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Copper Book: 2021-2030 Outlook

New framework predicts decarbonisation-led bull market*

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CITI'S TAKE

We introduce an exciting new theoretical and empirical framework for analyzing the copper market. Using the framework, and drawing on our updated bottom-up demand forecasts and evaluation of over 250 mining projects, we find that decarbonisation-led consumption growth is set to outpace mine supply growth over the next 5-10 years, requiring record high levels of scrap supply to fill the gap. We estimate that the rising 'call on scrap' will require a long-term copper price of $9,000/t in our baseline decarbonisation scenario (up from $7,500/t), and $12,000/t in our bull case, in order to generate a sufficient scrap response to clear the market. We highlight that a copper sell-off over the next 3-6 months – our base case – will provide a strong long-term buying opportunity.

We view the outlook for copper consumption as intrinsically linked to humanity's chances of meeting its climate change mitigation goals, owing to copper's use in decarbonisation related sectors, such as renewable power generation and electric vehicles, based on current technologies. Indeed, the world is significantly less likely to have a climate crisis on its hands if decarbonisation-related copper consumption growth meets the paths we outline in our base case consumption scenario (IPCC 2-degree central scenario consistent) or bull case consumption scenario (IPCC 1.5-degree central scenario consistent). In our base case decarbonisation-related consumption drives around 70% of our copper consumption growth forecast of 2.7%p.a. over the coming decade, and in our bull case scenario drives ~86% of our consumption growth forecast of 3.3%p.a.

We upgrade our base case long-term copper price to $9,000/t ($2021), based on the estimated price required to incentivize sufficient scrap to rebalance the market, reflecting an IPCC 2-degree (Paris agreement) consistent path for decarbonization related consumption. We highlight that our bull case long-term forecast is now $12,000/t, which is ~30% higher than spot and ~40% higher than long-term copper forwards, based on the estimated price required to incentivize sufficient scrap to rebalance the market, reflecting an IPCC 1.5-degree (Paris aspirational target) consistent path for decarbonization related consumption.

Though our base case long-term copper outlook is even stronger than we had previously thought, and we are still strong believers in a copper Supercycle, we highlight that we continue to be outright bearish in the near term. Specifically, we see prices falling by more than 10% to $8,200/t over the next 3-6 months, which from a long-term perspective would be a strong buying opportunity. Our near-term bearishness reflects curtailments in manufacturing spurred on by shortages in global power, coal and gas markets, together with weakening Chinese growth, and ongoing shortages of chips and container ships. Depending on the winter weather and political factors, the developing energy crisis has the potential to turn our forecast copper 'dip' into a prolonged, deeper pullback.

Risk/Reward on the copper equities favourable, especially in the bull case: Copper equities are pricing in $8,050/t of copper on average globally in our view and on our $9,000/t long-term base case the sector would be at 0.82x NPV (i.e 22% upside from current levels). On our bull case of $12,000/t the copper equities would be at 0.63x NPV. Glencore, Freeport, First Quantum, Oz Minerals, Zijin are our preferred global copper equity exposures.

**Please find new content on copper scrap supply on pages 50-51.

Contents

Note: Sources for the following figures are listed at the end of this report: Figures 25-37, Figures 84-125, Figures 127-129 and Figures 133.

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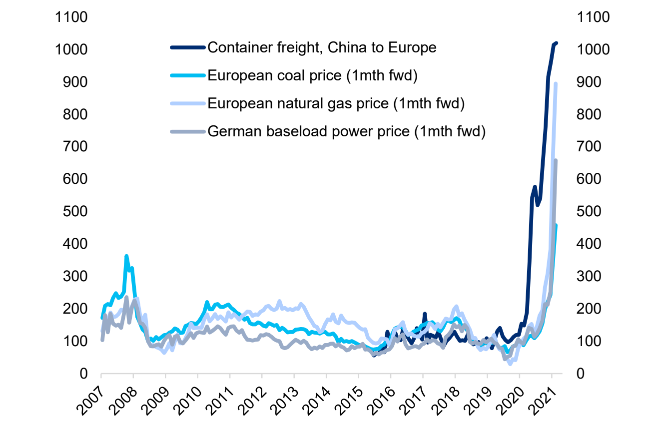
Executive summary: decarbonisation to underpin a decade of high prices

In this report, we provide a new framework for analyzing the copper market, based around the 'call on scrap', as well as our updated long-term demand, supply and price forecasts. Though we are bearish copper in the near term, we forecast a decade of high prices and strong producer margins, owing to strong decarbonisation-driven demand growth. Mine supply is not likely to be able to respond sufficiently over the same period, leaving a rising requirement for End of Life (EoL) copper scrap, a rising 'call on scrap', in order to balance the market.

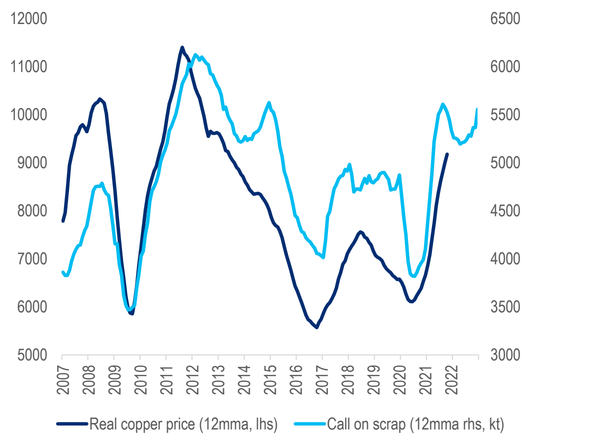
We are bearish on copper in the near term, and see prices falling to $8,200/t over the next 3-6 months (70% of our recent Instant Poll respondents thought copper would end the year below current levels). This may provide investors and consumers with an opportunity to buy into the copper Supercycle, in which we are still believers. Global growth is set to be sorely tested by the severe shortage of coal, gas, and power (particularly in Europe and China), as well as chip, container ship and other related shortages (please see Figure 1). We see copper consumption declining and mine supply rising over the coming months, and as a result the requirement for scrap should decline (see Figure 2), pushing down prices.

Figure 1. In the near term we are very concerned about the impact of shortages of chips, containers, coal, gas and power and their impact on global growth and copper demand…



Source: Citi Research, Bloomberg

Figure 2. …as a result we see copper demand declining sequentially in the near term, the call on scrap declining, and prices falling to $8,200/t



Source: Citi Research, ICA, Bloomberg, ICSG, Wood Mackenzie

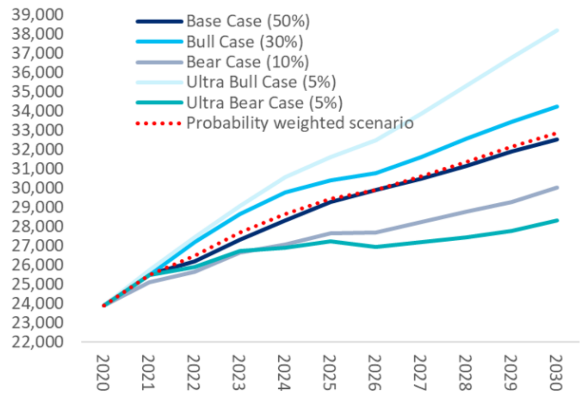
We explore a wide range of demand-side outcomes using different assumptions about the decarbonisation related and non-decarbonisation sectors (please see Figures 3 and 4). The base case transitions to a power generation and electric vehicle penetration path consistent with the 2-degree scenario, and assumes well below trend non-decarbonisation related 'cyclical' consumption growth. The bull case transitions to a demand path consistent with the IPCC's 1.5-degree scenario. We highlight our demand by sector table (Figure 51), and demand sensitivity tables (Figure 57).

Figure 3. Summary of bull/bear/base case demand scenarios

	Indicative probability	Power -Generation & Implied decarbonisation pathway		Cu thrifting in Solar (kg/Kwh)	China grid to '25-'30		Automotive		Cu thrifting in EV	Other Cyclical/ CAGR	
		Near term (2020-25)	Long term (2025+)		50% structural	50% cyclical	EV in 2030	Total PV sales		2020-'25	2025-'30
Base Case	50%	Economic/project base case	IPCC mid 2-degree scenario	4.55 currently to 3kg by 2025	-50%	Following China IP	40%	100M	BEV 83kg - >60kg PHEV 40kg ->30kg	1.6%	1.3%
Bull Case	30%	IPCC Central 1.5-degree scenario			-50%		70%			1.8%	1.3%
Bear Case	10%	Economic/current policy only - 3.3 degree warming			-50%		25%			1.3%	1.3%
Ultra Bull Case	5%	IPCC mid 1.5-degree scenario			0%		70%			2.5%	3.0%
Ultra Bear Case	5%	Economic/current policy only - 3.3 degree warming			-75%		25%			0.9%	0.0%

Source: Citi Research

Figure 4. Our bull/base/bear case scenarios employ different forecasts for decarbonisation demand whereas the ultra-bull/bear cases also assume higher/lower cyclical demand growth (kt)



Source: Citi Research, ICA, IPCC, BNEF

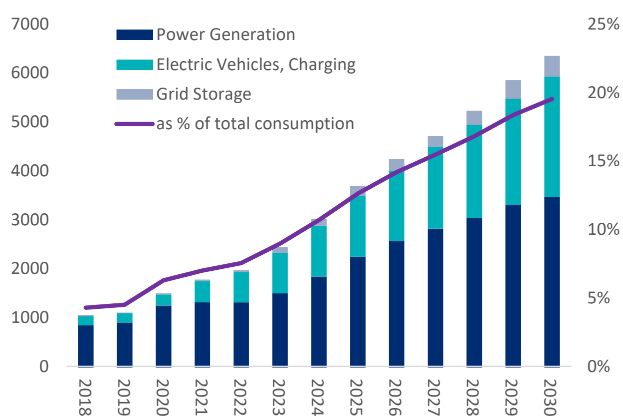
Figure 5. Bull/bear/base case demand scenarios, totals, and by source ('000t copper)

	Δ 2021-2030 (kt)			2021-2030
	Decarbonisation	Non-decarbonisation	Total	CAGR
Base Case (50%)	4555	2442	6997	2.7%
Bull Case (30%)	6664	2100	8764	3.3%
Bear Case (10%)	2157	2749	4906	2.0%
Ultra Bull Case (5%)	6664	5790	12454	4.5%
Ultra Bear Case (5%)	2918	-87	2832	1.2%

Source: Citi Research, ICA, IPCC, BNEF

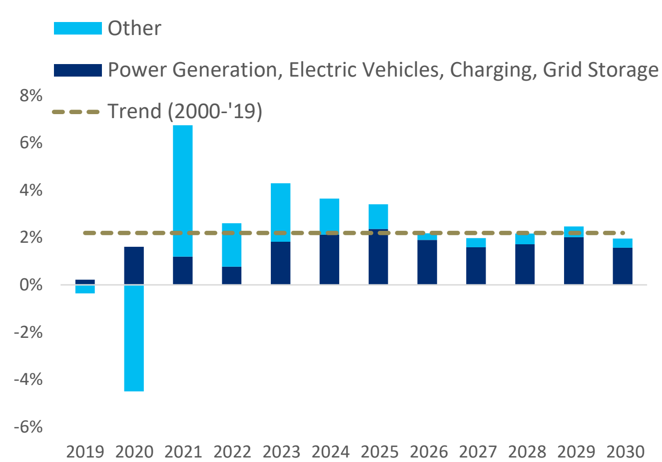
Decarbonisation-related consumption drives around 70% of our copper consumption growth forecast of 2.7%p.a. in our baseline scenario over the coming decade (please see Figures 5, 6 and 7). Copper consumption from the power generation, electric vehicle and grid storage sectors is set to rise by around 4.6mt over the coming decade, of a total of 7.0mt of forecast copper consumption growth over the same period. We incorporate explicit assumptions regarding Chinese grid demand and thrifting of copper in solar power generation and electric vehicle copper intensity. In our bull case scenario, the increase is set to be 6.7mt from decarbonisation related sectors, accounting for ~75% of the total consumption growth of 8.8mt by 2030. Please see the *Demand Outlook* section for details.

Figure 6. Medium to long-term copper consumption growth is set to be underpinned by decarbonisation ('000t, lhs, % total, rhs)…



Source: Citi Research, ICA, IPCC, BNEF

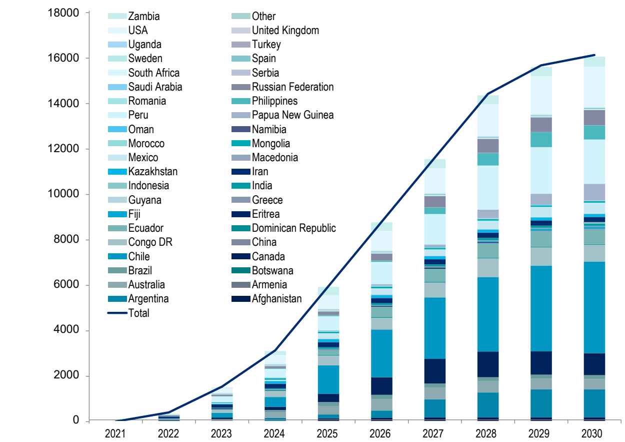
Figure 7. . . …driving around 70% of copper demand growth in our base case through 2030, and the vast bulk of growth from 2026-2030F



Source: Citi Research, ICA, IPCC, BNEF, Wood Mackenzie

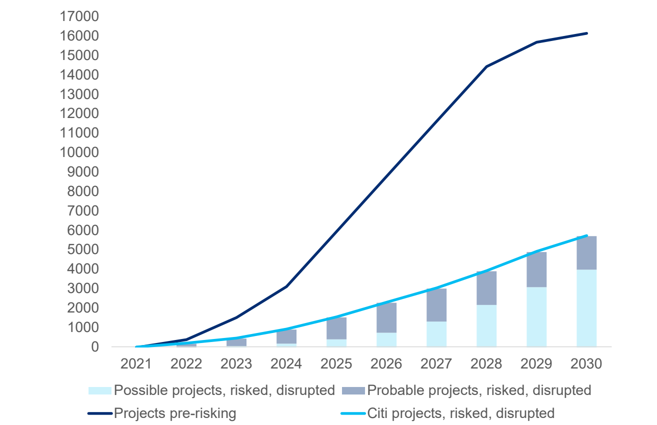
Meanwhile, mine supply is set to rise by a total 3.8mt over the coming decade, with a 5mt increase in supply from risked and disrupted projects partly offset by a decline in the baseline supply (please see Figures 8, 9 and 10). We update and evaluate over 250 copper projects and find that while capacity for these projects may be around 16mt, only ~5mt of this is likely to be brought online (on a risked basis) by 2030. The main mining regions to watch over the next couple of years are the DRC and Peru, since they both have a large number of potential growth projects. Please see the *Mine Supply Outlook* section for details.

Figure 8. Copper projects are in abundance on paper…



Source: Citi Research, Wood Mackenzie, BGRIMM

Figure 9. …but after de-risking >250 projects, the cupboard is bare



Source: Citi Research, Wood Mackenzie, BGRIMM

Rising consumption relative to mine supply is set to drive the 'call on scrap' to record high levels over the coming years, placing upward pressure on prices. Solid decarbonisation driven demand growth of ~7.0mt is projected to outpace mine supply growth ~3.8mt, resulting in an increase in the requirement for EoL scrap to fill the gap of ~3.2mt (please see Figures 10, 11, and 12). In our bull case scenario, the call on scrap rises by ~4.9mt. For context, EoL scrap recovered may be around ~4.7mt in 2021, so increasing scrap supply/use by 3.2mt will be no mean feat. If this does not occur, or if in any year there is a bottleneck, major copper deficits will ensue.

Figure 10. Our base, bull, and bear case consumption, mine supply, call on scrap, scrap supply, and implied balance forecasts – 2021F-2030F

		2018	2019	2020	2021F	2022F	2023F	2024F	2025F	2026F	2027F	2028F	2029F	2030F	2030-2021 change	2030-2021 p.a.
Base case	Consumption, estimated	24687	24642	23916	25528	26188	27306	28309	29271	29903	30488	31144	31906	32525	**6997**	**2.7%**
Base case	Mine supply, after losses	20107	20161	20189	20577	21071	21900	22664	23346	23579	23846	24154	24383	24410	**3834**	**1.9%**
Base case	Call on scrap	4580	4481	3726	4951	5117	5406	5645	5925	6324	6642	6990	7523	8115	**3163**	**5.6%**
Base case	Call on scrap as share pool	35%	33%	27%	34%	34%	35%	35%	36%	38%	39%	40%	43%	46%	**12%pts**	**3.4%**
Bull case	Consumption, estimated	24687	24642	23916	25482	27186	28657	29783	30409	30774	31631	32564	33443	34246	**8764**	**3.3%**
Bull case	Mine supply, after losses	20107	20161	20189	20577	21071	21900	22664	23346	23579	23846	24154	24383	24410	**3834**	**1.9%**
Bull case	Call on scrap	4580	4481	3726	4905	6115	6757	7119	7063	7195	7785	8410	9060	9836	**4930**	**8.0%**
Bull case	Call on scrap as share pool	35%	33%	27%	34%	41%	44%	45%	43%	43%	46%	49%	52%	56%	**22%pts**	**5.7%**
Bear case	Consumption, estimated	24687	24642	23916	25120	25631	26640	27065	27649	27699	28241	28760	29290	30027	**4907**	**2.0%**
Bear case	Mine supply, after losses	20107	20161	20189	20577	21071	21900	22664	23346	23579	23846	24154	24383	24410	**3834**	**1.9%**
Bear case	Call on scrap	4580	4481	3726	4543	4560	4740	4401	4303	4120	4395	4606	4907	5617	**1073**	**2.4%**
Bear case	Call on scrap as share pool	35%	33%	27%	32%	31%	31%	28%	26%	25%	26%	27%	28%	32%	**0%pts**	**0.2%**
	Scrap pool, estimated	13096	13439	13895	14411	14877	15410	15950	16364	16676	17022	17328	17417	17545	**3134**	**2.2%**
Base case	Scrap supply at $9,200/t, '07-08 price to scrap recovery r/ship	4449	4372	4077	4734	5132	5461	5652	5799	5909	6032	6140	6172	6217	**1483**	**3.1%**
Base case	Implied supply and demand balance (Scrap supply less CoS)	-131	-109	351	-217	15	54	7	-126	-414	-610	-849	-1351	-1897		

Source: Citi Research, ICA, Wood Mackenzie, IPCC, BNEF

The core of our new copper framework is that the direction of the 'call on scrap' explains the bulk of copper price developments over the past two decades (please see Figure 2, Figure 11), predicting prices in 16 of 21 years. The call on scrap is also more trackable than the refined supply and demand balance. Other factors such as the supply of scrap, marginal cost developments and speculative positioning (when a function of non-supply and demand-related factors such as US-China trade war escalation) help explain the other years. Please see the section titled *A New Forecasting Framework* for details.

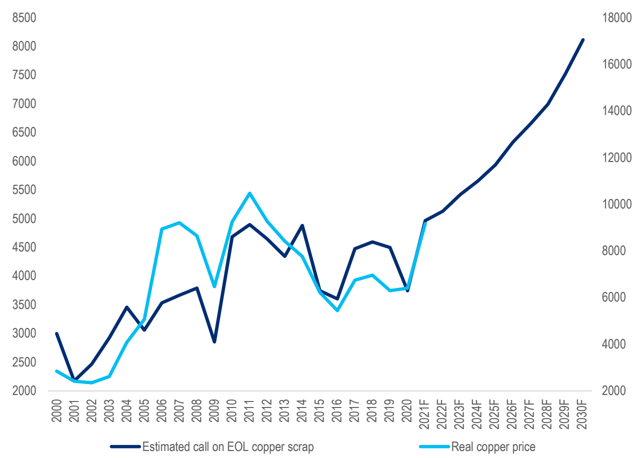
Figure 11. Forecasting the 'call on scrap' generally means forecasting price correctly

Signals	Number	Returns % total
Correct Bullish	9	276%
Correct Bearish	7	-104%
Incorrect (see Notes)	5	-43%
Signal net returns	**18**	**337%**

Source: Citi Research

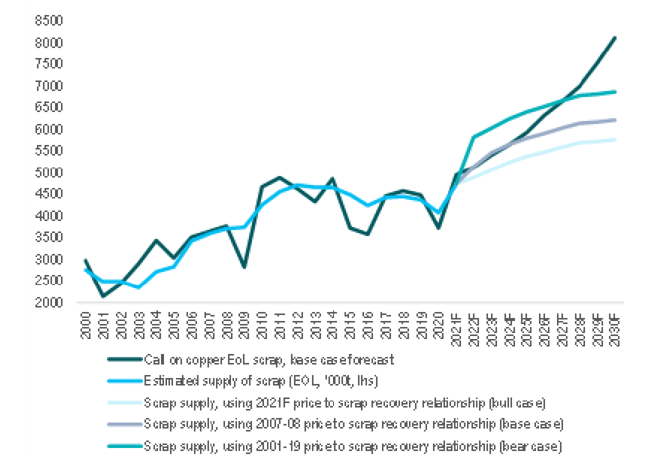
Though the outlook for a rising call on scrap should support prices at high levels (Figure 12), whether we see major copper inventory draws, last seen back during 2003-2005, resulting spreads tightness, and strong price upside will depend on the scrap supply response. Our base case scrap supply scenario indicates that current prices of $9,200/t are not enough to stop major copper deficits from occurring during the 2025 to 2030 period. Please see Figure 10 for our base case scrap supply forecasts and implied balances, Figure 13 for a graphical illustration, and Figure 127 for a graphical illustration of the implied balance. Further, we estimate that average implied copper prices required to balance the market over this period, based on long run price to scrap recovery relationships and the call on scrap are around ~$9,000/t in our base case. Please see Figures 14 and 157 for details. Both of these results support our long-term copper price upgrade to $9,000/t in our view. Please see the section titled *What kind of scrap supply response and supply and demand balances will we see?* for details.

Figure 12. Decarbonisation led demand growth is set to drive the 'call on scrap' up sharply over the next decade (by over 3mt)



Source: Citi Research, ICA, IPCC, Wood Mackenzie

Figure 13. The rising call on scrap will support prices at high levels, however whether we see major copper inventory draws (similar to 2003-2005), resulting spreads tightness, and strong price upside will depend on the scrap supply response



Source: Citi Research, ICA, IPCC, Wood Mackenzie

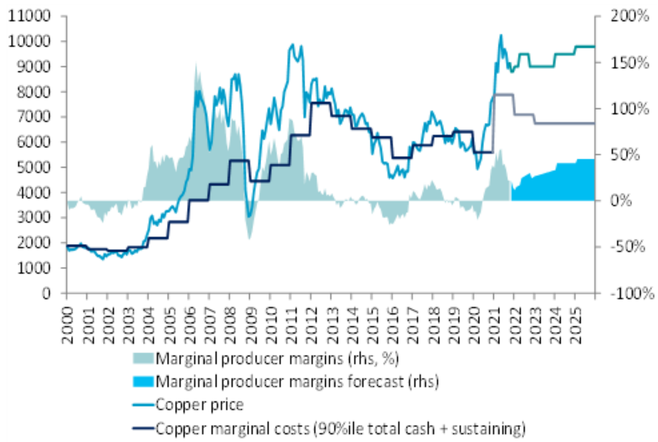
Overall our work leads us to expect a decade of high prices and high producer margins (please see Figures 14 and 15), notwithstanding a difficult period in the nearer term. Cyclical volatility will continue to affect the copper market over the coming decade; however, we expect the range of prices to be around $2.5k/t higher than that seen over the past decade ($7-11k/t, relative to $4.5-8.5k/t). The main downside risks surround global growth risks, and more aggressive than assumed thrifting and technical (substitution) risks. Please see the section *Call On Scrap Outlook* for details.

