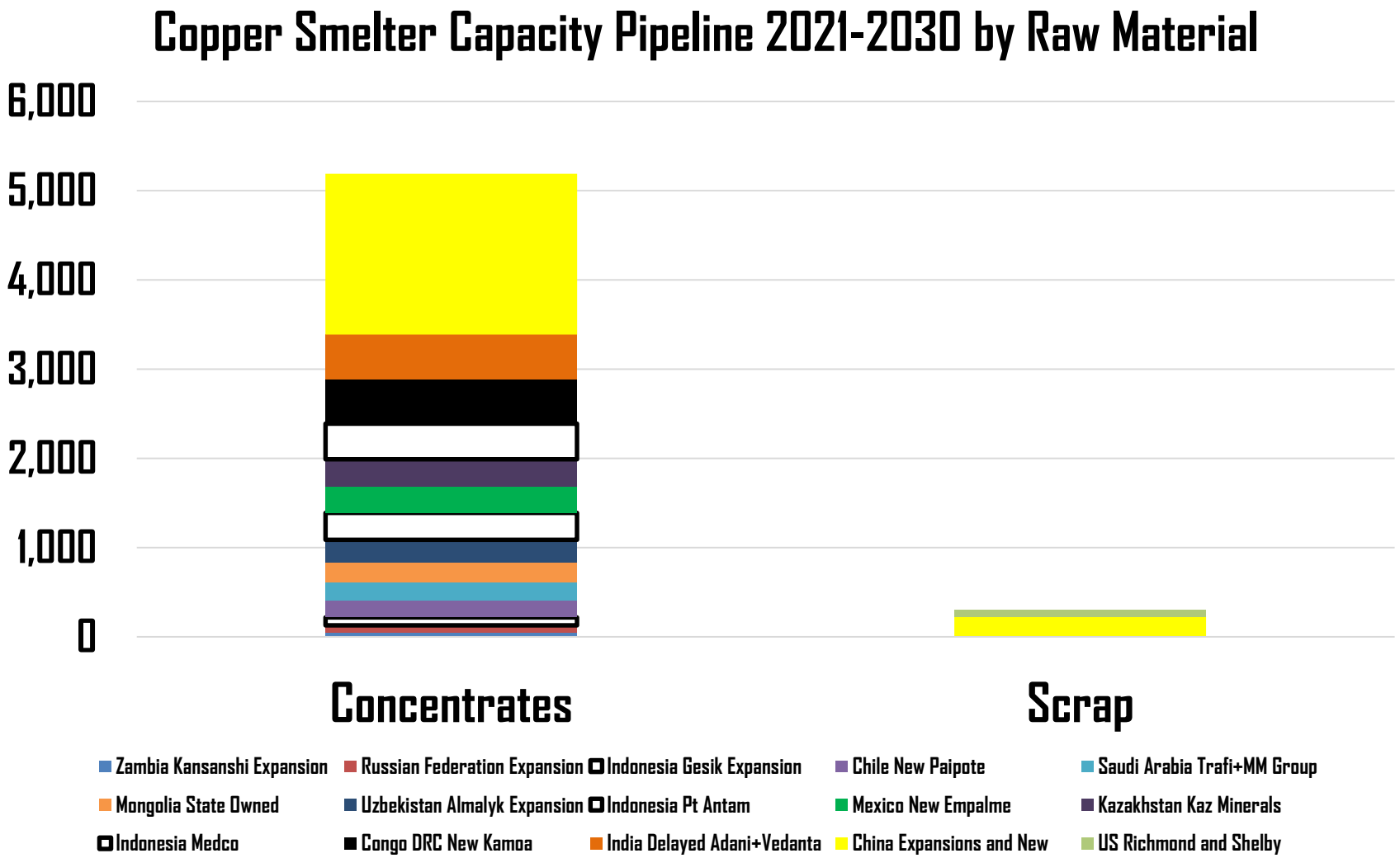
A second wave of new copper smelter capacity, some already confirmed commissioned around 2026 and beyond might add over 2.03 Mt-Cu more.



Increase in copper smelter capacities expected by 2030:

+ 5.2 Mt/year for concentrates and only 310 kt / year for copper scrap.

Global copper mine capacity utilization in 2021: 81%.



Conclusions

1. New generation of large copper fabrication plants, driving 2020-2030 demand from mines and smelters.
2. Industrial use and investment demand for refined copper recovered strongly in 2021.
3. Restrictions to international trade of copper in 2022 risk to create shortages in some regions.

4. Contraction in copper output and exports of concentrates in 2020 followed by record volumes in 2021.
5. New generation of mines producing concentrates in 2022-2030 to increase supply and As volumes.
6. Arsenic and other minor metals in concentrates spreading to Asia, Europe, ROW via blending plants.

7. End of Indonesian conc. exports in 2026 versus +DRC clean concentrates in 2023, then DRC smelter.
8. Global copper smelter capacity: many in development for 2022-2030 and not only in China.
9. "Impurities" increasing smelter waste treatment costs and polluting slag use in Asian infrastructure.
10. CAPEX, water and environmental permits: main constraints instead of falling ore grades for miners.

11. New generation of smelter technology capturing impurities making obsolete some smelters ex China.
12. Smelters specialized in processing complex concentrates in mining districts versus +blending plants.
13. More pressure on clean concentrates balance for 2022 that look vs trade disruption risks.

14. Governments and industry to focus on Arsenic capture, stabilization and safe disposal.
15. First in mines, concentrators, smelters and refineries. Tailings As management and reprocessing ahead.

ICSG

International Copper Study Group

Next ICSG Member Countries Meetings: 28-29 April 2022

- Global Copper Mine Supply Forecast
- 2022 Copper Recycling Survey
- Global Refined Copper Market Balance and Forecast
- Speakers: IMF Forecast, Mining Companies, Copper Users