Figure 14. Copper base, bull and bear price forecasts, including long term forecasts and 'call on scrap' implied price levels

	Scenario Weight	Unit	2021F	2022F	2023F	2024F	2025F	2026F	2027F	2028F	2029F	2030F	$2021 LR real (from 2026, 2% inflation)	Average 2021F-2030F	Call on scrap implied average 2021F-2030F
Copper - Bull	35%	$/t	9292	10500	12000	12500	13000	13249	13514	13784	14060	14341	12000	12624	12417
Copper - Base	50%	$/t	9067	9150	9000	9500	9800	9937	10135	10338	10545	10756	9000	9823	8725
Copper - Bear	15%	$/t	8917	7500	7500	8000	8000	8281	8446	8615	8787	8963	7500	8301	

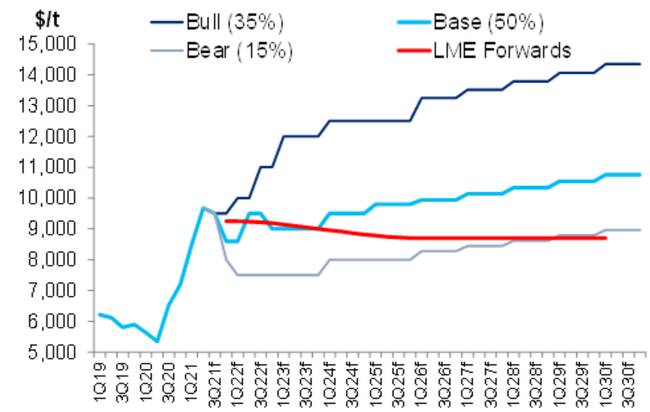
Source: Citi Research, Bloomberg

Figure 15. We expect a Supercycle in copper miner margins



Source: Citi Research, Wood Mackenzie, Bloomberg

Figure 16. We forecast bullish prices over the medium to long-term

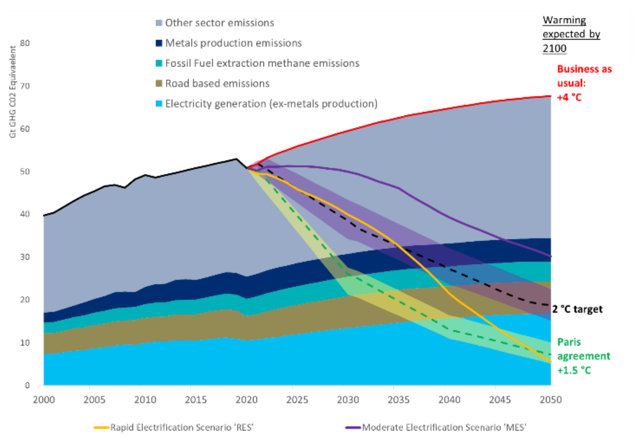


Source: Citi Research, Bloomberg

Box A: Copper makes climate change mitigation possible

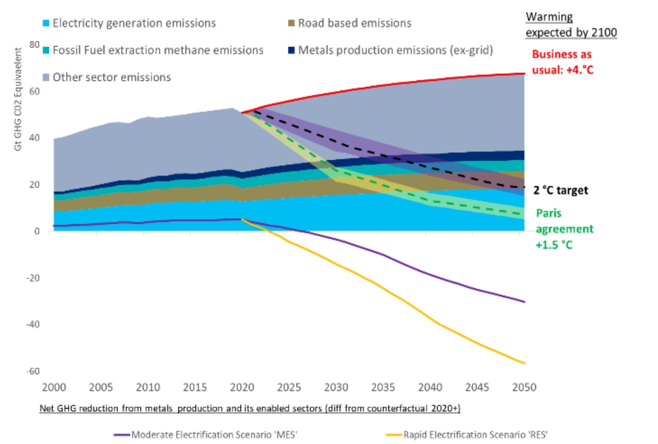
By facilitating the shift to renewable energy, the electrification of transport, and the development of carbon capture and storage, we find that the metals industry as a whole has the ability to enable the bulk of decarbonisation required by the Paris agreement by 2050 (please see Figures 17, 18, and 19). When judged relative to the decarbonisation that metals allow based on current technology, we find that all emissions directly and indirectly related to the metals industry could well be deeply negative over the vast bulk of the period through 2050, in both our moderate electrification scenario (purple) and rapid electrification scenarios (yellow).

Figure 17. Metals enable a significant net reduction in global GHG emissions over the next 30 years in our moderate and rapid electrification scenarios, even assuming metals are responsible for all global emissions (all direct and indirect emissions)



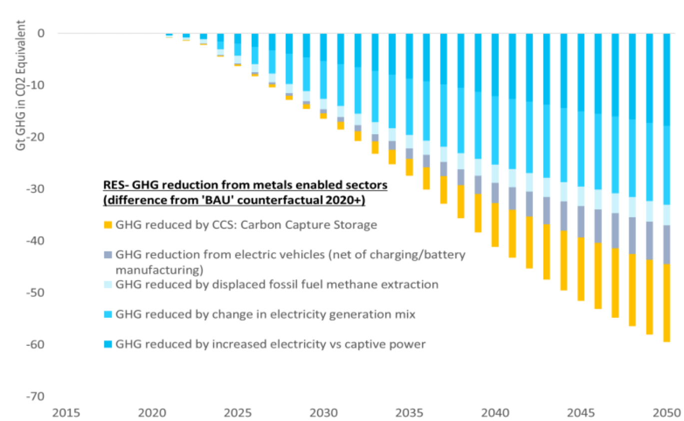
Source: Citi Research, IPCC, BNEF, Climate Action Tracker

Figure 18. Metals enable a significant net reduction in global GHG emissions over the next 30 years in our moderate and rapid electrification scenarios, assuming metals are responsible for only scope 1 and 2 production related emissions (direct emissions only)



Source: Citi Research, IPCC, BNEF, Climate Action Tracker

Figure 19. Metals enabled GHG reductions in the rapid electrification scenario (Gt of CO2 Eq) compared to the 'business as usual' counterfactual



Source: Citi Research, IPCC, BNEF

Critically, in our 'rapid electrification' scenario we estimate that the marginal tonne of metal produced over the next 30 years lowers GHG emissions by more than 175t, with cumulative metals output increases of 5.5bt lowering GHG emissions by almost 1,000GT relative to the 'business as usual' scenario

(please see Figure 20). This is more than 2/3rds of the reduction required to meet the 2100 carbon budget for the 1.5 degree IPCC scenarios (50/66%). We find that whether you attribute 11% of global GHG emissions, or even all global emissions to metals (given their integral role in facilitating modern society), metals ability to simultaneously facilitate global growth and decarbonize the planet is stark.

Figure 20. Each incremental unit of metal produced reduces GHG emissions by 176Gt in our rapid electrification scenario

Billion tonnes metals, Gigatonnes GHG C02 Eq	Business as usual scenario	Moderate electrification scenario	Rapid electrification scenario
Global GHG emissions, 2020-2050, cumulative	1,904	1,349	938
Global GHG emissions reduction relative to business as ususal, 2020-2050, cumulative	**--**	**-555**	**-966**
Global GHG emissions from:			
Electricity generation (inc metals production)	*502*	*308*	169
Captive power emissions	*465*	*361*	198
Road transport	*226*	*182*	139
Fossil fuel extraction methane	*140*	*117*	62
Metals production (ex-grid)	*108*	90	79
Other sectors	*462*	462	462
Less Carbon Capture Storage	*0*	-171	-171
Metals output, 2020-2050, cumulative	88	90	94
Metals output increase relative to business as ususal, 2020-2050, cumulative		**1.4**	**5.5**
Net global GHG emisssions per tonne of metal, relative to business as usual scenario		**-384**	**-176**

Source: Citi Research, IPCC, BNEF, Various Metals Industry Associations

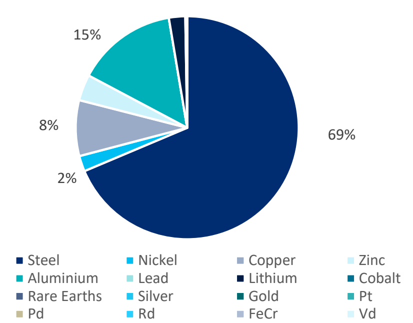
With respect to copper, specifically, the metal drives decarbonisation and climate mitigation in a net positive way on all three measures we consider to evaluate metals net emissions. Whether attributing the net decarbonisation gains using equal weights (6%), volume (8%), or value weights (28%), copper is a key driver of decarbonisation in our rapid electrification scenario (please see Figures 21, 22 and 23).

Figure 21. Copper is a critical contributor to decarbonisation efforts

	Cumulative 2020-2050, incremental decarbonisation metals demand RES vs BAU					Metals enabled GHG reduction in the RES vs BAU	
	A	B	C	D = A/Total of A	E = A X C	F= D x Total of F	G= E x Total of G
	Incremental decarbonisation demand in tonnes (BnT)	Long term price estimate ($/t or $/oz)	In value at LT price forecast (Bn USD)	Tonnage share %	Value share %	Allocated by tonnage share of decarbonisation demand (Gt of GHG)	Allocated by value share of decarbonisation demand (Gt of GHG)
Steel	3.8	870	3,286	69%	23%	-663	-220
Nickel	0.1	17000	2,116	2%	15%	-22	-142
Copper	0.4	9000	4,002	8%	28%	-78	-268
Zinc	0.2	2400	498	4%	3%	-36	-33
Aluminium	0.8	2500	2,007	15%	14%	-141	-134
Lithium	0.1	9900	1,294	2%	9%	-23	-87
Cobalt	0.013	55000	690	0%	5%	-2	-46
Rare Earths	0.001	51300	70	0%	0%	0	-5
Silver	0.001	17	473	0%	3%	0	-32
Other - not included	-	-	-	-	-	-	-
Total	**5.5**		**14,438**	**100%**	**100%**	**-966**	**-966**

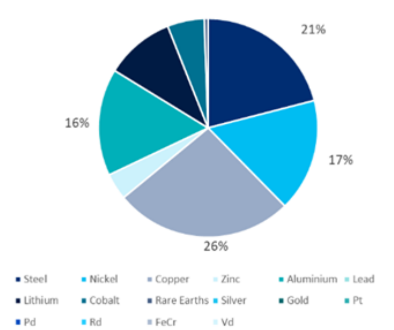
Source: Citi Research, IPCC, BNEF

Figure 22. Share of incremental metals demand by tonnage, into decarbonisation in the 'rapid electrification scenario' RES



Source: Citi Research, IPCC, BNEF

Figure 23. Share of incremental metals demand by value, into decarbonisation in the 'rapid electrification scenario' RES



Source: Citi Research, IPCC, BNEF

A new forecasting framework

We discuss the theoretical and empirical rationale for our new copper forecasting framework in this section. First, we look at the copper flow model, then the theoretical rationale for our pricing framework, and finally the empirical power of the framework historically.

The copper flow sheet

We highlight the most important parts of the global copper market flow sheet, how they relate to each other, in advance of using them in the pricing framework. Our 2021 estimates for the key components are as follows (N.B. Figure 24 illustrates the 2018 global copper market flow sheet estimates):

1) Copper mine supply after smelting/refining losses = 21mt, labelled (a), dark brown, top left, Figure 24

2) End of Life (EoL) copper scrap (also known as 'old' scrap) = ~5mt, labelled (i), dark green, bottom left, Figure 24

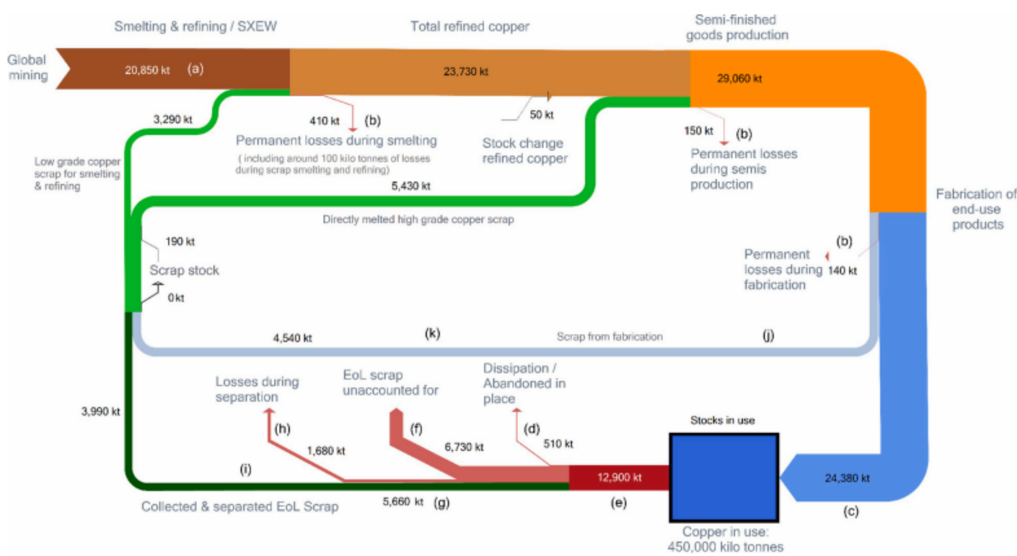
3) Scrap from fabrication (also known as 'new' or 'turnaround' scrap) = ~5mt, lablled (j, k), thing light blue line, middle of Figure 24

4) Copper semi-finished goods production was ~31mt, orange, top right, Figure 24. Semi-finished goods output is equal to copper mine supply of ~21mt in (1) after losses, plus EoL scrap (2) plus scrap from fabrication (3)

5) Copper end-use consumption = ~26mt, labelled (c), blue, bottom right, below. This is the portion of semi-fabricated output that enters stocks in use in any given year. This is equal to semi-fabricated (4) output less scrap from fabrication (new scrap) (3)[1]

6) The flow of potentially reclaimable EoL scrap ~14mt, labelled (e), red, bottom of Figure 24

Figure 24. The copper flow sheet (2018) – note that consumption is labelled (c) and is roughly equal to semi-finished production less scrap from fabrication



Source: Citi Research, International Copper Association

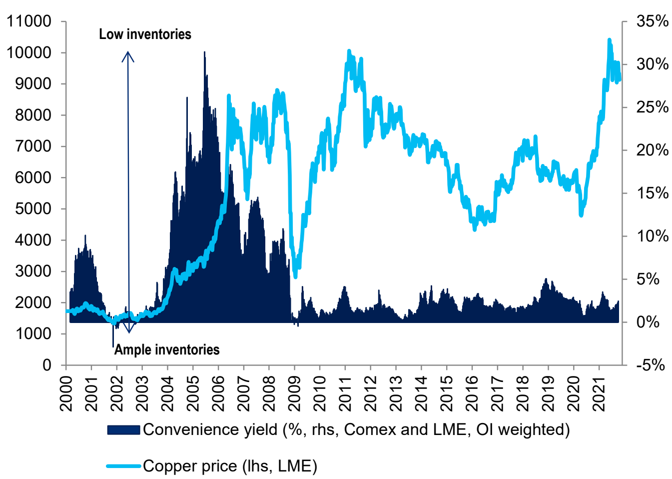
[1] Assuming scrap from fabrication (new scrap) turns around quickly, this also means that copper end use consumption equals mine supply plus old scrap (please contact us for the workings if of interest).

The need for a new framework

There is a need for a new framework for thinking about and modelling refined copper balances and prices because refined supply and demand balances have had extremely large 'error margins' for the past decade. This has rendered refined supply and demand balances useful merely for scenario analysis. A large portion of industry analysis regarding the copper market revolves around refined supply and demand modelling, which involves estimating mine supply, refinery scrap use and refined demand (N.B. refined demand is not actual copper consumption, it equal to semi-fabricated output less directly melted high grade copper scrap, as shown in Figure 24). During the 2000's one could partially overcome poor refined demand and refinery scrap data by calculating measures of apparent demand from refined supply and refined inventory data. However, after the global financial crisis, refined copper inventory visibility deteriorated markedly, owing to LME warehouse rule changes and trade houses becoming trader/producers, increasing incentives to hold inventory off-exchange (please see Box B, for details). To put it kindly, refined modelling became more of an art, as opposed to a science.

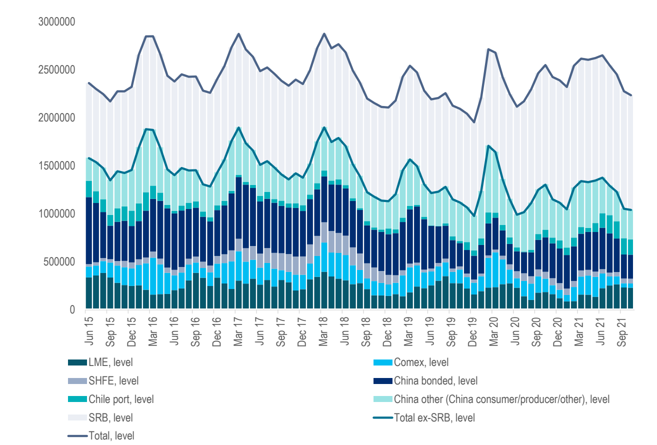
There is also a need for a new framework for thinking about and modelling refined copper prices because, unlike during the 2000s, refined copper price volatility over the past decade has not been associated with significant changes in measures of inventory tightness such as spreads and convenience yields. Figure 25 illustrates that convenience yields have been range bound from the global financial crisis until this very day, yet prices have traded in $6,000/t range over the period (see *Appendix I* for details of why these are a good guide as to aggregate inventory levels). If refined inventories are not changing much (admittedly, ex-post), then what is driving refined price volatility?

Figure 25. Massive price volatility over the past decade yet there has been limited spread volatility…



Source: Citi Research

Figure 26. …consistent with limited inventory volatility around high levels (though data quality here is poor)



Source: Citi Research

A new theoretical framework – the 'call on scrap'

In a pivot away from the refined supply and demand approach, we are now modelling and forecasting copper based on a new concept which we term the 'call on scrap'. The 'call on scrap' is the name we have given to the required EoL copper scrap needed in order to balance the market as a whole[2], and is equal to copper consumption less mine supply (after smelting/refining losses). This approach benefits from a relative abundance of relatively high quality data, though it has taken us a few years to build up the consumption model.

In this framework, equilibrium, as always is where D=S, where D=consumption (total semi-fabricated product output less fabrication scrap), and S=mS+eolsS, where mS is mine supply after smelting and refining losses, and eolsS is End of Life scrap supply. This equilibrium is an approximation based on the assumption that fabrication scrap is reused relatively quickly. Equilibrium is thus:

$$D = mS + eolsS \ (1)$$

Rewriting with the relatively price inelastic and higher data quality variables on the left hand side and relatively price elastic and poor data quality variables on the right, equilibrium is where:

$$D - mS = eolsS \ (2)$$

Naming D-mS the Call on Scrap, or CoS, the equilibrium equation becomes

$$CoS = eolsS \ (3)$$

Equation (3) illustrates that equilibrium is where the requirement or call on EoL copper scrap is equal to the supply of EoL copper scrap. Copper is in disequilibrium where supply chain inventories are falling[3] when CoS > eolsS, and is in disequilibrium where supply chain inventories are rising when CoS < eolsS.

The following are some of the key theoretical observations regarding the 'call on scrap' and refined copper pricing dynamics:

i) **When consumption is rising relative to mine supply (i.e. the 'call on scrap' is rising), the price needs to rise up the EoL scrap cost curve in order to incentivize relatively elastic scrap supply to respond, in the short run.** Once prices have reached a level that incentivizes enough scrap supply, the market rebalances, notably, at a higher price level (at least until that high cost to reclaim scrap unit is displaced with a lower cost one).

ii) **When the call on scrap is above the supply of the scrap the copper market is in deficit and this will tend to place upward pressure on copper prices.** In a deficit, supply chain inventories tend to be de-stocked first then eventually refined inventories. Upward pressure is placed on refined copper prices via the buying back inventory hedges, or by increasing the convenience yields for holding copper containing goods, or via rising supply chain prices**.**

[2] This is approximately true on an annual basis assuming that new scrap turns around relatively quickly (please reach out if you would like the detail on this).

[3] Supply chain inventories refer to inventories of copper mine supply (known as 'concentrate'), blister (smelter output), refined copper (SX-EW mine supply or refinery output), scrap (old or new scrap), semi-fabricated copper (wires, rods, shapes etc), or fabricated copper containing goods (fridges, freezers, machinery).

iii) **When the call on scrap is below the supply of scrap, supply chain inventories are under upward pressure, and placing downward pressure on copper prices.** Downward pressure is placed on refined prices via inventory hedges, falling supply chain prices, and as refined copper prices fall to incentivize higher inventory financing and eventually close copper mines in order to rebalance the market.

iv) **Speculative activity in the futures and physical markets can act to accelerate the rebalancing process (at higher, or lower levels on the EoL scrap cost curve), reducing the need for refined inventories to draw (build)**, where speculative activity is positively correlated with consumption and mine supply developments in real time (i.e. the ‘call on scrap’).

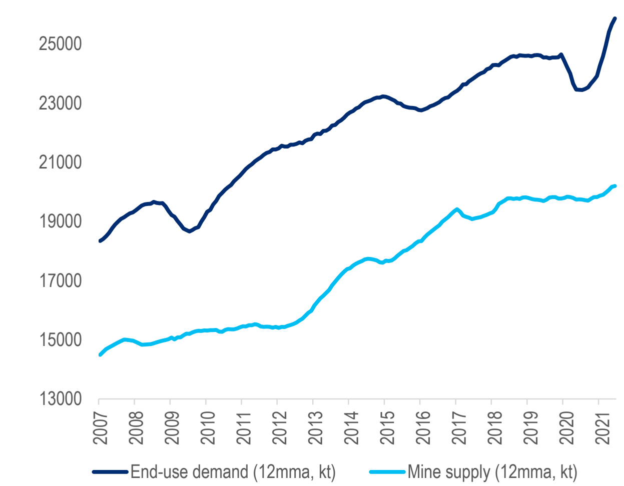
v) **It’s not just about the ‘call on scrap’, the cost structure of supply always matters too.** At all times the supply curve is the anchor for pricing, whether one is in a bull or a bear market. In bull markets where D>S the market needs the entire supply curve to be making money and as such P>MC. In bear markets where S>D only need some portion of S to be losing money, and P<MC. Miner marginal costs tend to be highly pro-cyclical (and pro-structural!), reflecting two factors, 50% cost input pricing correlated with demand for metals (oil/coal/steel derivatives), and labour/services, other 50% and they tend to demand higher payments / labour shortages during bull markets. On the scrap side, the scrap cost curve tends to shift to the right gradually over time, due to a rising pool of scrap, this means there is constant cost deflation pressure, however, the requirement tends to rise over time, offsetting this deflationary impact.

A new empirical framework – the ‘call on scrap’

This section displays our estimates of the call on scrap over the past two decades, its components, and its relationships with other variables such as EoL scrap (proxied by scrap consumed), supply chain inventory movements, and net speculative activity. The work shown in this section helped us to solve some of the puzzles of the copper market over the past two decades, including why spreads, convenience yields and inventories have been ample over the past decade, and why spreads, convenience yields got so tight and inventories drew so much during the 2000’s.

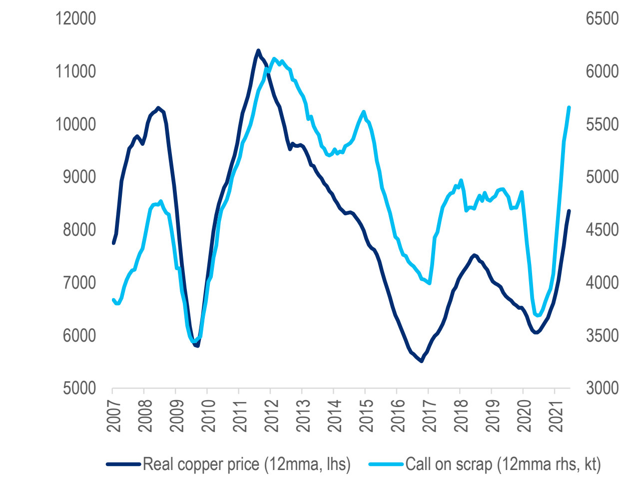
The ‘call on scrap’ is calculated as the difference between consumption and mine supply (after smelting/refining losses), and we find that it has a very strong positive historical correlation with copper prices (please see Figures 27 and 28 and 31). We observe that most of the volatility in the ‘call on scrap’ comes from the demand side (Figure 28), and that the ‘call on scrap’ has been positively correlated with our estimate of net speculative positioning on Comex and the LME (Figure 29).

Figure 27. The ‘call on scrap’ is calculated as the difference between consumption and mine supply (after smelting/refining losses)



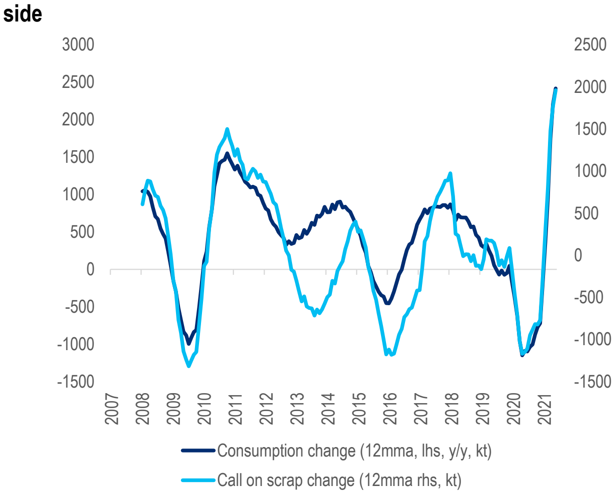
Source: Citi Research

Figure 28. The ‘call on scrap’ has a very strong historical relationship with copper prices



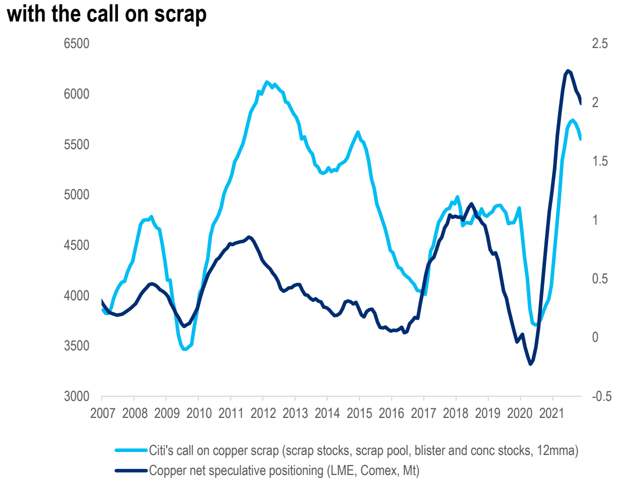
Source: Citi Research

Figure 29. Most but not all of the volatility comes from the demand side



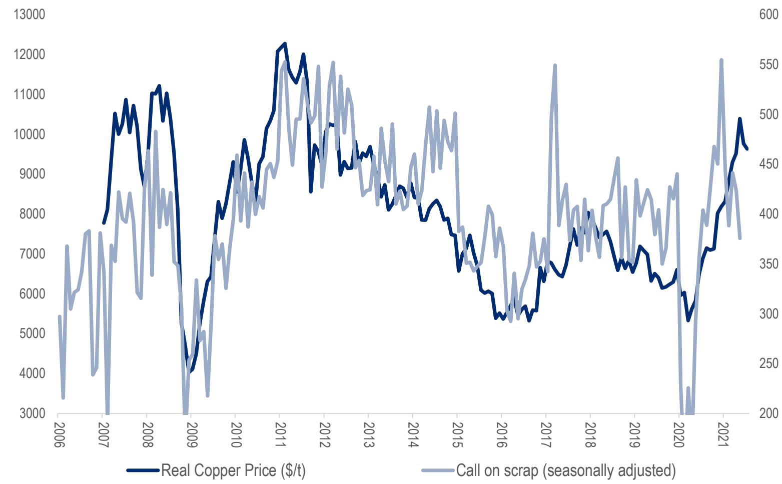
Source: Citi Research

Figure 30. Speculative positioning tends to be positively correlated with the call on scrap



Source: Citi Research

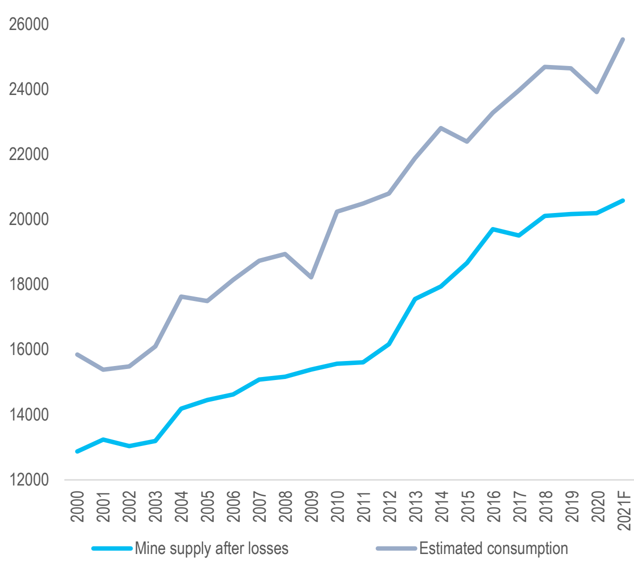
Figure 31. The 'call on scrap' has historically been strongly correlated with copper prices, and can be estimated on a monthly basis



Source: Citi Research, ICA, ICSG, Wood Mackenzie

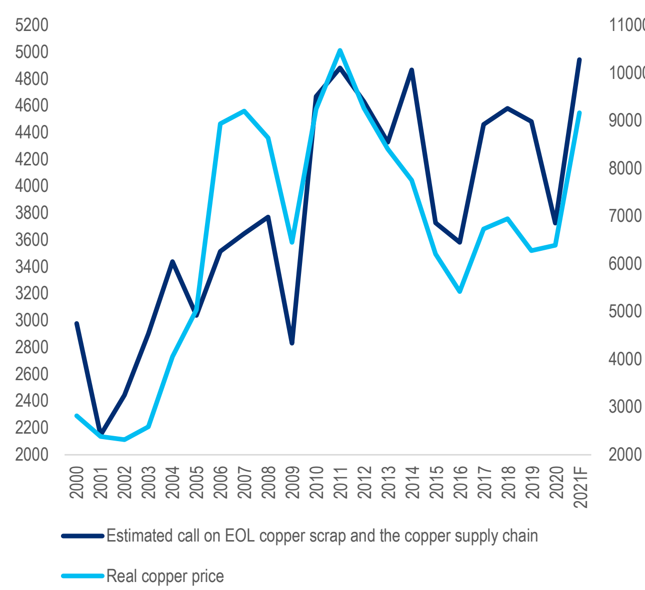
Using annual data we can estimate the call on scrap series all the way back to 2000, and here we find that relationship is similarly powerful (please see Figures 32 and 33). Indeed, using the direction of the call on scrap alone, we find that we can explain most of the variation in copper prices over the past 21 years. Specifically, the change in the 'call on scrap' provides an accurate price signal for copper price changes in 16 of the past 21 years and explain 337%pts of the 380%pts of price variation (please see Figure 34).

Figure 32. Estimated components of the call on scrap, annual data, series back to 2000



Source: Citi Research, Wood Mackenzie, ICSG, ICA

Figure 33. The 'call on scrap' has a very strong historical relationship with copper prices prior to 2008



Source: Citi Research, Wood Mackenzie, ICSG, ICA

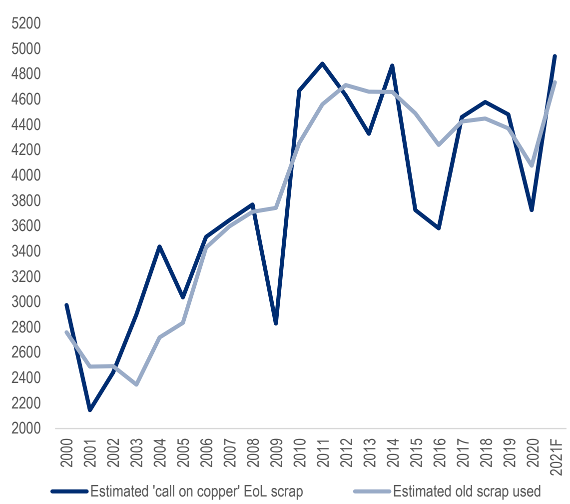
Figure 34. The change in the call on scrap explains most of the variation in copper prices over the past 21 years

	Signals	**Number**	**Returns % total**
	Correct Bullish	9	276%
	Correct Bearish	7	-104%
	Incorrect (see Notes)	5	-43%
	Signal net returns	**18**	**337%**
	Call on scrap, change	**Price change**	**Notes**
2001	Bearish	-15%	
2002	Bullish	-3%	Surplus dominated small rise in call on scrap
2003	Bullish	12%	
2004	Bullish	57%	
2005	Bearish	24%	Stock out dominated the falling call on scrap
2006	Bullish	77%	
2007	Bullish	3%	
2008	Bullish	-6%	Collapse happened 4Q08
2009	Bearish	-25%	
2010	Bullish	43%	
2011	Bullish	13%	
2012	Bearish	-12%	
2013	Bearish	-9%	
2014	Bullish	-8%	Collapse 2H on cost deflation
2015	Bearish	-20%	
2016	Bearish	-13%	
2017	Bullish	24%	
2018	Bullish	3%	
2019	Bearish	-10%	
2020	Bearish	2%	Speculative led rebound 2H rally
2021F	Bullish	44%	

Source: Citi Research

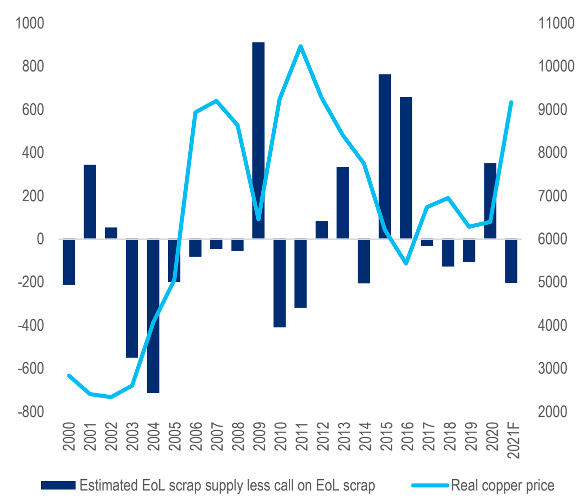
Of course, the copper market and copper price prediction is more complicated than just getting your consumption and mine supply forecasts right (and that is difficult enough!). Having a handle on the likely supply of scrap (proxied by scrap use in Figure 35 below), the outlook for marginal mine and scrap output costs (thankfully this is most usually pro-cyclical with demand and the call on scrap), and speculative positioning (this is also most usually pro-cyclical with demand and the call on scrap) can increase forecasting accuracy.

Figure 35. One can compare the 'call on EoL scrap' to EoL scrap supply (proxied by an estimate of scrap used)…



Source: Citi Research

Figure 36. …the difference between the two series gives a supply chain surplus (deficit) estimate, which is closely tied to copper prices, and helps to explain why prices rose in 2005 despite a fall in the 'call on scrap' in that year



Source: Citi Research

The call on scrap can be compared to the supply of scrap (proxied by an estimate of scrap used), giving an implied supply chain inventory change estimate, which has explained copper price changes well (please see Figures

35 and 36). Overall we find that forecasting the call on scrap is most often highly predictive in its own right, however having an idea as to whether or not scrap supply will meet the required call on scrap will help to confirm the view, give some information surrounding the outlook for copper spreads (and in some rare cases lead one to overrule the signal from the call on scrap). The year 2005 is one such year, where the call on scrap fell, but it fell to a level still above scrap supply, meaning sustained deficits in an already low inventory environment (i.e. this was not a year to get bearish basis the call on scrap declining). Overall though, we find that taking a view on whether scrap supply will be enough to meet the call on scrap adds some relatively modest additional value, as does taking a view on cost inflation/deflation and speculative positioning (please see Figure 37).

Figure 37. Taking a view on whether scrap supply will be enough to meet the call on scrap adds some modest additional value, as does taking a view on cost inflation/deflation and speculative positioning

Signals	Number	Returns % total
Correct Bullish	9	276%
Correct Bearish	6	-94%
Mixed	3	12%
Incorrect (see Notes)	3	-16%
Signal net returns	18	355%

	Call on scrap, change	Call on scrap, less scrap used/supply	Signal	Price change	Notes
2001	Bearish	Bearish	Bearish	-15%	
2002	Bullish	Bearish	Mixed	-3%	Surplus dominated small rise in call on scrap
2003	Bullish	Bullish	Bullish	12%	
2004	Bullish	Bullish	Bullish	57%	
2005	Bearish	Bullish	Mixed	24%	Stock out dominated the falling call on scrap
2006	Bullish	Bullish	Bullish	77%	
2007	Bullish	Bullish	Bullish	3%	
2008	Bullish	Bullish	Bullish	-6%	Collapse happened 4Q08
2009	Bearish	Bearish	Bearish	-25%	
2010	Bullish	Bullish	Bullish	43%	
2011	Bullish	Bullish	Bullish	13%	
2012	Bearish	Bearish	Bearish	-12%	
2013	Bearish	Bearish	Bearish	-9%	
2014	Bullish	Bullish	Bullish	-8%	Collapse 2H on cost deflation
2015	Bearish	Bearish	Bearish	-20%	
2016	Bearish	Bearish	Bearish	-13%	
2017	Bullish	Bullish	Bullish	24%	
2018	Bullish	Bullish	Bullish	3%	
2019	Bearish	Bullish	Mixed	-10%	Weak signals, trade war led sell-off
2020	Bearish	Bearish	Bearish	2%	Speculative led rebound 2H rally
2021F	Bullish	Bullish	Bullish	44%	

Source: Citi Research

Some interesting things that we learned…

i) The scrap market was not in position to respond to the large increase in the call on scrap during the early 2000s (Figures 35 and 36), resulting in major inventory draws and large refined exchange backwardations.

ii) The scrap supply chain was developed during the mid to late 2000's owing to the boom in copper, steel and other scrap metals prices.

iii) The call on scrap has been broadly unchanged over the past decade.

iv) The lack of increase in the call on scrap in (iii) and sufficient scrap supply capacity built out in (ii) meant that the market has been able to switch on and off scrap supply, thereby reducing refined inventory variation, keeping spreads range bound at relatively loose levels and convenience yields low.

v) Speculative positioning is positively correlated with the call on scrap, accelerating the process of scrap crowding out refined deficits/surpluses

vi) Copper has a long supply chain and as prices rise (fall) market participants across the supply chain look to de-stock (re-stock), helping to reduce refined inventory volatility.

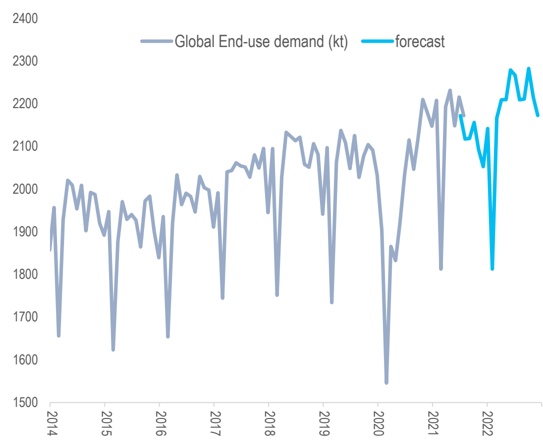
vii) To get what has been historically rare – refined copper deficits – one needs to have a sustained high call on scrap that supply struggles to meet.

Consumption outlook

Near term consumption to fall sequentially

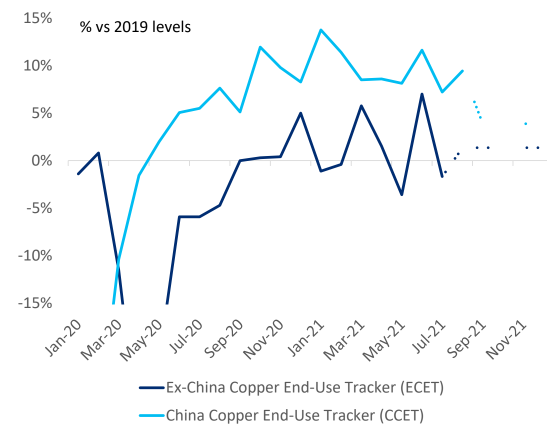
The rapid recovery in copper consumption from the Covid-19 pandemic most likely peaked in 3Q'21, and will likely sequentially decrease through the next 3-6 months, owing to a combination of industry bottlenecks, a slowdown in the Chinese construction sector, and the ongoing global coal, gas, and power crisis. At first, the recovery from the pandemic was impressively rapid as global consumption patterns turned incrementally metals-intensive. China took the lead and was back at 2019 levels as soon as April 2020. In 8M'21 China Copper end-use tracker even averaged +10% on 2019. Ex-China's recovery to 2019 levels by 4Q'20 was more measured but still impressive given that constraints on mobility persisted much longer. Our Global Copper End-Use Tracker (GCET) averaged +6% on 2019 levels in 7M'21, but we forecast that it will slide to ~3% on 2019 during September-December (or ~5% down to ~2% adjusted for autos destocking and grid demand).

Figure 38. We forecast a sequential decline in end-use consumption over the next six months. Our base case is for a recovery in 2Q'22 on a fading power crunch and China easing



Source: Citi Research, ICA, Bloomberg, Wind

Figure 39. Most principally this is led by a slowdown in China, with the China Copper End-use Tracker expected to average ~+4% on 2019 levels in Sep-Dec '21 down from +10% in 8M'21



Source: Citi Research, ICA, Bloomberg, Wind

We detail our bottom up short-term consumption forecasts in Figure 40. We have downgraded our consumption growth forecasts to 6.7% y/y in 2021 and 2.6% in 2022 (from 7.3% and 3.0% in September 2021) due to the growing short-term risks and the aforementioned shortages and bottlenecks. Our base case is also conditional on China TSF turning substantive in early 2022, and avoiding a disorderly fallout from its property developers. The largest contributors to demand growth from pre-Covid 2019 levels have been the automotive sector, consumer goods (especially in the DM), and renewable power capacity additions. The outlook for autos and consumer goods is highly dependent on the availability of semi-conductors and container freight, which continue to constrict manufacturing.

Coppers use in renewable power generation jumped in 2020, becoming a meaningful contributor to total consumption growth. However, we estimate flatter growth in 2021 and 2022 means decarbonisation-related demand is unable to offset macro weakness over this time frame. China's wind additions were up almost ~3x in 2020; a hard base for growth going forward although additions do remain higher than pre-Covid levels. 2021 copper demand in Chinese renewables is down ~25% y/y but still 135kt (~50%) above 2019, and forecast to grow 5% y/y in 2022. Copper consumption in renewables ex-China may be up ~200kt y/y in 2021 but growth also looks very lumpy and may be flat in 2022. We expect that the copper content in EV's boosts automotive copper consumption

~17% y/y in '22 compared to ~10% vehicle output, but this is only worth ~0.5% on total consumption.

Figure 40. Short term end-use demand outlook to 2022: China and Ex-China

In kt, or %	2019	2020	2021F	2022F	2022F vs 2019
Global copper end-use	24,642	23,916	25,528	26,188	6.3%
y/y	-0.2%	-2.9%	6.7%	2.6%	
Tracker only	21,441	20,673	22,269	22,768	6.2%
Mine supply (post smelter losses)	20,161	20,189	20,577	21,071	4.5%
Implied 'Call on scrap' vs 2019 levels					636
China copper end-use	11567	11494	12084	12337	6.7%
	-2%	-1%	5%	2.1%	
Citi China Copper End-Use Tracker Sectors	9374	9341	10034	10227	9.1%
CCET Y/Y	2%	-0.4%	7.4%	1.9%	
Automotive (y/y)	-7%	-3.8%	11.1%	12%	20.1%
Consumer goods (y/y)	-7%	-0.6%	4.8%	2.5%	6.8%
Machinery/Capital goods (y/y)	0%	-4.9%	13.6%	0.0%	8.0%
Construction & Infra (y/y)	3%	1.3%	4.5%	-1.5%	4.3%
Other (y/y)	2.0%	1.6%	8.7%	2.0%	12.6%
Grid & Power generation (not in the CCET)	2193	2153	2051	2110	-3.8%
of which Power Generation	294	578	429	448	
Renewable	230	493	363	381	
Fossil Fuel Gen	64	86	66	67	
Other grid	1898	1574	1622	1662	
Total Grid & Power y/y	-2%	-2%	-5%	3%	
Ex-China	13075	12,499	13,546	13,873	6.1%
	-1.1%	-4.4%	8.4%	2.4%	
Ex-China end-use tracker (ECET)	12067	11331	12235	12540	3.9%
ECET y/y	-1.2%	-6.1%	8.0%	2.5%	
Automotive (y/y)	-1.0%	-12.0%	9.4%	7.7%	3.7%
Consumer goods (y/y)	0.6%	-3.1%	11.3%	2.0%	10.0%
Machinery/Capital goods (y/y)	0.6%	-9.3%	12.7%	1.0%	3.3%
Construction & Infra (y/y)	-1.2%	-5%	5.5%	2.0%	2.4%
Power-generation & grid (not in the ECET)	1,071	1,168	1,311	1,333	24.4%

Source: Citi Research, Bloomberg, ICA, Wind

We summarize the year-to-date consumption by sectors for China and the World ex-China in Figure 41. For more on our end-use trackers and their methodology please see our initial China tracker launch-note here and the global/ex-China series background here. Please also get in touch with us if you would like to know how to track these series on Bloomberg or via Citi Velocity.

Figure 41. Global, China and Ex-China Copper End-Use Tracker summary (%, y/y)

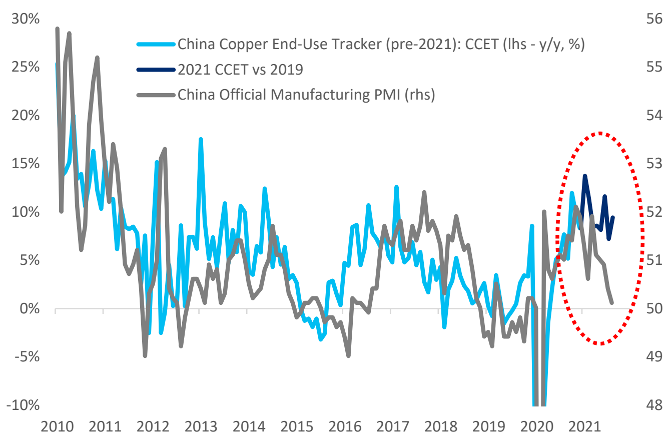
	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20
Global copper end-use tracker	-11%	-13%	-11%	-16%	-10%	-1%	-1%	1%	2%	6%	5%	7%
Vs 2019 Base												
Automotive (Copper content)	-5%	-17%	-19%	-16%	-9%	-2%	3%	-2%	5%	5%	3%	6%
Consumer Goods/ appliances	-8%	-8%	-5%	-8%	-6%	2%	2%	5%	2%	5%	5%	3%
Machinery	-9%	-8%	-7%	-10%	-8%	-5%	-3%	-1%	0%	0%	1%	4%
Construction/Infrastructure	-4%	-5%	-3%	-6%	-3%	1%	-2%	0%	0%	2%	1%	3%
China copper end-use tracker (CCET)	-21%	-28%	-10%	-2%	2%	5%	6%	8%	5%	12%	10%	8%
Vs 2019 Base												
Automotive (Copper content)	-20%	-79%	-44%	2%	16%	19%	25%	9%	18%	18%	16%	12%
Consumer Goods/ appliances	-28%	-28%	-10%	-6%	-5%	7%	7%	14%	5%	13%	13%	2%
Machinery	-35%	-35%	-18%	-7%	-5%	-5%	-1%	4%	6%	5%	5%	17%
Construction/Infrastructure	-21%	-35%	-1%	7%	13%	8%	-1%	5%	0%	13%	8%	9%
World ex-China copper end-use tracker	-1%	1%	-12%	-29%	-21%	-6%	-6%	-5%	0%	0%	0%	5%
Vs 2019 Base												
Automotive (Copper content)	-3%	1%	-33%	-57%	-44%	-22%	-7%	-15%	5%	5%	-2%	10%
Consumer Goods/ appliances	1%	1%	-8%	-33%	-23%	-2%	0%	3%	5%	6%	5%	10%
Machinery	-3%	-1%	-11%	-30%	-26%	-14%	-9%	-8%	-5%	-2%	-1%	1%
Construction/Infrastructure	-1%	1%	-8%	-22%	-14%	-1%	-6%	-4%	-1%	-2%	0%	3%

	Jan-21	Feb-21	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21
Global copper end-use tracker	18%	21%	20%	25%	13%	10%	3%	
Vs 2019 Base	6%	5%	7%	5%	2%	9%	2%	
Automotive (Copper content)	7%	96%	33%	42%	20%	6%	-1%	
Consumer Goods/ appliances	22%	23%	13%	18%	9%	3%	-3%	
Machinery	13%	12%	8%	15%	13%	11%	8%	
Construction/Infrastructure	7%	2%	7%	9%	4%	6%	1%	
China copper end-use tracker (CCET)	44%	55%	21%	10%	6%	6%	2%	2%
Vs 2019 Base	14%	11%	8%	9%	8%	12%	7%	9%
Automotive (Copper content)	43%	456%	89%	17%	2%	-5%	-2%	-4%
Consumer Goods/ appliances	67%	67%	30%	17%	10%	-2%	-12%	-10%
Machinery	50%	50%	19%	14%	15%	18%	14%	11%
Construction/Infrastructure	49%	40%	11%	-1%	1%	18%	1%	1%
World ex-China copper end-use tracker	0%	-1%	20%	44%	22%	14%	5%	
Vs 2019 Base	-1%	0%	6%	2%	-4%	7%	-2%	
Automotive (Copper content)	-7%	-8%	49%	136%	68%	25%	-4%	
Consumer Goods/ appliances	8%	10%	18%	64%	31%	20%	5%	
Machinery	5%	1%	15%	45%	33%	24%	19%	
Construction/Infrastructure	-1%	-3%	16%	27%	10%	8%	2%	

Source: Citi Research, ICA, Bloomberg

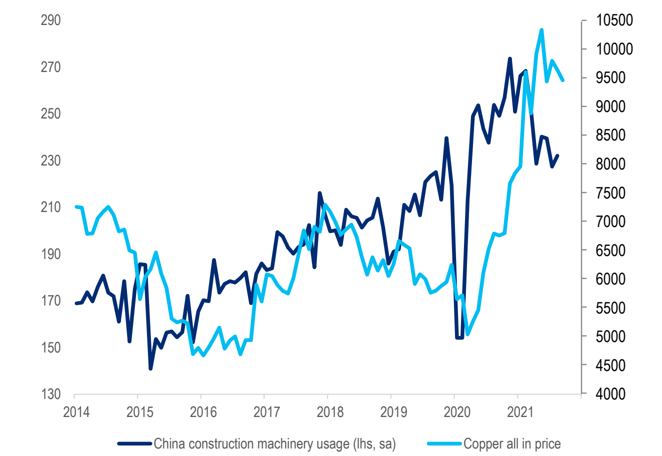
Our base case is the China Copper End-Use Tracker will slide from ~+10% on 2019 levels in 8M'21 to ~+4% September – December. This is consistent with the very weak PMI new orders less inventory prints in recent months, the latest being the worst September new orders level in over a decade, and credit tightening continuing into weakness. Citi economists have in turn downgraded 3Q/4Q'21 GDP expectations from 6.0/5.1% to 4.9/4.5% owing to the worsening impact of the power constraints on industrial activity and greater constraints on the property sector with major developers focusing on deleveraging.

Figure 42. A rare divergence between the China Copper End-Use Tracker (CCET) and the manufacturing PMI suggests that participants expect the worst is yet to come (latest CCET data August 2021)



Source: Citi Research, Bloomberg, Wind

Figure 43. Falling construction activity since 1Q'21 is a particular red-flag for short term consumption

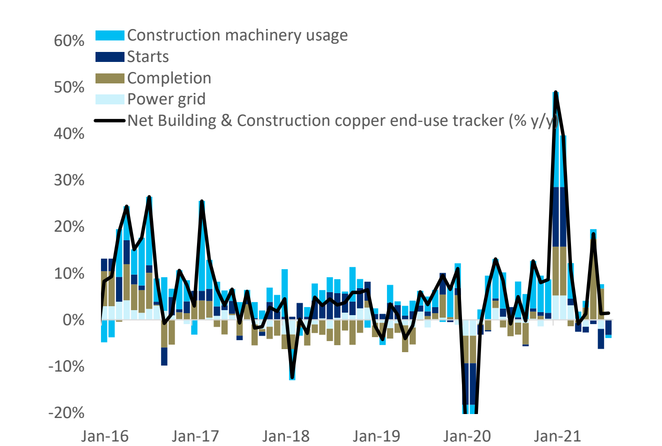


Source: Citi Research, Komatsu, Zoomlion, Hitachi, Bloomberg, S&P Global Platts

Our base case (~50% probability) is that the decline in copper consumption in Chinese construction next year amounts to just a 0.2% drag on total consumption. The bear case however is a 1.5% hit, and we assign a higher ~30% probability than the bull case. (Figure 45). In aggregate we total global copper's exposure to Chinese construction at ~15%, comprising both 10% building and construction and ~5% coming from a portion of associated consumer goods and grid-utility demand.

Solid growth in late construction cycle completions is buffering copper consumption from declines in early stage construction activity. We expect that some further growth in completions will prevent as harsh a downturn in 2022.

Figure 44. In our end-use model the weakness in starts and mid-stage activity has been buffered by higher completions



Source: Citi Research, ICA, Bloomberg, Wind, Komatsu, Zoomlion, Hitachi

Figure 45. Our base case for -1.5% demand from construction next year is based on the following real-estate and activity assumptions

		2021F	2022F Scenario Base Case	Bear Case	Bull Case
	Indicative probability		50%	30%	20%
Weights	Total construction demand	5.70%	-1.5%	-9.5%	2.5%
30%	Completions	8.50%	4.0%	-5.0%	8.0%
20%	Starts	-8.20%	-8.0%	-15.0%	0.0%
50%	Under-Construction (Machinery usage)	4%	-2.5%	-10.0%	0.0%
	Direct Cu content (kt-semi's)	2645	2605	2394	2711
	Est Indirect Cu content	972	974	894	1007
	Consumer goods (30% subset)	729	0.8%	-7.5%	4.0%
	Utility Grid (15% subset)*	243	-1.5%	-9.5%	2.5%
	% of global demand	15%			
	Impact on global copper cons	0.9%	-0.2%	-1.5%	0.3%

Source: Citi Research, Citi Research, ICA, Bloomberg, Wind, Komatsu, Zoomlion, Hitachi

Meanwhile, China's ongoing energy shortages should prompt the government to curb industrial power consumption and to secure basic winter power load and residential heating over the next two months, by around 12% under our base case. Guangdong, Zhejiang, Jiangsu, Shandong, and Fujian will likely mandate harsh industrial power curbs over the next two months at levels above national average. Coal inventories at these provinces' power plants can only cover 13 days of consumption compared to 31 days during the same time last year. Coal inventories in Zhejiang are currently only at nine days of cover. Local utilities urgently need to restock. These five eastern Chinese provinces combined account for 48% of copper fabricating capacity, respectively. They in combination also account for 33% of Chinese car production and 34% of Chinese property new starts.

We expect Chinese refined copper demand to sequentially take a bigger hit in the next two months relative to its supply, with China's industrial power curbs expanding from upstream industries such as metals smelting, cement and steelmaking to downstream industries such as construction, metals fabricating, auto and machinery production. In many cases, the potential hit to downstream sectors should outweigh that on the upstream. Under most cases, the market has priced in curbs on supply much more than curbs on demand, with price risks skewed to the downside.

The timing of China's copper demand crunch depends in part on when local governments are willing to pull the trigger on more power rationing, particularly in eastern China. We understand that there might be a sequential recovery in physical copper purchases after the Golden Week as the end-3Q energy control deadline passes, but we expect power shortages to bite soon, leading to declines in end-use copper demand likely from mid-October onwards.

Figure 46. China's cross-provincial commodity exposure

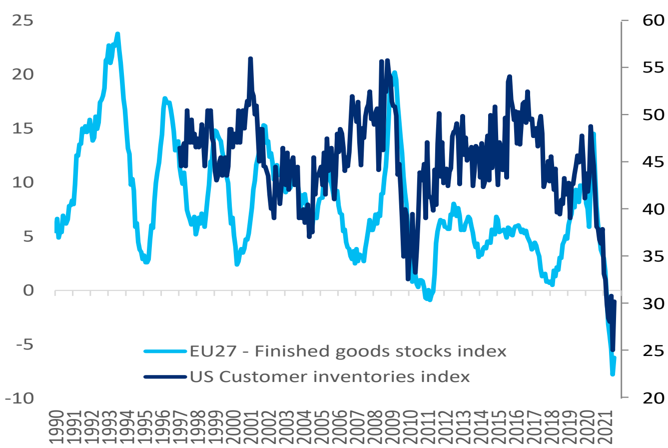
% share of China	Power importing provinces with low coal inventories					Northeastern provinces with heating challenges			Central provinces with power deficit			Western power exporting provinces - energy-intensive sectors already subject to cuts		
	Guangdong	Zhejiang	Jiangsu	Shandong	Fujian	Heilongjiang	Jilin	Liaoning	Henan	Hunan	Anhui	Inner Mongolia	Yunnan	Ningxia
Power														
Consumption	9%	6%	9%	10%	3%	1%	1%	3%	5%	2%	3%	5%	2%	1%
Generation	7%	5%	7%	8%	3%	1%	1%	3%	4%	2%	4%	7%	5%	2%
Downstream														
Automotive production	12%	6%	7%	8%	1%	1%	10%	3%	3%	4%	6%	0%	1%	0%
Property starts	8%	6%	9%	9%	4%	1%	2%	2%	7%	5%	5%	2%	3%	1%
Copper fabricating	13%	14%	18%	2%	1%	0%	0%	1%	4%	1%	11%	0%	1%	0%
Aluminium fabricating	9%	4%	7%	20%	3%	0%	0%	2%	16%	2%	2%	5%	1%	1%
Upstream														
Coal	0%	0%	0%	2%	0%	1%	0%	1%	2%	0%	3%	25%	1%	2%
Crude steel	3%	1%	11%	8%	3%	1%	2%	7%	3%	3%	4%	3%	2%	1%
Refined copper	1%	7%	3%	14%	7%	0%	1%	1%	6%	1%	11%	5%	7%	0%
Refined aluminium	0%	0%	0%	20%	0%	0%	0%	1%	5%	0%	0%	15%	9%	3%

Source: Citi Research, NBS, CRU

We have also downgraded our expectations for ex-China consumption given global power shortages, and ongoing bottlenecks in container freight and semi-conductors. Our base case is now that the Ex-China Copper End-Use tracker averages ~0.7% on 2019 levels in 2H'21 down from +1.5% in 1H'21. We are particularly concerned that surging electricity prices poses to Europe in 4Q'21.

Looking forward however, near term pain is in part the futures years' gain as a large scale restock looks to be in store once shortages abate, possibly starting in 2H'22. Our best estimate is that tightness in freight markets will peak in 1H'22 and while it will not fully resolve for some time, it will get sequentially better. Each incremental improvement should allow manufacturing to narrow the gap with higher demand and eventually to restock inventories that have drawn to ~30-year lows. A similar destock in autos is estimated to have displaced ~250kt copper consumption since March 2020. Semi-conductor shortages continue but the worst may have now passed. As chips supply increases, OEMs will likewise first be able to produce closer to sales demand before overproducing in order to rebuild critically low stocks.

Figure 47. Global goods inventories are at ~30 year lows

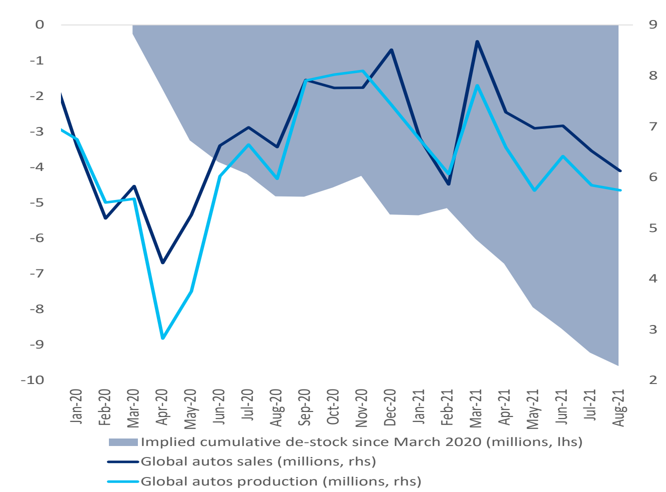


Source: Citi Research, Bloomberg

Figure 48. Coal, gas, and power shortages create issues incremental to shortages in container shipping and chips (Index = 100, 2019)

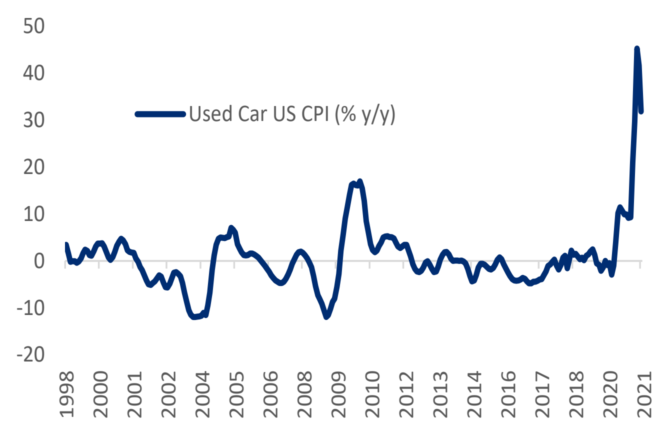
Source: Citi Research, Bloomberg

Figure 49. ~10M cars have been destocked since March 2020, equivalent to ~250k cars



Source: Citi Research, ihs, Bloomberg

Figure 50. ..and even with destocking is lagging consumer demand as surging prices for 2nd hand cars shows



Source: Citi Research, Bloomberg, US Census Bureau

Long term growth underpinned by decarbonisation

In Figure 51 we present our new base case copper consumption forecasts out to 2030 and find that copper looks set for a bright decade of above trend ~3% CAGR consumption growth; almost 1.5x the 2.2% average of 2000-'19. By our forecasts this breaks down as a ~4% CAGR 2020-25 and is still impressively close to trend at ~2.1% CAGR in 2025-'30. We combine bottom-up models for copper consumption in electricity generation, grid storage, and automotive (EV's, charging and non-EV automotive) with traditional top-down, and slowing, IP based approach to other sectors (post our bottom-up forecasts in '21/'22 as presented earlier). We discuss each sector individually in the latter half of this chapter.

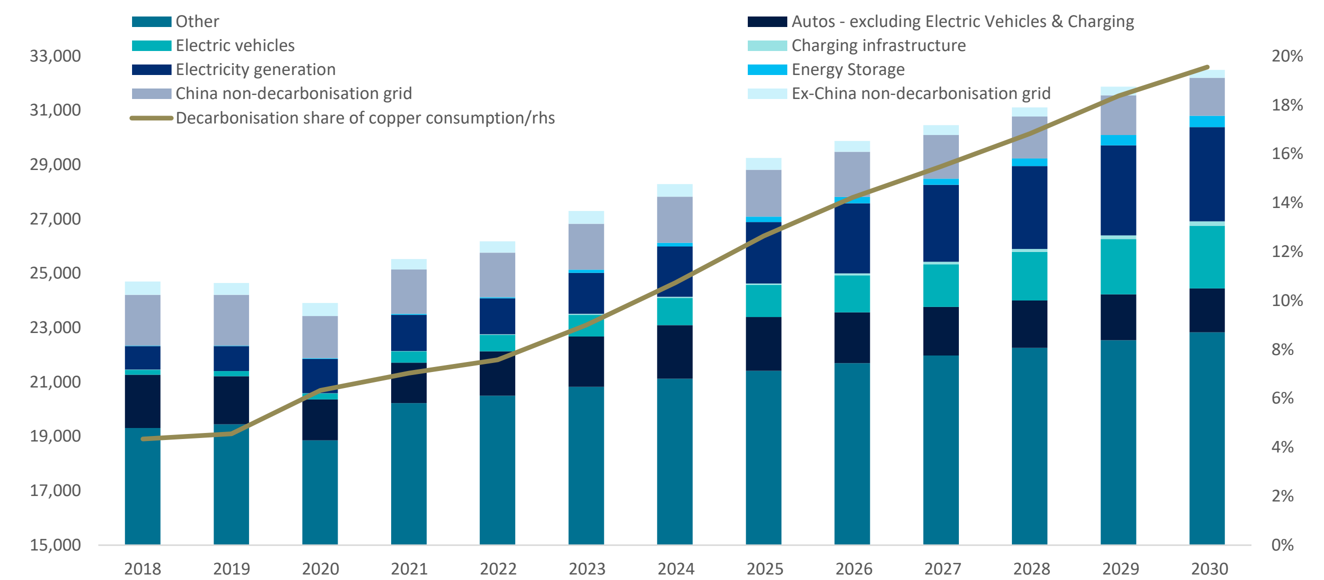
Figure 51. Base case copper consumption forecasts to 2030, by sector

kt	2019	2020	2021f	2022f	2023f	2024f	2025f	2026f	2027f	2028f	2029f	2030f
Base case end-use copper consumption	**24,642**	**23,916**	**25,528**	**26,188**	**27306**	**28309**	**29271**	**29903**	**30488**	**31306**	**32231**	**32525**
y/y	*-0.2%*	*-2.9%*	*6.7%*	*2.6%*	*4.3%*	*3.7%*	*3.4%*	*2.2%*	*2.0%*	*2.7%*	*3.0%*	*0.9%*
Decarbonisation sectors	**1123**	**1515**	**1797**	**1987**	**2459**	**3035**	**3699**	**4249**	**4718**	**5236**	**5856**	**6351**
y/y	*-3%*	*35%*	*19%*	*11%*	*24%*	*23%*	*22%*	*15%*	*11%*	*11%*	*12%*	*8%*
Electricity Generation	**917**	**1264**	**1333**	**1329**	**1514**	**1856**	**2262**	**2579**	**2835**	**3047**	**3316**	**3472**
Grid Storage	**13**	**23**	**33**	**33**	**118**	**140**	**203**	**240**	**224**	**286**	**378**	**417**
Electric vehicles & charging	**193**	**227**	**431**	**625**	**828**	**1038**	**1233**	**1430**	**1660**	**1902**	**2162**	**2462**
Passanger vehicles	143	190	367	533	709	879	1046	1181	1338	1489	1643	1811
Commercial vehicles and bus	45	32	50	71	88	118	137	180	234	305	386	491
Charging infrastructure	5	5	14	22	31	42	51	69	87	109	134	160
Non-decarbonisation sectors	**23519**	**22401**	**23731**	**24201**	**24847**	**25275**	**25572**	**25654**	**25770**	**26070**	**26374**	**26174**
y/y	*-0.1%*	*-4.8%*	*5.9%*	*2.0%*	*2.7%*	*1.7%*	*1.2%*	*0.3%*	*0.5%*	*1.2%*	*1.2%*	*-0.8%*
Non-decarbonisation grid demand	**2313**	**2033**	**2011**	**2063**	**2161**	**2160**	**2158**	**2060**	**1971**	**2039**	**2105**	**1684**
Ex-China tansmission line additions	451	479	381	417	474	465	433	400	369	341	315	290
China grid ex-power gen	1862	1554	1630	1646	1686	1695	1724	1661	1602	1698	1790	1393
Of which China structural grid	931	777	815	823	823	823	823	734	655	736	817	412
OF which China cyclical grid	931	777	815	823	863	872	901	926	947	961	973	982
Automotive - excluding electric vehicles & charging	**1772**	**1505**	**1485**	**1625**	**1840**	**1967**	**1975**	**1873**	**1792**	**1738**	**1687**	**1617**
Stocking/production adjustments	-95	-127	-154	-45	47	160	170	70	18	0	0	0
PV- Hybrids/MHEV (Sales)	109	131	172	210	241	272	303	353	403	456	512	572
ICE - Passanger vehicles (Sales)	1428	1172	1146	1129	1209	1175	1140	1085	1007	920	821	704
ICE -Commercial vehicles (Sales)	351	329	322	331	343	360	362	365	365	362	354	342
Other	**19,434**	**18,862**	**20,235**	**20,512**	**20,847**	**21,148**	**21,439**	**21,721**	**22,006**	**22,293**	**22,582**	**22,873**
y/y	*0.7%*	*-2.9%*	*7.3%*	*1.4%*	*1.6%*	*1.4%*	*1.4%*	*1.3%*	*1.3%*	*1.3%*	*1.3%*	*1.3%*
Building & construction	6879	6680	7025	7087								
Consumer goods	4113	4047	4346	4446								
Machinery & capital goods	2899	2686	3037	3054								
Other	5461	5450	5827	5926								

Source: Citi Research, ICA, IPCC, BNEF, Wind, Wood Mackenzie, BGRIMM

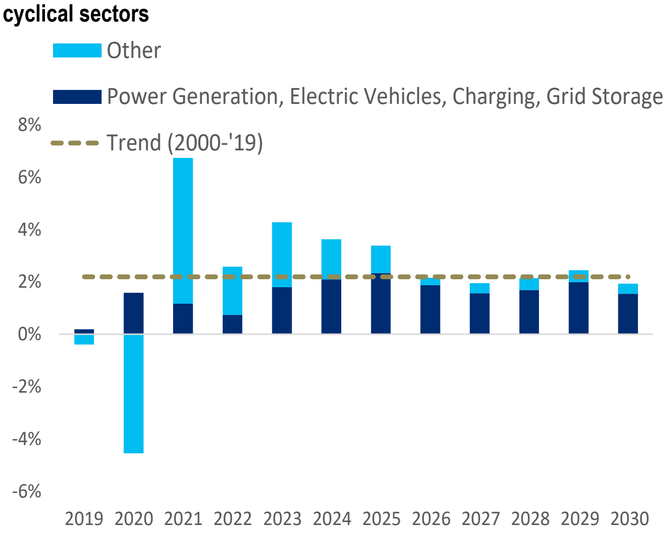
Copper owes its bright long term demand outlook to the increased contribution from the fast growing 'decarbonisation sectors' (electricity generation, grid storage, and electric vehicles and charging) which are forecast to more than offset substitution and maturing growth in copper's traditional 'cyclical' demand sectors. As per Figure 52-53 copper's demand share in decarbonisation sectors is expected to more than double from ~8% in 2020 to ~20% in 2030, and make up on average ~50% of copper's consumption growth in 2021-25, and 80% of consumption growth between 2025-2030. In comparison we model a 2% 2021-30 CAGR decline in non-decarbonisation grid demand (e.g. connectivity lines), effectively flat consumption from 2022 onwards from the automotive excluding electric vehicle and charging sector, as well as a slowdown in non-decarbonisation sectors (Figure 56) from ~2.2% CAGR in 2000-19 to ~1.5% CAGR 2021-'25 and 1.3% in 2025-30.

Figure 52. Copper consumption growth set to be led by decarbonisation sectors over the next decade



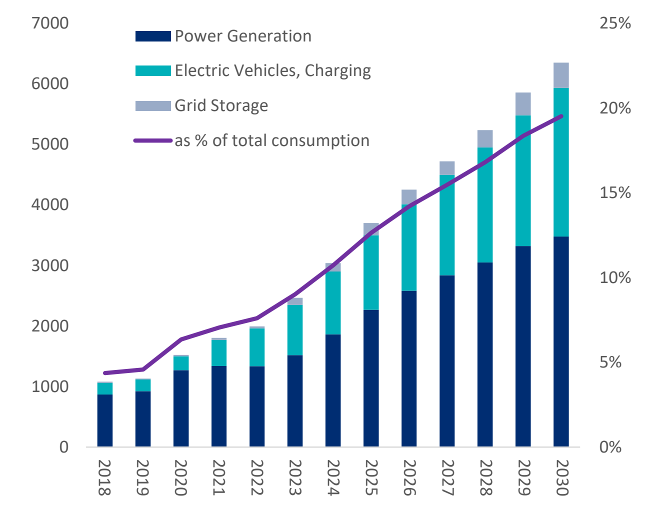
Source: Citi Research, ICA, Bloomberg, BNEF, Wood Mackenzie, IPCC

Figure 53. The decarbonisation sectors (electricity generation, grid storage, and electric vehicles and charging) are forecast to increasingly dominate copper demand growth compared to other-cyclical sectors



Source: Citi Research

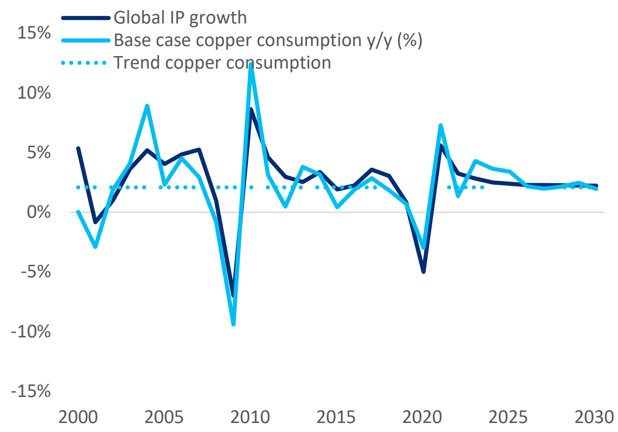
Figure 54. In our base case copper consumption in the three decarbonisation sectors are expected to grow by ~5Mtpa from 2020-2030, and go from ~5% to 20% of total copper consumption



Source: Citi Research

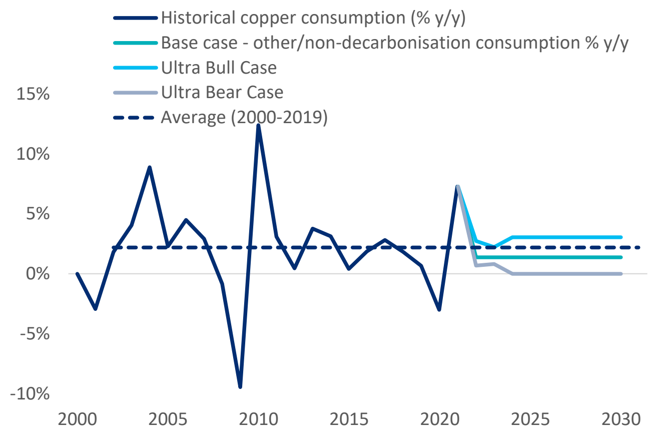
Copper consumption is set to keep pace with IP for the next decade, reflecting strong demand from decarbonisation related sectors (Figure 55). This comes even as we model a slowing IP-intensity relationship among all of coppers 'other' non-decarbonisation sectors (Figure 56), excluding automotive and grid, which currently dominate ~80% of consumption. Our base case is the IP-intensity of copper's main stream consumption sectors fall from an average 0.98x in 2000-'19 to ~60% of those levels by 2025-2030. This is consistent with slowing growth in building and construction (~30% of 2021 consumption), and heightened substitution away from copper at high prices in sectors such as consumer goods and air-conditioning.

Figure 55. Owing to the strong contribution from decarbonisation we forecast total consumption keeping pace with IP



Source: Citi Research, ICA, Bloomberg, Wood Mackenzie, IPCC

Figure 56. ..Even though in our base case we model the non-decarbonisation or 'cyclical' demand falling to almost half trend, and half its prior average elasticity to IP



Source: Citi Research, Bloomberg, ICA, Wood Mackenzie

Forecasting out to 2030 naturally depends on a wide range of inputs and we present the demand sensitivity of each main variable in Figure 57. Crucially this exercise reminds us that while decarbonisation plays a key role, copper will still remain highly 'macro' since cyclical variables remain the most impactful on top line demand. Indeed, even in 2030 we forecast that ~78% of consumption remains in sectors are still closely linked to the economic cycle (automotive- excluding EV's and charging, China's cyclical grid demand, and "other"), and ~70% specifically from the "other" we model directly on IP. A 1%pa change in IP through 2023-30 therefore has the biggest delta impact of the sensitivities listed below, equating potentially to a ~3% increase on 2030 demand. We also note that a 1% change in the gross passenger vehicle market matters more than a 10% change in EV penetration, and that core economic variables such as energy consumption growth sets the bar for de-carbonization and renewables to meet the needs of economic growth without incurring additional emissions and global warming – a subject we discuss later.

Figure 57. Sensitivities of our 2030 demand estimates by variable

Sector/Variable	2021F	2030 baseline	Baseline unit	Delta	Delta impact 2030 ('000t)	*Delta impact 2030 (% total consumption)*
Copper consumption	**25,528**	**32525**	**000t**			
Copper consumption growth (p.a., 2021-2030F)		2.7	%	+-1%pt pa	2960	*9.1%*
Automotive (total inc. electric vehicles and charging)	**1916**	**4079**	***000t***			
Electric vehicle penetration		40	%	+-10%pt	240	*0.7%*
Gross passanger vehicle market size		100	M sales/pa	+-1%pt	310	*1.0%*
BEV share of electric vehicles		70	%	+-10%pt	660	*2.0%*
BEV copper content (vs 83kg in 2020)		60	kg/unit	+-10kg	240	*0.7%*
PHEV copper content (vs 60kg in 2020)		40	kg/unit	+-10kg	100	*0.3%*
EV fleet per Public charger (global average)		7	Ratio	+-1	110	*0.3%*
% of public charging fast		80	%	+-10%pt	20	*0.1%*
Electricity generation	**1333**	**3472**	***000t***			
Total energy usage		0.80	% pa	+-0.1%pt pa	290	*0.9%*
Grid share of energy		25	%	+-1%pt	1150	*3.5%*
Renewable generation share		65	%	+-1%pt	330	*1.0%*
Wind & solar utilization		17% Solar/ 32% Wind	%	+-1%pt	-100	*-0.3%*
Wind generation as % wind & solar		40	%	+-10%pt	-270	*-0.8%*
% of wind capacity offshore		10	%	+-10%pt	310	*1.0%*
Solar copper content (vs 4.6kg in 2020)		3	Kg/Kwh	+-1kg	460	*1.4%*
Nuclear as share of generation		9	%	+-1%pt	-70	*-0.2%*
Non-Decarbonisation grid	**2011**	**1684**	***000t***			
China structural grid growth (50% of 2021; 21-2030F)		-7.3	%	+-1%pt pa	40	*0.1%*
China cyclical grid growth (50% of 2021; 2021-2030f)		2.1	%	+-1%pt pa	90	*0.3%*
Ex-China non-decarbonisation grid growth ('21-2030F)		-3.0	%	+-1%pt pa	30	*0.1%*
Other	**20,235**	**22,873**	***000t***			
Global IP growth (pa 2023-2030)		2.3	%	+-1%pt pa	1060	*3.3%*
Intensity to IP (average 2023-2030)		0.6	Ratio	+-0.1pt pa	430	*1.3%*

Source: Citi Research, ICA, BNEF, IPCC, Wood Mackenzie, BGRIMM

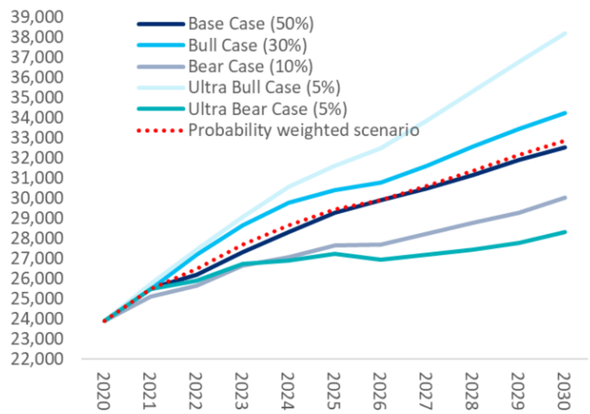
We present additional bull/bear and lower indicative probability ultra-bull and ultra-bear scenarios for consumption in Figure 58, Figure 59, and Figure 60. The most significant difference between these scenarios comes from electricity generation with each modelled on a different outlook for global-warming. The base case migrates to a pathway consistent with a 2-degree outlook from 2024+, the bull case is on track to a 1.5-degree warming, whereas the bear case is based solely on existing economics and is on track for over 3-degrees warming. Additionally the bull/bear scenarios vary by their outlook for EV penetration. The ultra and bear scenarios also make variations on China's non-decarbonisation grid demand, and the IP elasticity of consumption by the "other" sectors.

Figure 58. Summary of bull/bear/base case demand scenarios

<table>
<tr><th rowspan="2"></th><th>Indicative</th><th colspan="2">Power -Generation & Implied decarbonisation pathway</th><th>Cu thrifting in</th><th colspan="2">China grid to '25-'30</th><th colspan="2">Automotive</th><th>Cu thrifting in</th><th colspan="2">Other Cyclical/ CAGR</th></tr>
<tr><th>probability</th><th>Near term (2020-25)</th><th>Long term (2025+)</th><th>Solar (kg/Kwh)</th><th>50% structural</th><th>50% cyclical</th><th>EV in 2030</th><th>Total PV sales</th><th>EV</th><th>2020-'25</th><th>2025-'30</th></tr>
<tr><td>Base Case</td><td>50%</td><td>Economic/project base case</td><td>IPCC mid 2-degree scenario</td><td rowspan="5">4.55 currently to 3kg by 2025</td><td>-50%</td><td rowspan="5">Following China IP</td><td>40%</td><td rowspan="5">100M</td><td rowspan="5">BEV 83kg - >60kg PHEV 40kg ->30kg</td><td>1.6%</td><td>1.3%</td></tr>
<tr><td>Bull Case</td><td>30%</td><td colspan="2">IPCC Central 1.5-degree scenario</td><td>-50%</td><td>70%</td><td>1.8%</td><td>1.3%</td></tr>
<tr><td>Bear Case</td><td>10%</td><td colspan="2">Economic/current policy only - 3.3 degree warming</td><td>-50%</td><td>25%</td><td>1.3%</td><td>1.3%</td></tr>
<tr><td>Ultra Bull Case</td><td>5%</td><td colspan="2">IPCC mid 1.5-degree scenario</td><td>0%</td><td>70%</td><td>2.5%</td><td>3.0%</td></tr>
<tr><td>Ultra Bear Case</td><td>5%</td><td colspan="2">Economic/current policy only - 3.3 degree warming</td><td>-75%</td><td>25%</td><td>0.9%</td><td>0.0%</td></tr>
</table>

Source: Citi Research

Figure 59. Our bull/base/bear case scenarios employ different forecasts for decarbonisation demand whereas the ultra-bull/bear cases also assume higher/lower cyclical demand growth (kt)



Source: Citi Research

Figure 60. Bull/bear/base case demand scenarios by demand component ('000t copper)

	Δ 2021-2030 (kt)			2021-2030
	Decarbonisation	Non-decarbonisation	Total	CAGR
Base Case (50%)	4555	2442	6997	2.7%
Bull Case (30%)	6664	2100	8764	3.3%
Bear Case (10%)	2157	2749	4906	2.0%
Ultra Bull Case (5%)	6664	5790	12454	4.5%
Ultra Bear Case (5%)	2918	-87	2832	1.2%

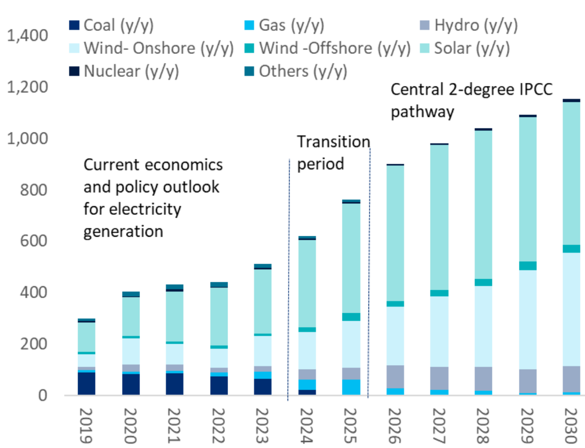
Source: Citi Research

Review of individual consumption sectors

1. Electricity generation

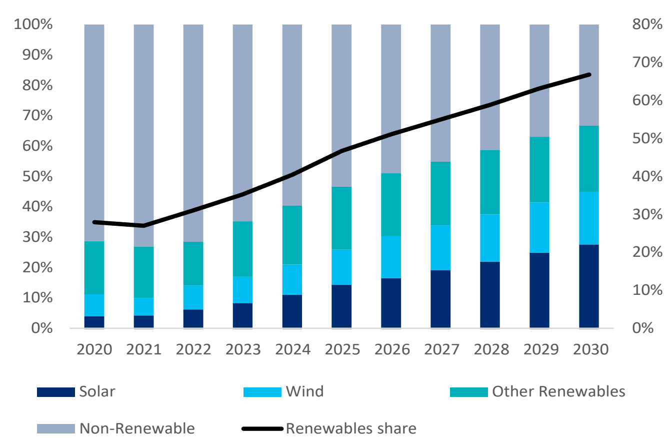
Our base case (50% indicative probability) for copper consumption in electricity generation combines near term estimates of the capacity pipeline, and from 2024+ transitions to a path consistent with meeting the higher bound 2-degree global warming target of the global Paris agreement. Specifically our near term forecasts for 2021-2023 follow capacity generation estimates from Citi's utility team for China, and BNEF's economic transition scenario for ex-China, both of which are based on current capacity plans and policy. From 2024, the base case for generation capacity transitions to the 2-degree pathway as set out in a central scenario by the Inter-governmental Panel on Climate Change (IPCC). 2024 and '25 assume a transition period before being fully on the 2-degree pathway 2026+. The required renewable capacity for the 2-degree pathway not built in 2021-2025 we assume gets made-up in 2025-2030.

Figure 61. Base Case annual capacity additions by type (Gw)…



Source: Citi Research, IPCC, BNEF, Wind

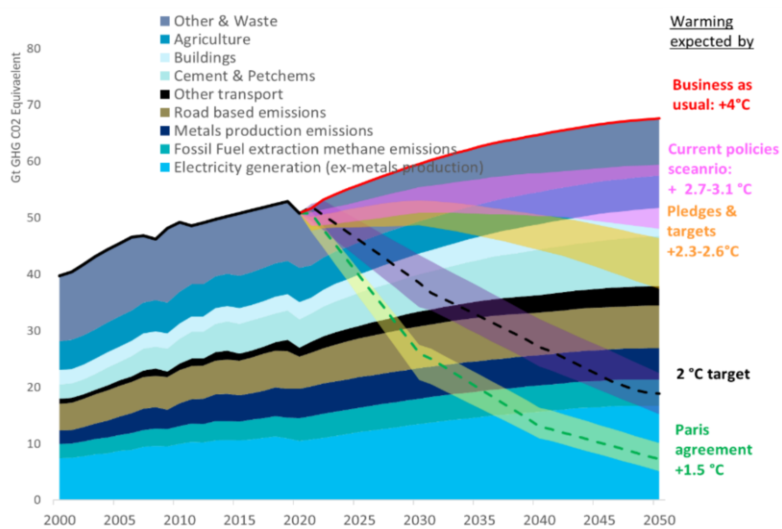
Figure 62. ..driving more than a doubling of the share of electricity generation from renewable sources by 2030



Source: Citi Research, IPCC, BNEF, Wind

The IPCC's latest report on climate change reinforces the need for imminent, rapid and large-scale action if humanity is to have a chance of avoiding above 2-degree levels of global warming. In this context, it is unsurprising that modelling a transition to a 2-degree pathway from 2024+ requires a steep jump in renewable capacity additions. Our own calculations in Figure 63 concur with this stark need. Emissions under a "business as usual" approach to the electricity generation and vehicles mix appear to put us on the path for almost double the levels of 'acceptable' warming. In fact avoiding this requires a steep jump in total electricity capacity additions overall given both the generally lower utilization by renewables (see below), and the expectation that the grid will grow its share as a source of energy, displacing oil in cars, and typically dirtier captive power.

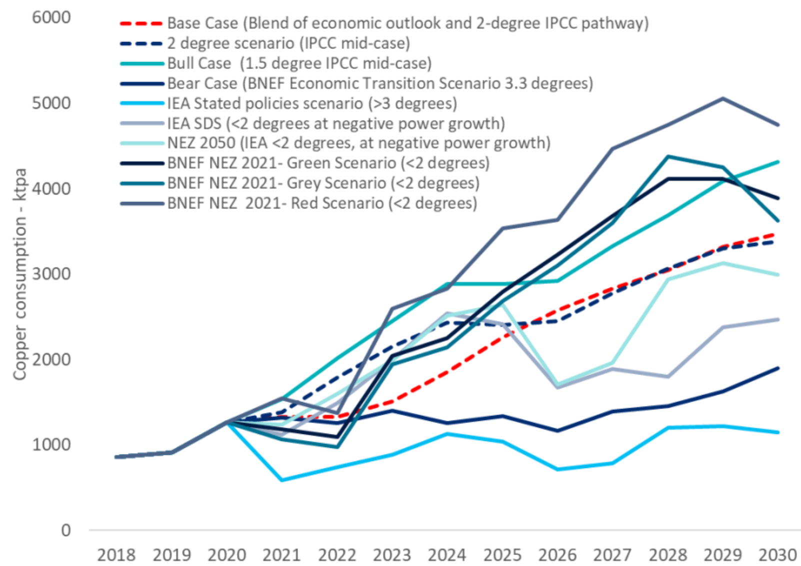
Figure 63. The scale of the challenge to sufficiently decarbonize is significant –requiring large scale capex and shift to renewable electricity generation



Source: Citi Research

There are many different routes to decarbonisation but we find that our base case 2-degree pathway for power generation is in fact a modest base case in copper terms compared to other agencies' scenarios (Figure 64). In this sense the risk to our copper demand numbers is to the upside (if the world is to indeed decarbonize), but we take comfort in being on the conservative side of estimates. The pathway in our base case implies lower copper consumption than BNEF's three scenarios for net zero by 2050 outlined in its *2021 New Energy Outlook* (also arriving at <2 degree warming). IEA's scenarios are incomparable in our view since they do not assume sufficient power growth. We have chosen this IPCC scenario as our base case from ~500+ IPCC for its ability to meet 2-degree emission targets within what we view as sufficient power growth and a reasonable mid-point on other drivers of decarbonisation such as renewable utilization and CCS installation.

Figure 64. Our base case 2-degree pathway for power generation comes out fairly "copper-efficient" compared to BNEF's net-zero pathways. Those scenarios with lower consumption either do not assume sufficient power growth in our view, or result in more warming (kt)



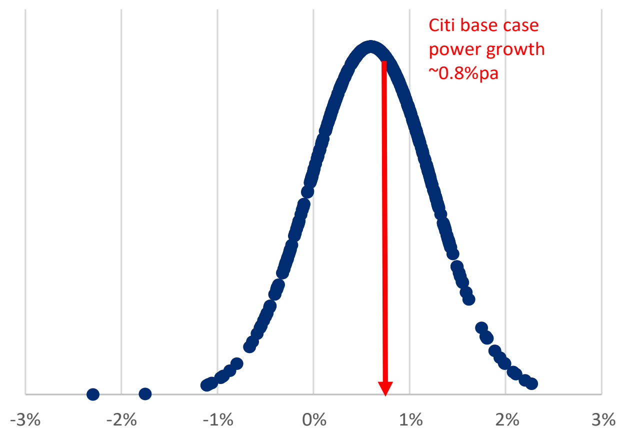
Source: Citi Research, BNEF, IPCC, IEA

Our bull case (~30% indicative probability) also shown in Figure 64 is consistent with a pathway towards the lower bound, 1.5 degree global warming target, of the Paris agreement. We again select a mid-point IPCC scenario consistent with economic variables of the base case (e.g total energy consumption growth). In this scenario, electricity generation consumes a cumulative 29Mt of copper in semi's 2022-30 and 4.3Mt in 2030 compared to 22Mt cumulative in the base case and 3.5Mt in 2030.

Our bear case (~10% indicative probability) assumes the electricity generation pipeline does not diverge from what current economics and policy supports, and is consistent with global warming above the Paris target of ~3.3 degrees. Specifically we model this scenario basis BNEF's economic-transition scenario which is modestly more copper intensive option than the IEA's stated policies scenario which implies similar levels of global warming.

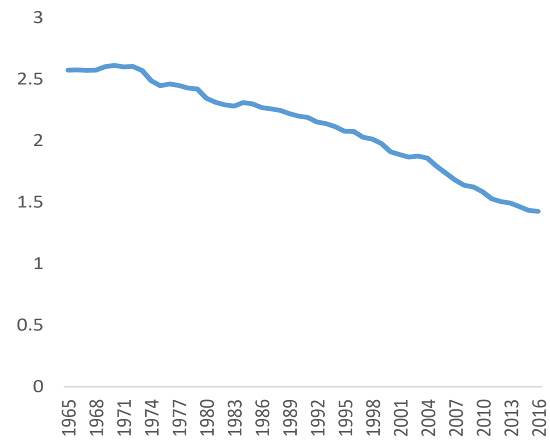
We strongly disagree with the 'copper light' decarbonisation scenarios that assume sub-par energy (power) consumption growth to achieve emissions targets. In our view this is akin to assuming falling economic growth whereas we assume ~0.8%pa energy consumption across all of our bull/bear/base cases. Figure 65 shows that this is around the central point of ~500+ IPCC scenarios and is in fact the assumption of BNEF, and the IEA's stated policies scenarios (but not its sustainable development or net-zero cases). This is about half the prior 10-year average of power consumption (2010-18), consistent with a plateau in heavy industry and rising efficiencies, but as Figure 66 makes clear the energy intensity of GDP is a long way from supposing a negative relationship in which power consumption falls while GDP stays positive. A +/- 0.1%pa assumed difference in power growth has a delta of ~290kt copper demand in 2030 according to our sensitivity analysis.

Figure 65. Our base case for long-term power growth, and therefore the required path for decarbonisation technologies, is about the mid-point of the distribution of 500+ IPCC climate scenarios…



Source: Citi Research, IPCC

Figure 66. ..This is consistent with a scenario where economic growth stays positive. Energy intensity of GDP may be falling but is a long way from negative (kwh per unit of GDP in 2011$)

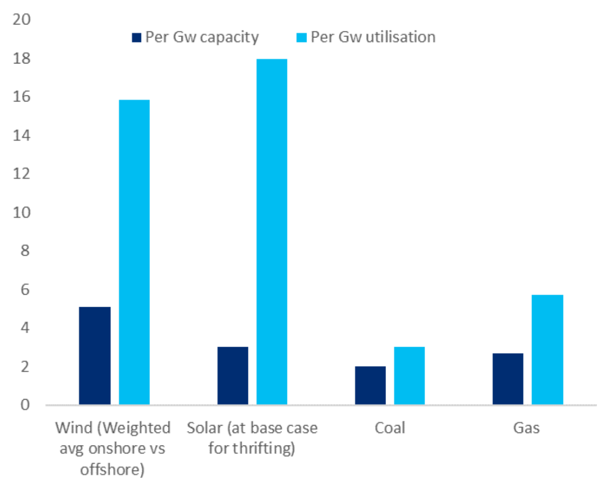


Source: Citi Research, WorldinData

The greater copper intensity of a renewables based grid is made clear in Figure 67 which considers both the higher copper intensity per Gw capacity, and per Gw of generation after accounting for lower utilization in the mainstream renewables; wind and solar. Wind capacity utilization is expected to average ~32% and solar ~17%, which lifts its respective 5.1kg/kw (weighted onshore/offshore average) and 3kg/kw (after forecast thrifting) copper-intensity to ~16kg/kw and ~18kg/kw on a generation basis. That is ~3-6x the equivalent copper per kwh of coal and gas generation in the case of solar, and ~3x in the case of wind.

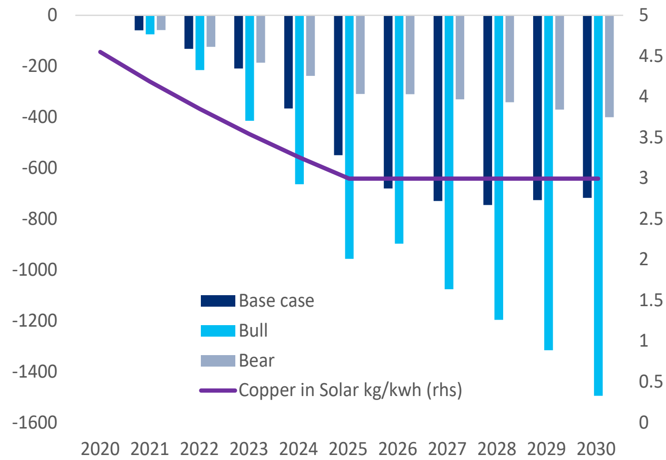
In line with industry feedback, our base case assumes that the copper content of solar capacity falls to 3.0kg/kw by 2025 from ~4.55kg/kw at present. Each kg/kw of incremental substitution would cost ~460kt (1.4%) of 2030 demand. According to BGRIMM, our 2030 estimates may even already be behind some of the substitution trend ongoing in China. They cite TBEA, China's largest solar power equipment supplier, claiming copper intensity in utility solar power installation has fallen to as low 1.12kg/kw due to aluminum PV wires being used in place of copper. Ex-China suppliers have likely been slower behind to substitute but we expect will move similarly given the cost advantages. Aluminum does carry greater risk of oxidization and as such is particularly less suited for solar use in damp or corrosive environments and equally its exposure to heat can lead to unwanted expansion. Alloying and protective coatings should be able to overcome this for many projects, however, as Chinese suppliers have already demonstrated.

Figure 67. After accounting for the lower utilization rates of renewables, particularly solar and wind, copper content is multiples of fossil fuels (even after assumed thrifting in solar) (tonnes)



Source: Citi Research

Figure 68. Solar thrifting impact on demand assumptions versus the counterfactual (kt)



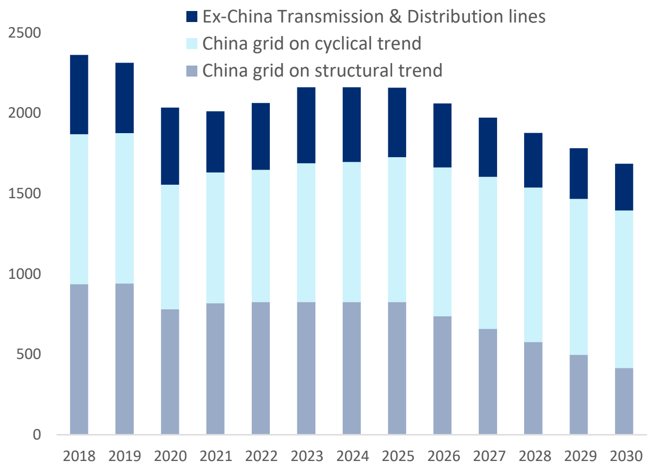
Source: Citi Research

A greater role for nuclear generation to achieve emissions targets seems to pose the greatest downside for copper consumption in electricity generation. As outlined in our sensitivities table each additional 1% role for Nuclear in electricity generation versus 9% in the base case would cost ~70kt of copper consumption since it displaces the need for more copper-intensive renewable capacity. Nuclear power has a much higher utilization than other renewables at ~80%+, meaning its copper content per generation works out ~4kg/kwh, not much higher than coal, and ~1/4 of gas and wind. Public opinion however would seem to make a much higher role for nuclear unlikely at this stage.

2. Non-decarbonisation grid demand

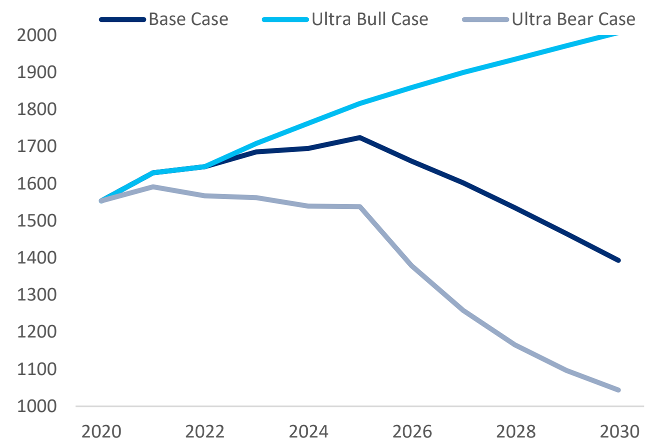
Our base case is a ~2% CAGR decline in non-decarbonisation grid demand between 2021-2030, (i.e. excluding electricity generation and energy storage). Principally this led by a decline in China from what we see as unsustainable levels. According to ICA data, copper consumption in the Chinese grid, outside of buildings and electricity generation, is ~3x the entire consumption by the same sector in ex-China! and ~6% of total global consumption. We model half of this huge consumption base as structural and set to decline ~50% by 2030 as growth in rural-connectivity hits a peak as does upgrading potential. Comparatively we expect the other half of the Chinese grid will follow cyclical trends, responding to rising electricity consumption and industry activity, and as such our forecasts are based on a cyclical-IP relationship.

Figure 69. Grid demand excluding power generation in China is ~3x all of ex-China combined (kt)



Source: Citi Research

Figure 70. Our base case assumes half of Chinese grid demand is in structural decline to ~50% of 2025 levels by 2030 (the other half grows with IP). Our ultra-bull/bear cases assume the non-cyclical half holds flat, or falls to ~25% of 2025



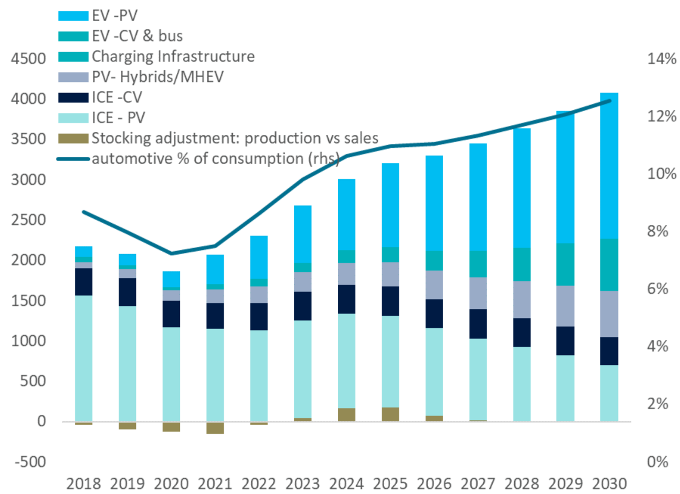
Source: Citi Research

3. Electric vehicles, charging, and other automotive

Our base case for 40% EV penetration by 2030 implies that copper consumption in the automotive market will grow ~9% CAGR 2021-2030; more than 3x the ~2.7% CAGR seen between 2012-2019. Demand is to be driven by higher copper content as the share of EV grows rather than total automotive production which market is forecast to grow at a more modest ~4% CAGR (commercial and passenger). In our base case for EV penetration, we forecast the average copper content of a passenger vehicle will grow to 37kg/unit from ~24kg currently. Our forecasts also include modest growth in commercial vehicles with ~25% electrification, and for growth in slightly more copper intensive hybrids that displace regular ICE.

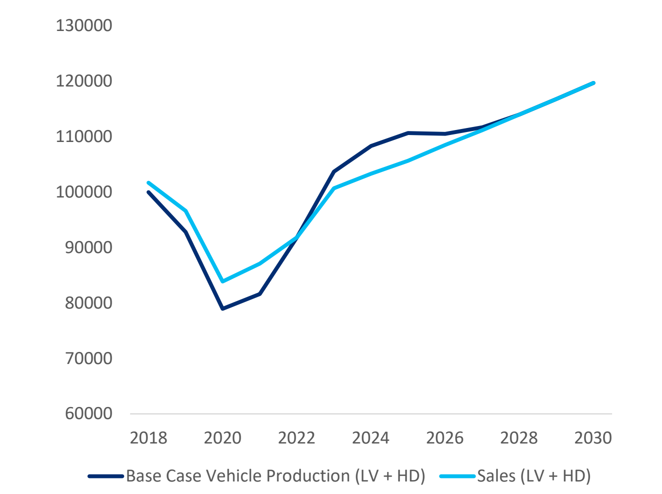
Once semi-conductor availability sufficiently improves, we expect automotive production, and with it copper demand, will outperform sales for a number of years in order to rebuild critical levels of inventory. In our base case this is worth a cumulative ~460kt of copper consumption in 2023-2027. A ~10M car destock during March 2020-August 2021 follows ~5.5M destocking during the 2018/19 trade war and is expected to reach a total ~17.5M by the end of 2022. Our base case is that most (~80%, ~14M) of the inventory will be rebuilt during 2023-2027. OEMs already report that critical stock levels at dealerships and the supply chain are too low operationally, and are a drag on sales so given the chip availability we expect they will target higher production to replenish inventories.

Figure 71. Autos copper consumption and share of total copper market consumption



Source: Citi Research

Figure 72. Automotive production is due to run ahead of sales to replenish inventories once semi-conductor chip availability improves



Source: Citi Research

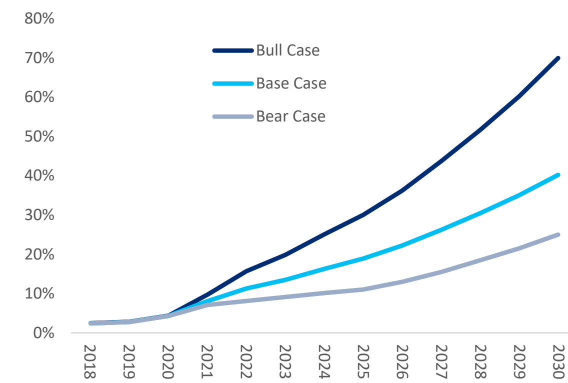
Our base case for electric vehicle penetration is ~40% by 2030; based on stated OEM targets, a ~50% penetration in China (consistent with our China autos team seeing 30%+ by 2025), and Tesla growing to a ~10% global market share (<1% currently) (Figure 73). Conversely, in our ~70% bull case we assume the higher end of OEM targets is replicated globally, and the US reaches Biden's target of ~50% EVs by 2030 compared to our base case ~40%. Our bear case of ~25% global penetration is less likely than the bull case in our view given recent EU sales are already rivalling these levels of penetration.

Figure 73. OEM Electrification targets imply a global share of 40% by 2030 (if not higher)

OEM	2030 Electrification Target	Ex-China market share	Implied EV share
VW group	50%	10%	5%
GM	*70%	6%	4%
Ford	100% in EU*	6% (EU)	2%
Toyota	*30%	15%	4%
Honda	66%	5%	4%
BMW	*40%	3%	1%
Volvo/Geely	100%	1%	1%
Mazda	100%	2%	2%
		58%	29%
		Tesla at 10% mkt share	10%
		All other at 5%	2%
		Ex-China	40%
		China	50%
* = estimate inferred from other targets		Global	43%

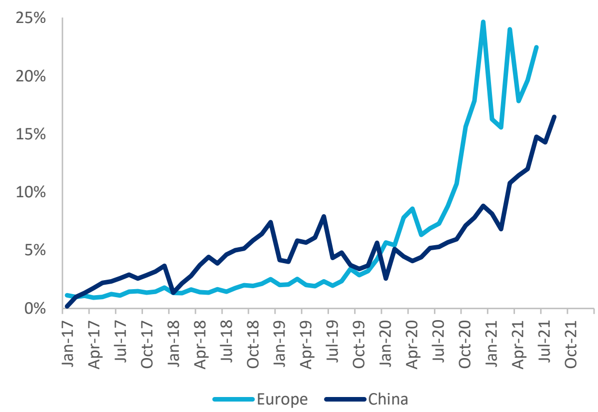
Source: Citi Research

Figure 74. Bull/Bear/Base Scenarios for EV demand



Source: Citi Research, BNEF, Wood Mackenzie,

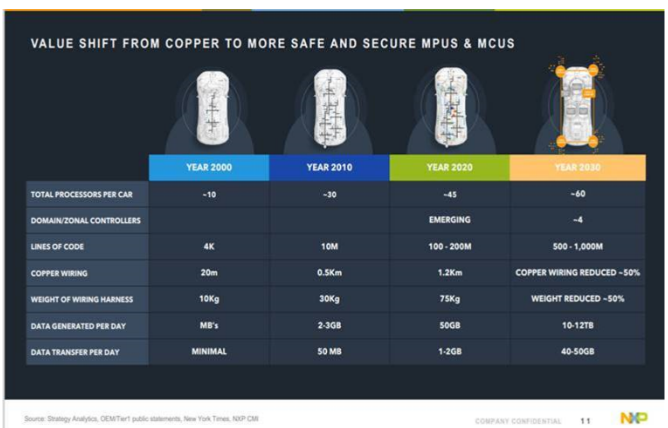
Figure 75. EU and China EV penetration has taken a material step up in 2021



Source: Citi Research, BNEF, NBS, Bloomberg

Consistent with industry feedback our analysis assumes a reduction in the copper intensity of electric vehicles from ~83kg in BEV's currently to ~60kg by 2030 and a reduction in PHEV copper content from ~60kg currently to ~40kg by 2030. Our base incorporates ~800kt of losses related to thrifting compared to the constant intensity assumption BNEF assumes (Figure 77). Each additional 10kg lost across BEV and PHEV's would reduce our base case 2030 copper consumption by ~1%.

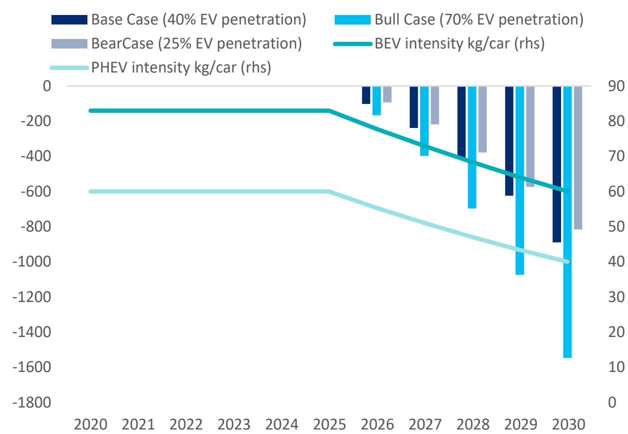
Figure 76. NXP estimates a ~50% reduction in copper wiring in EV's by 2030



	YEAR 2000	YEAR 2010	YEAR 2020	YEAR 2030
TOTAL PROCESSORS PER CAR	~10	~30	~45	~60
DOMAIN/ZONAL CONTROLLERS			EMERGING	~4
LINES OF CODE	4K	10M	100 - 200M	500 - 1,000M
COPPER WIRING	20m	0.5Km	1.2Km	COPPER WIRING REDUCED ~50%
WEIGHT OF WIRING HARNESS	10Kg	30Kg	75Kg	WEIGHT REDUCED ~50%
DATA GENERATED PER DAY	MB's	2-3GB	50GB	10-12TB
DATA TRANSFER PER DAY	MINIMAL	50 MB	1-2GB	40-50GB

Source: Citi Research, NXP

Figure 77. Impact of forecast level of thrifting in electric vehicles on copper consumption in the bull/bear/base case versus if copper intensity were constant (kt, kg/car)



Source: Citi Research,

Some particular risks to the long-term intensity of electric vehicles we would highlight include:

- **Reduced low-voltage connectivity wiring (impacting ~23kg of BEV-PHEV copper content) –** For example NXP (Figure 76), an OEM chip supplier, estimates a ~50% decline in copper wiring in EV's by 2030 as more localized semi-conductors should allow OEMs to massively simplify the amount of connectivity points across the car body.

- **Reduced battery foil thickness (impacting ~30kg of BEV, ~15kg of PHEV) -** Copper foils typically vary between 6 µm to 20 µm and usage in EV's has so far averaged around the 10 µm mark; leaving room for reduction. Foil makers are now reportedly boosting supply of thickness' even sub 6 µm for the EV industry (see link).

- **Copper free battery technology (impacting ~40kg of BEV, ~20kg of PHEV) –** Graphene-Aluminum-ion batteries are one example being pursued by the University of Queensland with a battery pack solution that has copper completely absent from the anode (see link), as well as boasting high energy density and thermal stability. This particular technology is aiming for commercial roll out in 2024. It would be unlikely to dominate near term but any share this technology, or similar, takes could bring down the global average copper-content in EV's.

- **Alternative motors and aluminum substitution (impacting up to ~5kg).** EV's are already dominated by Permanent Magnet Motors 'PMM' (~75% of total), which are typically half as copper intensive as their AC Induction Motor 'IM' peers. Lower levels of efficiency for IM will likely continue to see its share falling. Scarcity of rare earths for PMM magnets, as well as light weighting, may see even less copper intensive designs take share also in the future. Bentley is for example pursuing an aluminum alternative aimed at completely removing the copper windings currently used (link).

Figure 78. Base case copper consumption in autos to 2030 (kt)

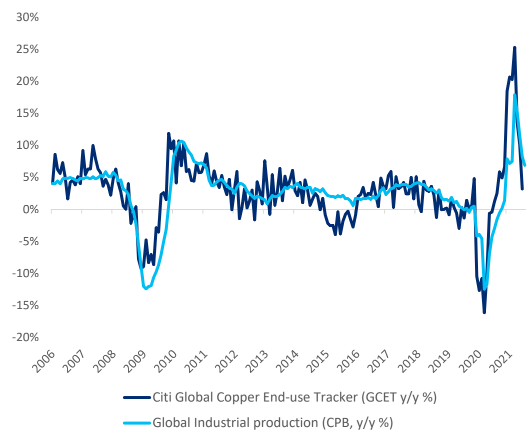
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total copper consumption net of internal scrap	**2145**	**1981**	**1754**	**1942**	**2258**	**2660**	**2978**	**3180**	**3291**	**3449**	**3641**	**3849**	**4079**
Copper consumption including scrap	2592	2386	2113	2339	2720	3203	3587	3830	3963	4153	4384	4636	4913
Of which internal scrap generation (~17%)	447	405	358	397	461	543	608	650	672	705	744	787	833
Base Case Vehicle Production (LV + HD)	**100,011**	**92,844**	**79,055**	**81,335**	**89,243**	**101,170**	**107,826**	**110,259**	**110,428**	**111,654**	**113,977**	**116,787**	**119,663**
Sales (LV + HD)	101,711	96,644	83,955	86,835	90,743	99,670	102,826	105,259	108,428	111,154	113,977	116,787	119,663
Stocking adjustment (M cars)	**-1.7**	**-3.8**	**-4.9**	**-5.5**	**-1.5**	**1.5**	**5**	**5**	**2**	**0.5**	0	0	0
Average intensity of passanger vehicles (kg/unit)	**25**	**25**	**26**	**28**	**30**	**31**	**32**	**34**	**35**	**35**	**36**	**37**	**37**
Contained copper in stocking changes	**-43**	**-95**	**-127**	**-154**	**-45**	**47**	**160**	**170**	**70**	**18**	**0**	**0**	**0**
Copper consumption in vehicle sales	**2634**	**2481**	**2240**	**2493**	**2765**	**3157**	**3427**	**3660**	**3893**	**4136**	**4384**	**4636**	**4913**
EV -Passanger vehicles	157	172	229	442	642	854	1058	1259	1423	1611	1793	1978	2181
EV -Commercial vehicles	71	54	39	60	85	106	142	165	216	282	367	465	592
Charging	2	6	6	17	26	37	50	61	83	105	131	161	193
Hybrid & MHEV	96	131	158	207	253	290	327	365	425	485	549	617	689
ICE - Passanger vehicles	1879	1720	1412	1380	1360	1456	1416	1373	1307	1213	1108	989	847
ICE - Commercial vehicles	407	423	396	387	399	414	433	436	439	439	436	427	411
Base Case autos Passanger Vehicle unit sales ('000)	86,956	81,362	69,646	72,758	76,108	84,340	86,531	88,623	91,251	93,412	95,553	97,773	100,073
Of which EV	2,045	2,218	2,992	5,870	8,548	11,361	14,081	16,758	20,261	24,494	29,076	34,237	40,276
BEV	1,479	1,702	2,154	3,900	5,604	7,479	9,282	11,033	13,428	16,534	19,981	23,893	28,480
PHEV	566	517	839	1,970	2,944	3,882	4,799	5,725	6,832	7,960	9,095	10,345	11,796
EV penetration	2.4%	2.7%	4.3%	8.1%	11.2%	13.5%	16.3%	18.9%	22.2%	26.2%	30.4%	35.0%	40.2%
Hybrid	3,210	4,381	5,277	6,890	8,447	9,674	10,907	12,176	14,153	16,166	18,292	20,554	22,957
Regular ICE	81,702	74,763	61,376	59,998	59,113	63,305	61,544	59,689	56,838	52,752	48,185	42,982	36,840
EV copper content													
BEV Kg/ unit	83	83	83	83	83	83	83	83	78	73	68	64	60
PHEV kg/unit	60	60	60	60	60	60	60	60	55	51	47	43	40
Hybrid & MHEV kg/unit	30	30	30	30	30	30	30	30	30	30	30	30	30
Commercial Vehicles Sales ('000)	**14756**	**15282**	**14309**	**14078**	**14635**	**15330**	**16295**	**16636**	**17176**	**17743**	**18424**	**19014**	**19589**
China	3876	3850	4681	4257	3981	3969	4124	4230	4327	4477	4731	4845	4933
Ex-China	10879	11432	9629	9821	10654	11361	12171	12405	12849	13266	13692	14170	14657
Electric commercial	222	189	164	240	393	562	816	1,062	1,482	2,064	2,835	3,779	4,897
EV penetration	1.5%	1.2%	1.1%	1.7%	2.7%	3.7%	5.0%	6.4%	8.6%	11.6%	15.4%	19.9%	25.0%

Source: Citi Research, I.H.S, BNEF, Wood Mackenzie,

4. Other non-decarbonisation demand

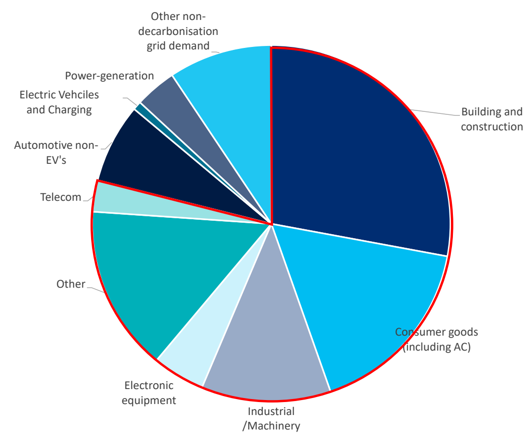
The relationship between copper demand and industrial-production is well known and is expected to continue to dominate the trend among the largest ~70-80% share of copper consumption not covered in #1-3 above. This correlation is not going away although its relationship may mature as we discuss below. Indeed it is hard to think of much industrial activity that does not involve copper and Figure 80 demonstrates the broad spread of the end-uses within this "other" segment which straddles all corners of the global economy.

Figure 79. The Global Copper End-Use Tracker Closely follows IP



Source: Citi Research, ICA, Bloomberg, Wind

Figure 80. Copper consumption by sector (2019), "other" non-decarbonisation sectors highlighted in red



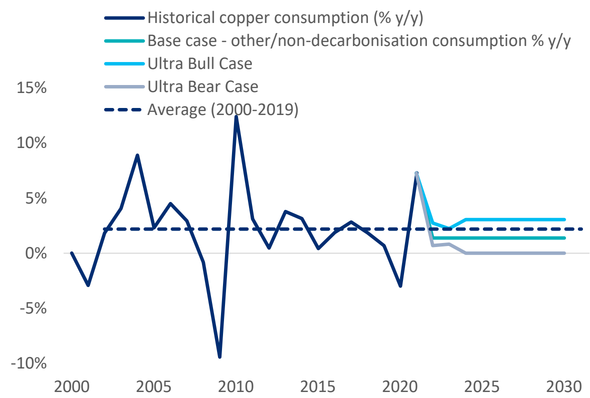
Source: Citi Research, ICA

This large segment is therefore likely to keep copper highly cyclical but relatively less than before since demand from decarbonisation sectors (which is counter-cyclical according to policy to avoid global warming) should increasingly serve as a buffer in down-cycles, and support higher overall demand CAGRs. As shown earlier, IP remains the most sensitive variable for copper consumption with a +-1% p.a. in IP ('23-30) calculated to drive +3.3% in 2030 consumption. This is in fact a light estimate since we have also pointed that consumption remains highly sensitive to other key economic variables such as total energy consumption (linked to GDP), and that changes in the gross size of the automotive market (linked in part to broader consumer spending) can outsize the impact of EV penetration.

Our base case is that the elasticity between copper and industrial production however will decline by 2025 to about 60% of its prior 2000-19 average; taking growth in these 'other' sectors to just over half trend ~1.3% '25-'30. Specifically we model the intensity in consumption: IP falling to ~0.58x from a 200-19 average of ~0.98x and 0.8x in the last 5-years ('17-'21). The IP intensity was elevated in 2021 to an 8-year of ~1.3x high of due to shifting consumption patterns but is expected to normalize as spending patterns gradually shift back to a more equal services mix.

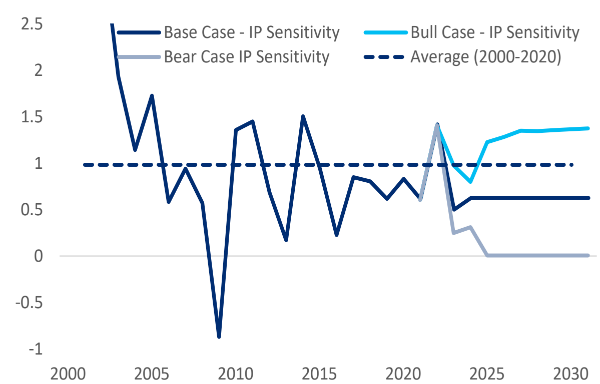
A falling elasticity makes sense in our view owing to some faster maturing end-use sectors such as building and construction, as well as substitution for other materials at high prices. The building and construction sector is the largest share of the "other" segment estimated at ~28% of total consumption in 2021 and ~10% from China specifically. China's falling urbanization impulse is well known (see the bulks book) and is expected to become a drag on consumption in building and construction in the latter part of the decade. Construction activity will also likely taper off in certain other EM's as it has already matured in much of the DMs.

Figure 81. Our base case assumes the other cyclical sectors decline to about half trend demand growth



Source: Citi Research

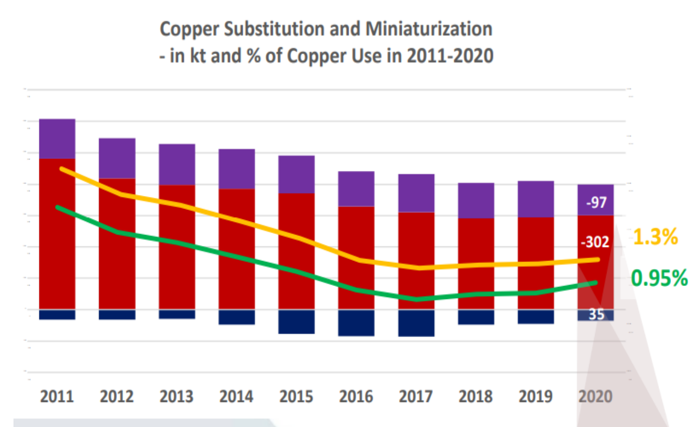
Figure 82. This is also consistent with the IP-intensity of the sector falling to about 60% its long term average



Source: Citi Research

Substitution at high prices will likely also ebb into copper's IP-elasticity. Analysis conducted by the ICA (link) suggests the last time copper reached ~$9-10k/t in 2011 substitution was ~200kt higher than present (Figure 83). Cumulative repeats of such large scale substitution likely lie ahead given that prices have not lingered above $9k/t for as long a period of time as our average forecasts suggest. An additional 200ktpa substitution from 2021-30 would account for ~80% of the difference between our base case forecasts for 'other' sectors consumption in 2030 compared to if it were to grow the 20 year average intensity of our IP forecasts.

Figure 83. The last time copper reached 9-10k/t substitution was around 200kt higher than it was in 2020



Source: Citi Research, DMM Advisory, ICA

Our 'ultra bear case' is that copper consumption falls to 0% from 2025+ due to substitution. This would most likely be due to ongoing high prices and a squeeze on supply from rapid decarbonisation. The ultra-bear case in which this occurs alongside low decarbonisation demand is therefore given a very low 5% indicative probability but the odds of this happening at higher prices are greater.

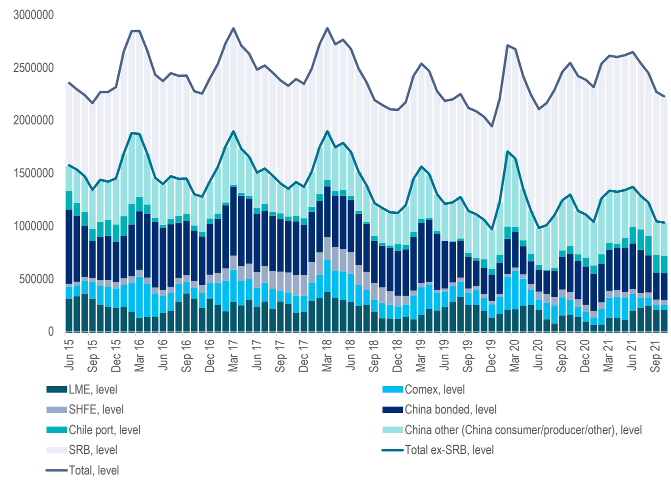
Evidence of substitution at high prices is growing. The largest recent public example being in air-conditioning with Daikin targeting a ~40kt reduction in

copper content by '23-25, in favor of aluminum (link). This will commence with ~50% reduction in its Japanese copper consumption targeted by the end of FY'23/24, with a similar scale reduction aimed globally by FY25.

Box B: Inventories and convenience yields

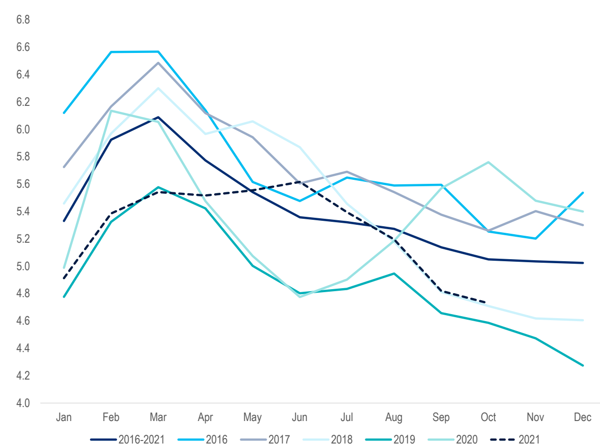
Our judgement is that copper inventories are ample (please see Figures 84-87), based on the available inventory data together with the information contained in LME and Comex implied convenience yields (the price that inventory financiers are paying to hold physical metal). At a touch over 1mt excluding China SRB stocks (2.2 weeks of consumption), and over 2.2mt including estimates of SRB inventories (4.7 weeks of consumption); refined inventories appear ample, albeit recently falling towards the lower end of their 6 year range.

Figure 84. Refined copper inventories appear to be ample…



Source: Citi Research

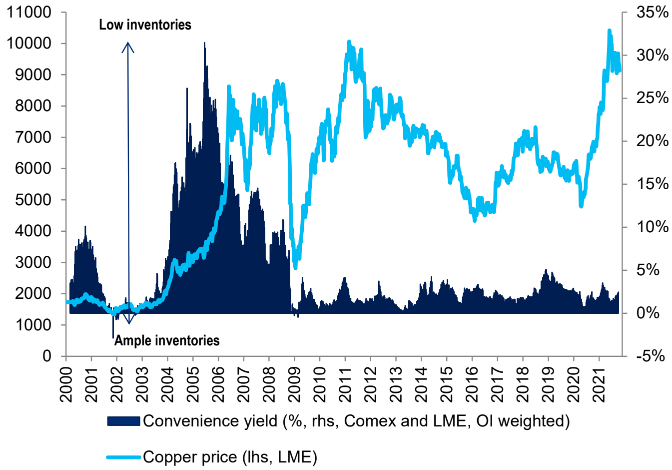
Figure 85. …albeit around the lower level of their 5-6 year range relative to consumption



Source: Citi Research

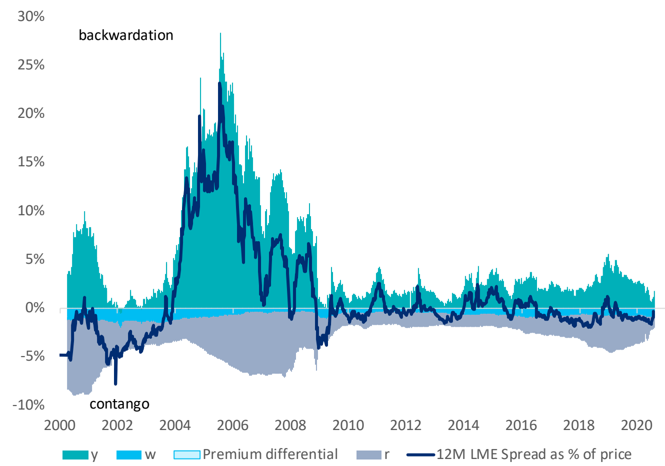
Our estimate of the price that traders, banks, and other financiers are willing to pay to hold off-exchange physical copper – the convenience yield – based on LME and Comex spreads, suggests that there is no tightness in the refined copper market at present (please see Figure 86). Convenience yields remain low, as they have been for the past decade, and we do not see this changing over the next 3-6 months. We note that while most of the variation in convenience yields reflects changes in copper spreads, interest rate changes over time can also be important in helping decipher whether copper spreads are truly signally a tightening or lessening market. Please see *Appendix I: Inventories, curve shape, and convenience yields, the theory* for details.

Figure 86. Convenience yields have pointed to a loose refined copper market for well over a decade now



Source: Citi Research

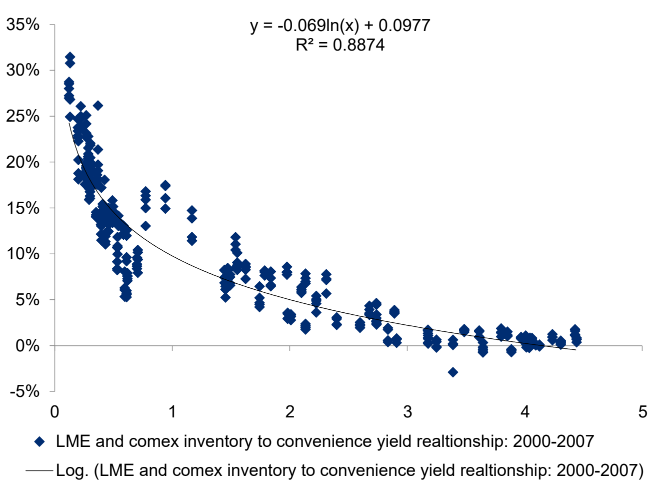
Figure 87. Copper convenience yield decomposition – most of the volatility is driven by spreads



Source: Citi Research

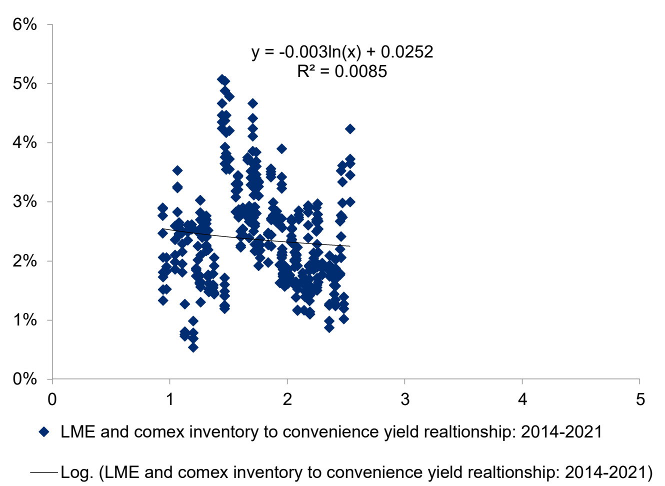
We highlight that refined copper inventory visibility has deteriorated markedly over the past decade, with LME and Comex inventories almost uncorrelated with implied convenience yields. Indeed, the relationship between LME and Comex exchange-implied convenience yields and trackable inventories weakened from an r-square of 0.88 during the 2000-2007 period to an r-square of 0.01 since 2014 (please see Figures 88 and 89 and 90 below). **This partly reflects LME warehouse rule changes, and trade houses becoming trader/producers, which has tilted market competitiveness in favor of off-market storage at the expense of on-exchange storage and visibility.**

Figure 88. Exchange copper inventories correlate especially well with the convenience yield from 2000-07 (y axis = y -copper convenience yield, x-axis = trackable stocks in weeks of use)



Source: Citi Research

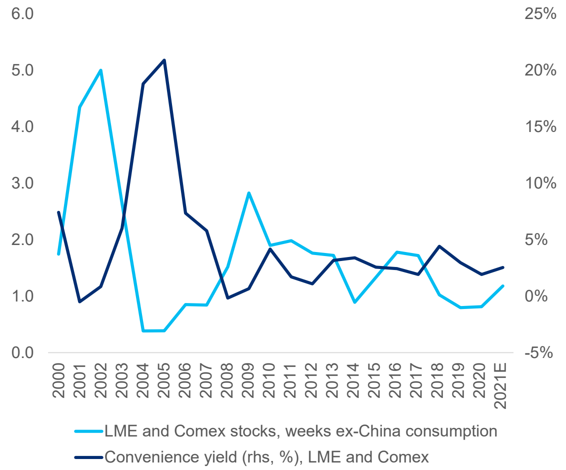
Figure 89. Post the LME warehouse rule changes in 2013/14 the relationship between exchange inventories and exchange convenience yields deteriorates significantly (2014-21)



Source: Citi Research

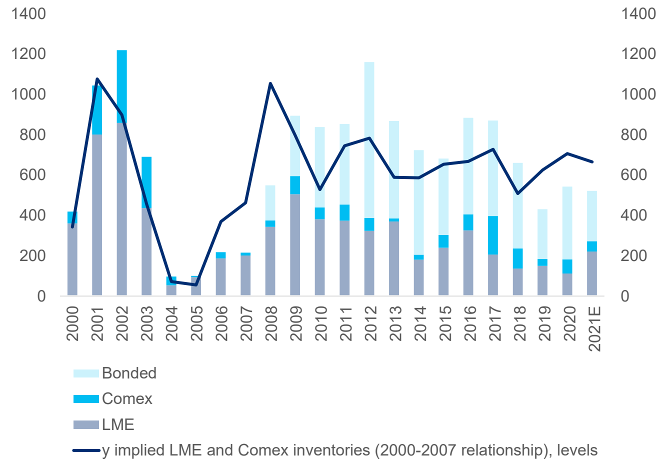
To help to gauge off market stocks (at least those hedged or priced into LME and Comex spreads), we can use the historical 2000-2007 relationship (Figure 88). Here we find that, even after accounting for bonded inventories, there is likely to be around 150-200kt of off-exchange stock outside of China. Since we know convenience yields have a theoretically and empirically robustly convex relationship with inventories we can imply off-exchange stocks (hedged on LME) using the historical relationship, with the results shown in Figure 91 below. By comparing this to LME, Comex, and Bonded stocks (these seem to explain much of the wedge since 2008 well), we can get a potential sense as to off market stocks.

Figure 90. The relationship between LME and Comex stocks and implied convenience yields has broken down over the past decade



Source: Citi Research

Figure 91. Since we know convenience yields have a theoretically and empirically robustly convex relationship with inventories we can imply off-exchange stocks (hedged on LME) using the historical relationship



Source: Citi Research

Refined inventories tend to be the focus of the market, since exchange prices reflect the price of refined metal located in an exchange warehouse. However, copper inventory comes in a variety of forms, including concentrate, blister, scrap, refined, semi-fabricated products for fabricated product. Changes in supply chain inventories are important for copper pricing, since inventory exposure to copper is often hedged on one of the major exchanges (LME, Comex, SHFE).

Mine supply outlook

The outlook for mine supply growth is for it to trend to above trend growth over the next 2 years, before growth slows sharply during the second half of the decade. We provide details of our mine supply forecasts in this section, beginning with the nearer term outlook (2021F-2023F) which depends on baseline mine supply and projects already under construction, and subsequently the long run outlook (2024F-2030F), which depends heavily on projects not presently under construction.

Mine supply growth to accelerate near term

Mine supply growth is set to pick up over the next 2 years, to around trend at 2.4% in 2022, and to above trend rates of 3.9% in 2023 (Figure 92). We see higher output coming from a variety of countries, though the DRC, Peru and Indonesia are the ones to watch (Figure 93), accounting for 34%, 27%, and 12% of the growth by country over the 2021-2023 period (please see Figure 94).

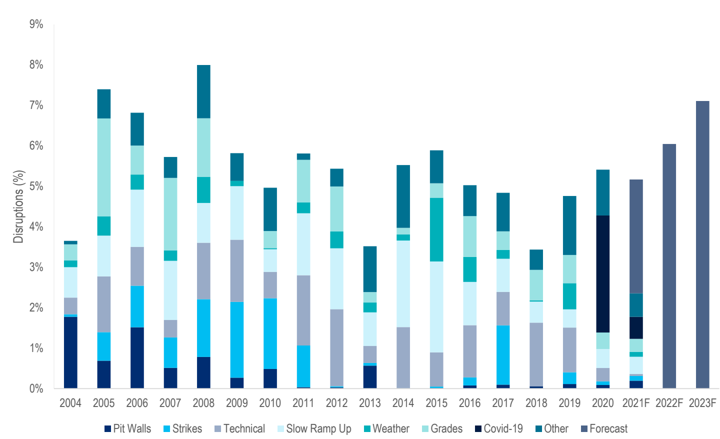
Figure 92. Copper mine supply growth by mine/project, 2021F-2023F

Mine	Country	2021F	2022F	2023F	2023F-2021F	Share of growth
Kamoa-Kakula	Congo DR	86	188	326	**240**	**18%**
Quebrada Blanca	Chile	0	19	223	**223**	**16%**
Quellaveco	Peru	0	19	186	**186**	**14%**
Grasberg	Indonesia	587	712	704	**117**	**9%**
Escondida	Chile	863	957	973	**109**	**8%**
Udokan	Russia	0	48	104	**104**	**8%**
Mutanda SxEw	Congo DR	0	47	93	**93**	**7%**
Timok	Serbia	20	94	112	**92**	**7%**
Qulong	China	20	66	84	**64**	**5%**
Spence	Chile	280	324	336	**56**	**4%**
Batu Hijau	Indonesia	98	151	150	**52**	**4%**
Aktogay	Kazakhstan	98	122	140	**8**	**1%**
Subtotal		2052	2747	3429	**1344**	**99%**
Other		19102	18914	19085	**16**	**1%**
World total		**21154**	**21662**	**22514**	**1360**	**100%**

Source: Citi Research, Company Reports

With respect to our near term disruption allowance forecasts, we assume an overall disruption allowance of 6.0% for 2022, and 7.1% for 2023 (please see Figure 96). The forecasts are at the upper end of historical ex-post ranges, in part to reflect the likely impact of COVID-19 and sustaining capex cuts on future output. The high appearance of the 2023 forecast supply disruption allowance owes to the fact disruptions as a share of forecast output tend to be higher the further away the forecast year is. Further, there is quite a high share of new projects ramping up in that year, meaning higher risk to supply than would normally be the case.

Figure 93. Historical and forecast mine supply disruption allowances (% forecast supply)



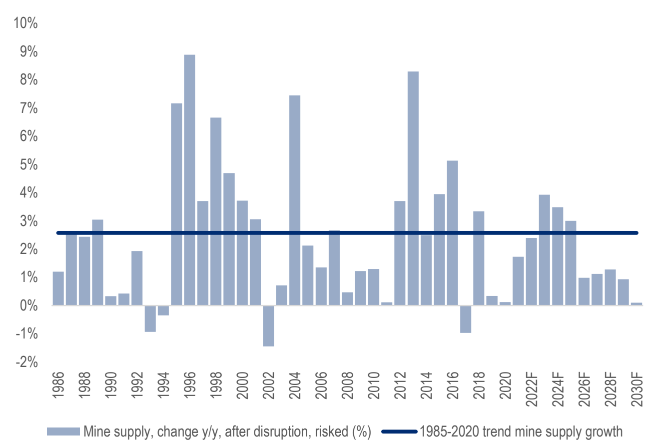
Source: Citi Research

Mine supply growth looks challenged longer term

Though the near term outlook for mine supply growth looks solid, the long term outlook for mine supply growth looks much weaker (please see Figures 94-97**).** After de-risking over 250 copper projects, we find that the net increase in supply is less than 4mt between now and 2030, taking mine supply from 21.1mt in 2021F to 25.0mt in 2030F (this around 1.7%p.a. or, two-thirds of long-term trend mine supply growth of ~2.5%p.a). The 3.9mt net increase in mine supply over the next decade (after de-risking, after disruption allowance, before smelting and refining losses) reflects a 4.0mt increase in possible project supply, a 1.7mt increase in probable project supply, less a 1.8mt decrease in baseline supply.

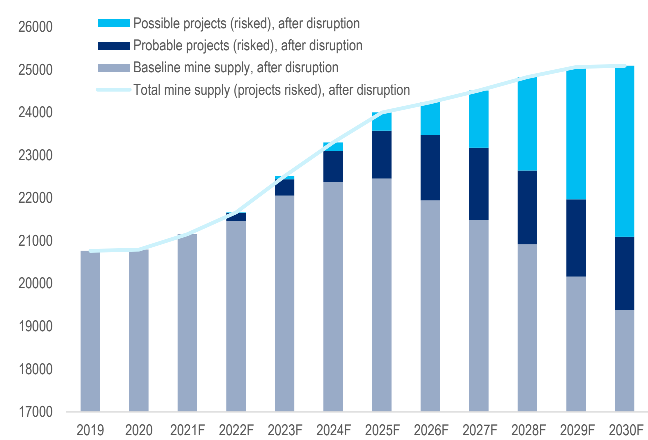
With lead times from project approval to production around 4-6 years, decisions need to occur soon for their not to be a major leg down in supply growth during the middle part of this decade. In the second half of the decade mine supply growth is set to be growing at only one-third of trend (0.9%p.a).

Figure 94. After a period of solid mine supply growth in the nearer term, we project a major slowing in supply growth in the second half of the decade



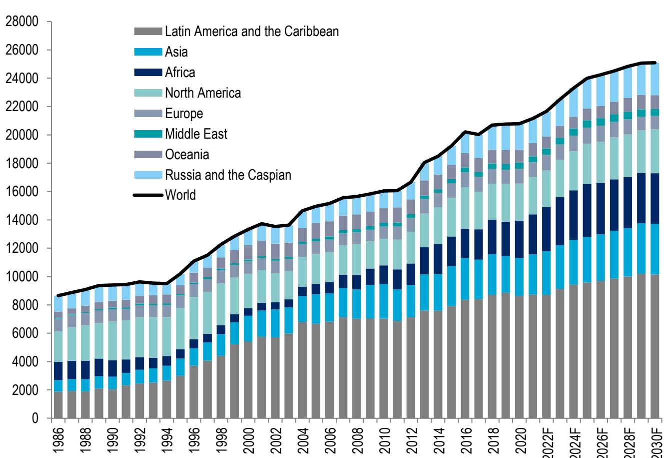
Source: Citi Research

Figure 95. We forecast only a modest net increase in copper supply over the next decade, with supply growth increasingly depending on a long list of possible (but often more challenging) projects



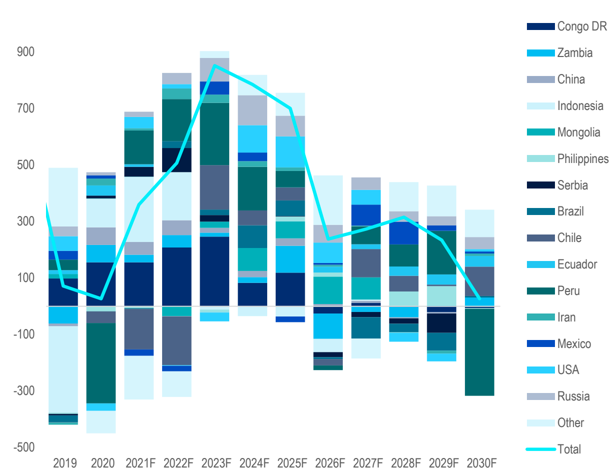
Source: Citi Research

Figure 96. Copper mine supply by country ('000t)



Source: Citi Research

Figure 97. Supply growth is driven by a small number of countries in the near term, but this broadens during the second half of the decade



Source: Citi Research

A broader range of countries will likely drive net mine supply growth over the medium to long term, compared to the small range of countries driving growth in the near term (please see Figures 97 and 98). This partly reflects the nature of how we put together the mine supply forecasts, de-risking all of the projects on a case-by-case basis. This also reflects the fact that copper projects are getting more difficult to find and so miners may need to bring on projects in relatively undeveloped copper mining countries, such as Ecuador, Argentina, Panama, and Serbia. For details of some of the major baseline and de-risked projects contributing to growth by country, please see Figure 99 below.

Figure 98. Copper mine supply growth by country, 2021F-2030F

kt		2021F	2023F	2030F	2030F-2021F	2030F-2023F	Growth share 2023F-2030F
Latin America		**8716**	**9120**	**10147**	**1431**	**1027**	**40%**
of which:	Argentina	0	0	373	373	373	14%
	Chile	5678	5662	6003	325	341	13%
	Peru	2285	2654	2837	552	183	7%
	Ecuador	59	56	201	142	145	6%
Asia/Middle East		**3265**	**3587**	**4072**	807	**485**	**19%**
of which:	Mongolia	301	289	606	305	317	12%
	Phillipines	50	40	191	141	151	6%
	China	1590	1659	1716	126	57	2%
	Iran	352	419	458	106	39	2%
North America		**2622**	**2622**	**3097**	**475**	**475**	**18%**
of which:	US	1344	1328	1609	265	281	11%
	Mexico	748	774	973	225	199	8%
CIS/Capsian		**1740**	**1873**	**2291**	**551**	**418**	**16%**
of which:	Russia	867	990	1387	521	397	15%
Africa		**2834**	**3379**	**3566**	732	**187**	**7%**
of which:	DRC	1791	2247	2414	623	167	6%
	Zambia	875	933	939	64	6	0%
Oceania		**925**	**839**	**976**	**51**	**137**	**5%**
of which:	Australia	856	746	682	-174	-63	-2%
Europe		**1052**	**1094**	**946**	**-106**	**-148**	**-6%**
of which:	Serbia	90	199	78	-12	-121	-5%
Total after disr (incl all projects)		**21154**	**22514**	**25095**	**3941**	**2581**	**100%**
Mine supply growth (p.a.)					**1.7%**	**2.2%**	
of which: disruption allowance		432	1394	2211			
of which: disruption allowance (%)		2%	6.0%	8.1%			

Source: Citi Research

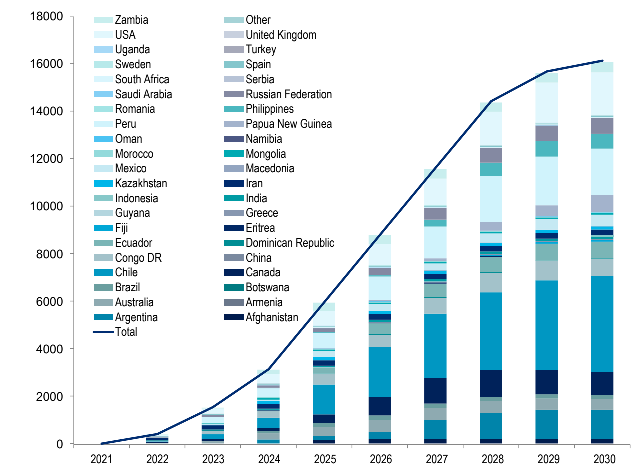
Figure 99. Major baseline and de-risked projects contributing to growth by country, after disruption allowance, 2023F-2030F

Country	2030F-2023F 000t	2030F-2023F Growth share	Main baseline drivers	Main (risked) project drivers
Russia	397	15%	Udokan, Norilsk, Tominsky	Baimskoye, Malmyzh, Ak Sug
Argentina	373	14%	-	Josemaria, Taca Taca, Los Azules, El Pachon
Chile	341	13%	Mantoverde, Spence	Centinella Mill, Escondida OGP 2
Mongolia	317	12%	Oyu Tolgoi	-
US	281	11%	-	Bagdad Exp, Rosemont, Ann Mason, Pumpkin Hollow Open Pit
Mexico	199	8%	-	El Arco, Bahuerachi, San Nicolas
Peru	183	7%	Quellaveco	List >10 incl. Michiquillay, Canariaco Norte, Coroccohuayco, Zafranal, Tia Maria etc
DRC	167	6%	Dikuluwe-Mashamba	Kamoa-Kakula Exp, Dezia Exp
Phillipines	151	6%	-	Tampakan, Kingking
Ecuador	145	6%	-	Cascabel, Mirador Exp
China	57	2%	Qulong	-
Iran	39	2%	-	Darhezar, Taft
Subtotal	2252	87%		
Others	329	13%	Glogow Gleboki Przemyslowy, Almalyk, Carrapateena	Golpu, Ak Sug, Casino
Total change	**2581**	**100%**		

Source: Citi Research

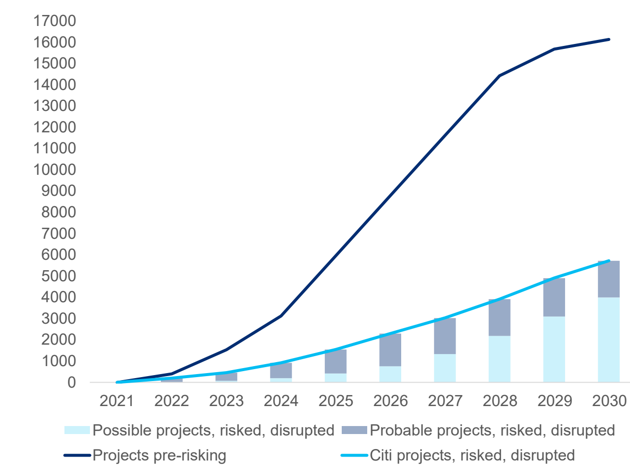
Looking more deeply at the project pipeline, we can see that there is no shortage of copper projects on paper, but when one goes through the list, less than a third are likely to come online before 2030, on a de-risked and disrupted basis (please see Figures 100 and 101). We have risked projects adding to supply across 32 countries, with the top 5 countries accounting for 60% of project supply growth (Chile, Peru, US, Russia and DRC) and the top 10 representing 83% growth (please see Figure 102). Many of these projects are to replace baseline mine losses, though they nevertheless require sanctioning and investment.

Figure 100. Copper projects everywhere…



Source: Citi Research

Figure 101. …but very few are likely to be delivered



Source: Citi Research

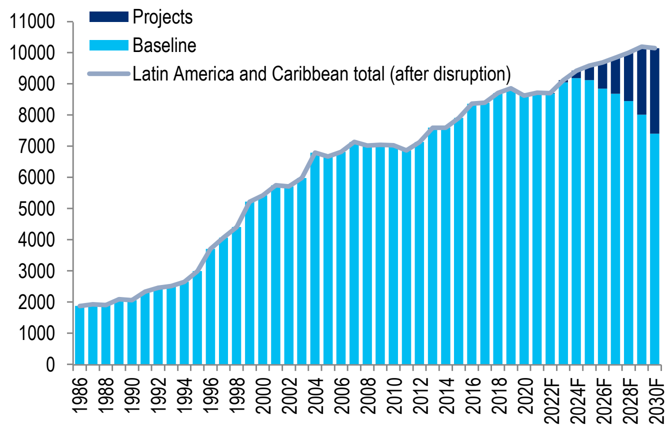
Figure 102. Projects by country, after risking and after disruption allowance

	Projects by country	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Share of 2030	Cumulative
1	Chile	0	0	0	39	88	235	404	643	923	1119	**19.0%**	**19.0%**
2	Peru	0	5	51	118	243	321	424	546	883	1060	**18.0%**	**37.0%**
3	Congo DR	0	32	60	109	204	236	315	355	429	468	**7.9%**	**44.9%**
4	USA	3	50	84	167	220	287	370	456	463	461	**7.8%**	**52.7%**
5	Russian Federation	0	0	28	84	119	181	241	281	364	406	**6.9%**	**59.6%**
6	Argentina	0	0	0	0	0	127	184	199	283	385	**6.5%**	**66.1%**
7	Mexico	0	1	19	34	34	48	126	223	283	304	**5.2%**	**71.3%**
8	Canada	0	9	18	39	38	59	53	137	210	268	**4.6%**	**75.8%**
9	Papua New Guinea	0	0	0	0	9	40	65	181	226	205	**3.5%**	**79.3%**
10	Zambia	0	6	15	45	140	121	147	148	162	191	**3.2%**	**82.5%**
11	Australia	0	0	16	30	67	145	184	186	175	175	**3.0%**	**85.5%**
12	Philippines	0	0	0	0	17	31	31	86	162	155	**2.6%**	**88.1%**
13	Ecuador	0	0	0	0	0	21	38	72	112	148	**2.5%**	**90.6%**
14	Iran	0	49	81	102	112	117	118	117	110	116	**2.0%**	**92.6%**
15	Brazil	0	0	0	59	111	120	112	104	96	95	**1.6%**	**94.2%**
16	Afghanistan	0	0	0	0	0	0	0	0	61	77	**1.3%**	**95.5%**
17	Kazakhstan	0	0	0	31	35	35	35	35	48	51	**0.9%**	**96.4%**
18	Greece	0	0	0	0	5	18	33	32	30	31	**0.5%**	**96.9%**
19	Dominican Republic	0	12	23	23	25	26	26	26	24	25	**0.4%**	**97.3%**
20	Morocco	0	0	0	0	7	18	26	26	23	22	**0.4%**	**97.7%**
21	Spain	0	0	0	0	9	20	22	22	20	21	**0.4%**	**98.1%**
22	India	0	0	0	0	1	5	10	16	18	20	**0.3%**	**98.4%**
23	South Africa	0	0	0	0	8	18	18	18	18	18	**0.3%**	**98.7%**
24	Sweden	0	0	0	0	9	18	17	17	16	17	**0.3%**	**99.0%**
25	Macedonia	0	0	0	11	17	17	16	16	15	15	**0.3%**	**99.3%**
26	Eritrea	0	13	35	19	18	31	42	33	14	13	**0.2%**	**99.5%**
27	Oman	0	0	0	0	9	18	17	17	16	9	**0.1%**	**99.6%**
28	Turkey	0	5	7	6	5	4	8	9	7	8	**0.1%**	**99.8%**
29	Uganda	0	0	0	0	4	5	7	7	6	7	**0.1%**	**99.9%**
30	Romania	0	0	0	0	3	6	6	7	4	5	**0.1%**	**100.0%**
31	Guyana	0	0	0	6	5	4	2	2	2	2	**0.0%**	**100.0%**
32	Portugal	0	18	27	18	13	11	0	0	0	0	**0.0%**	**100.0%**
	Total	**3**	**199**	**466**	**939**	**1575**	**2341**	**3097**	**4018**	**5202**	**5896**	**100%**	

Source: Citi Research

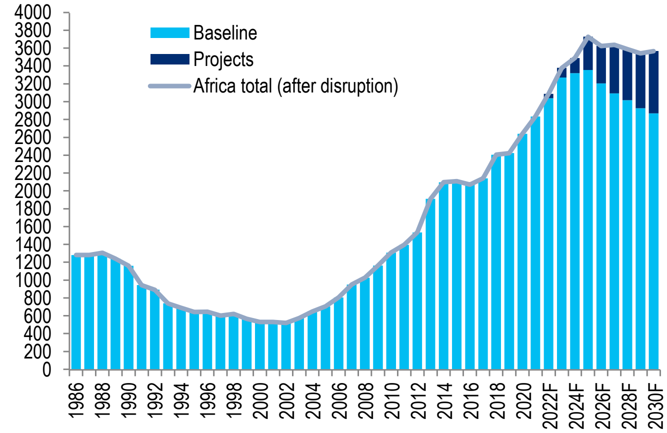
Figures 103-110 illustrate our forecast net mine supply growth developments by region, after disruption. We see most regions contributing to higher net mine supply over the coming decade, with the exception of Europe.

Figure 103. Latin America should see some net growth in mine supply



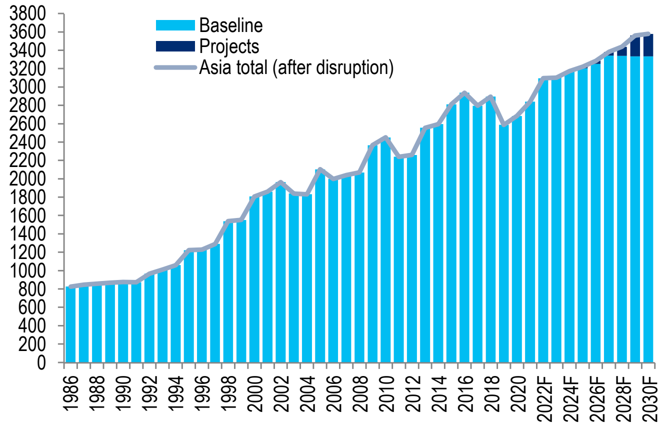
Source: Citi Research

Figure 104. Africa should see strong mine supply growth



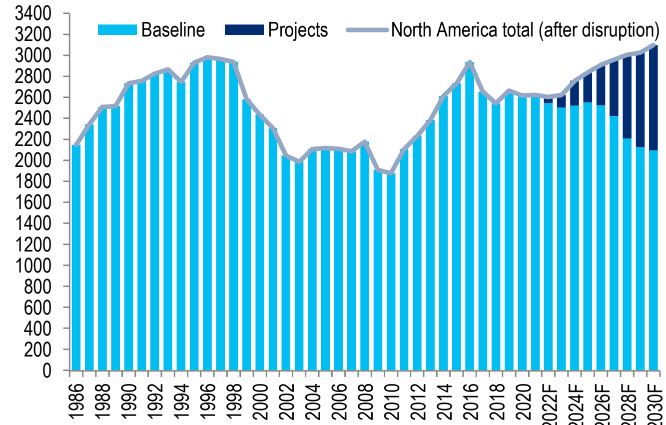
Source: Citi Research

Figure 105. Asia should see mine supply growth



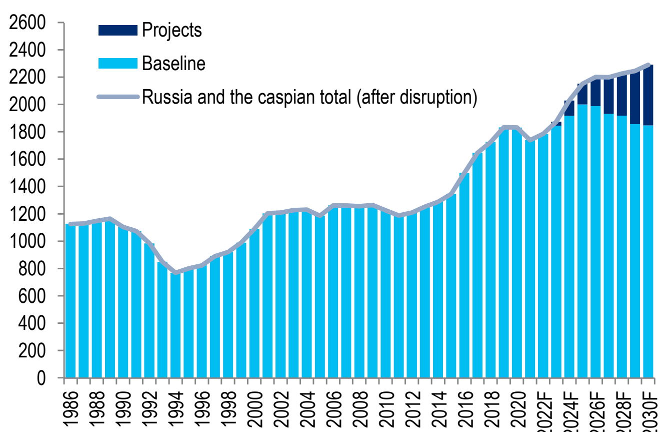
Source: Citi Research

Figure 106. North America should see net mine supply growth



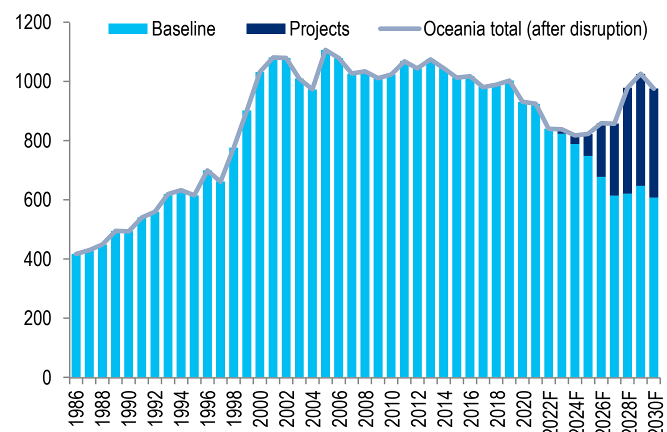
Source: Citi Research

Figure 107. Russia is forecast to see mine supply growth



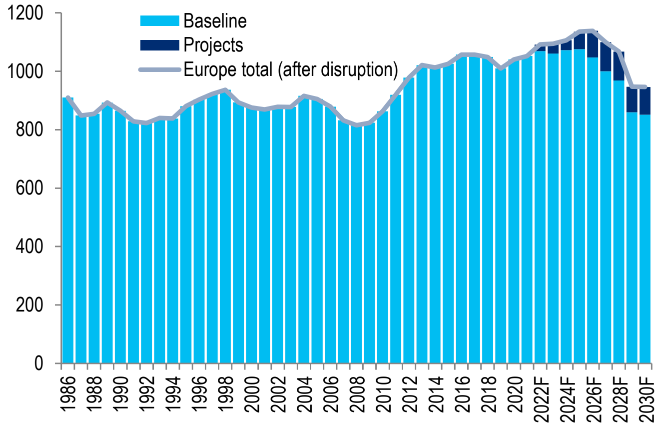
Source: Citi Research

Figure 108. Australia is forecast to see some mine supply growth later on in the decade



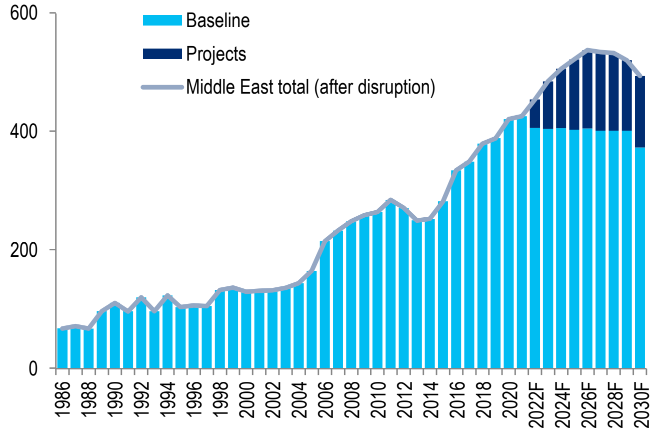
Source: Citi Research

Figure 109. European copper mine supply is expected to fall over the coming decade



Source: Citi Research

Figure 110. We assume an increase in the supply of mined copper from the Middle East over the next decade

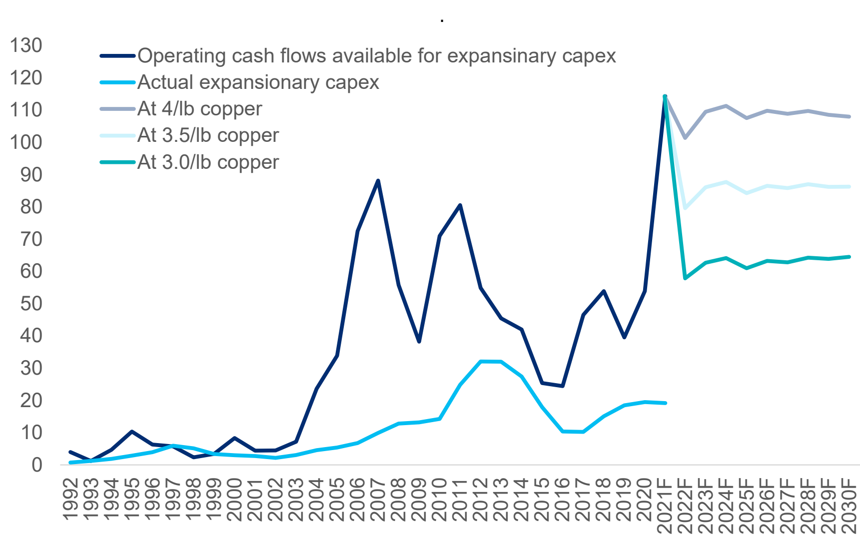


Source: Citi Research

Incentive prices, cash flows, and capex – money's not the problem

The issue is not money; it is the lack of investing it (please see Figure 111). We find that cash flows available for expansionary capital expenditure are at present more than $100bn per year, compared to a total capex requirement of ~$100bn (at ~15-20k/t capital costs) for the 5.7mt of copper projects that we have in our baseline scenario. Even at $7,500/t ($3.5lb) copper prices, cash flows available for expansionary capex would still be over $80bn per year over the coming years.

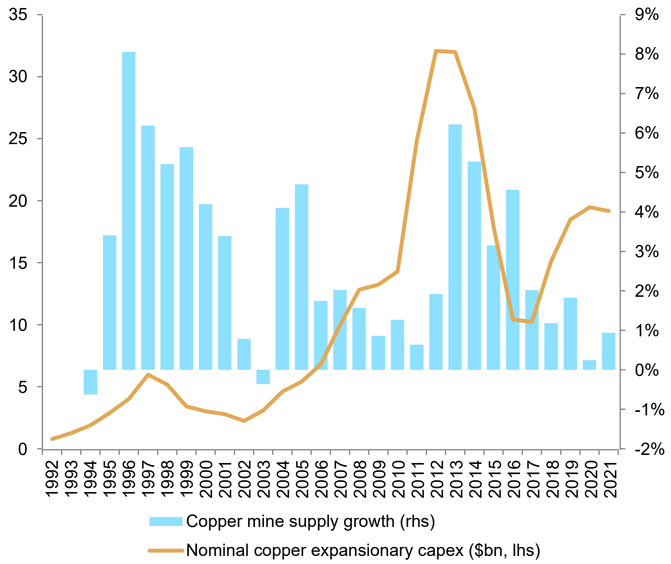
Figure 111. Copper mining industry cash flows available for expansionary capex at different copper prices, compared to actual historical expansionary capex



Source: Citi Research

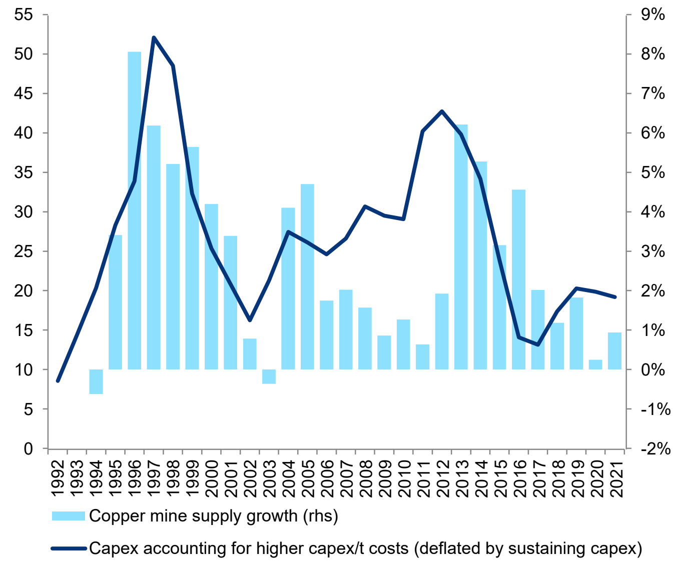
For reference, total expansionary capital expenditure has been $108bn over the past 10 years (please see Figures 112-113). We will need to see this pace more than double over the next 3-5 years in order to fund the 5.7mt of copper projects that we model in this note, and we believe achievable.

Figure 112. Nominal capital expenditures have picked up over the past few years to almost $20bn…



Source: Citi Research

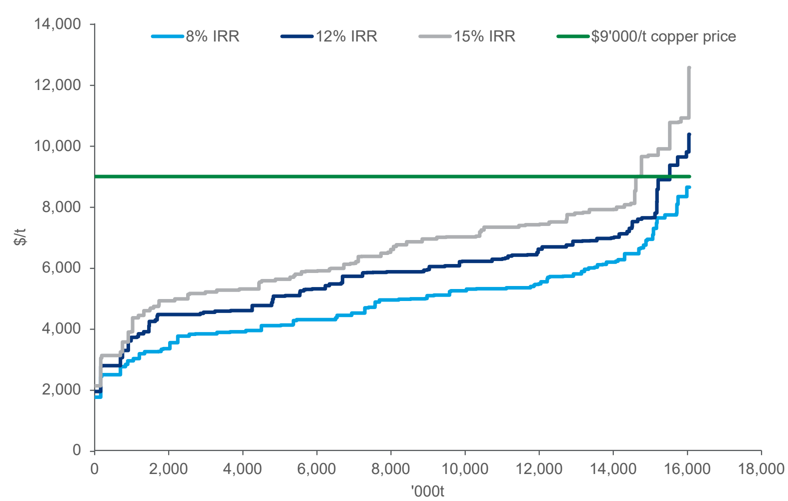
Figure 113. …however after attempting to account for the rise in capex costs per tonne, the pick-up is negligible in historical context



Source: Citi Research

Regarding project viability, we find that the vast bulk of copper projects have incentive prices at or below current copper prices (please see Figure 114). We estimate that over 14mt of copper projects could be profitable at an IRR of 15%, after scaling up the incentive curve from 6mt to 16mt, and assuming the >100 projects accounting for the 6mt of modelled projects are representative of the other 150 or so projects without capital expenditure estimates.

Figure 114. The vast bulk of copper projects are, on paper, profitable at current prices (this is a scaled up incentive curve which implicitly assumes the 100+ projects that are modelled are representative of the >250 known projects)



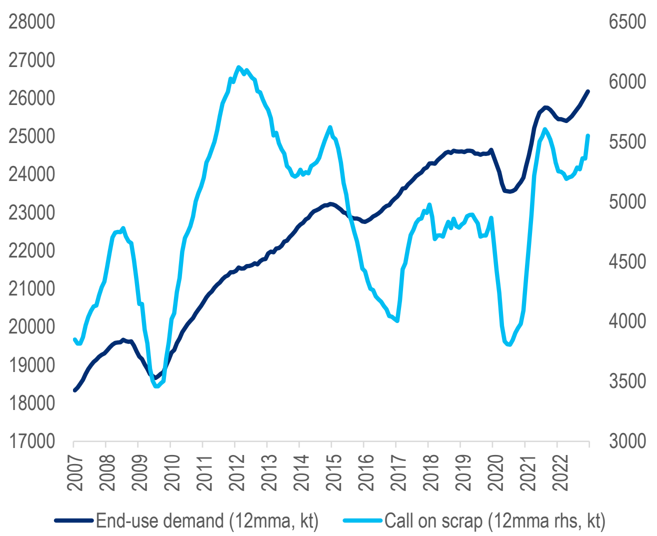
Source: Citi Research

Call on scrap outlook

Near term – red sky in the morning

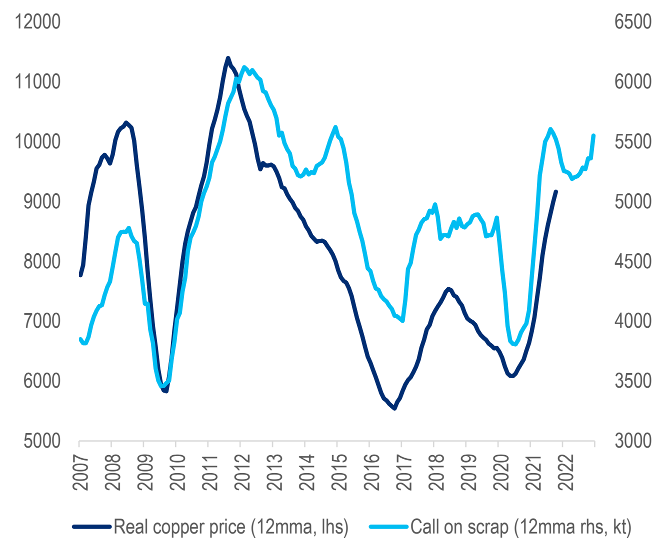
We see copper consumption declining and mine supply rising over the coming months, and as a result the requirement for scrap should decline (please see Figures 115-118), pushing down prices. Our detailed demand forecasts for 2022 are located in Figure 40. By the 2H'22 we see consumption and the call on scrap rebounding and prices following suit. Over the period, we are expecting modestly sub-trend mine supply growth. The main upside risk to this view is that scrap supply is restricted at a level below the call on scrap, or that a smelter/refinery bottleneck bites in China.

Figure 115. We see copper consumption falling sequentially and mine supply rising over the coming months…



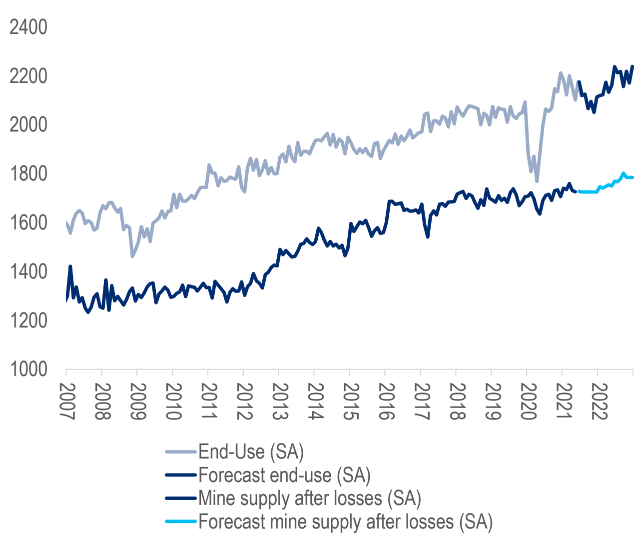
Source: Citi Research

Figure 116. …placing downward pressure on copper prices



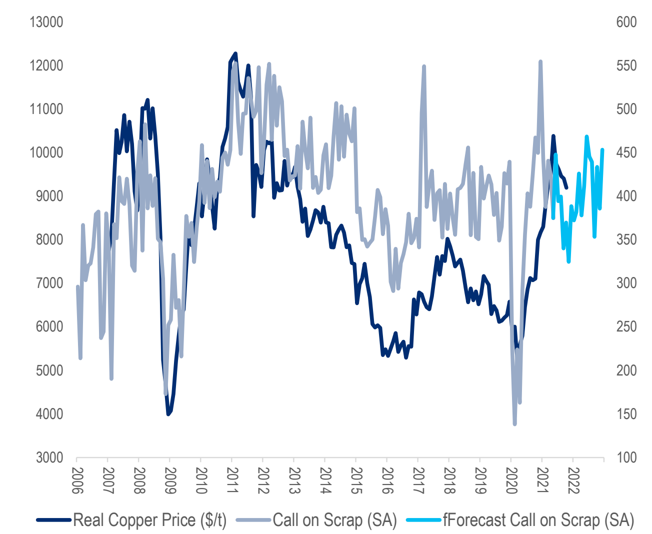
Source: Citi Research

Figure 117. Near term consumption weakness and rising mine supply (higher frequency data, seasonally adjusted)…



Source: Citi Research

Figure 118. …is set to drive a decline in call on scrap (higher frequency data, seasonally adjusted), before it rebounds during 2022

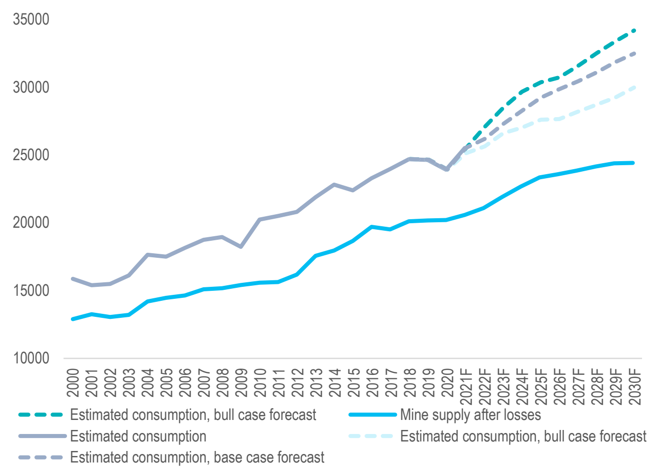


Source: Citi Research

Longer-term – the scrap market's decade long 'show me' moment

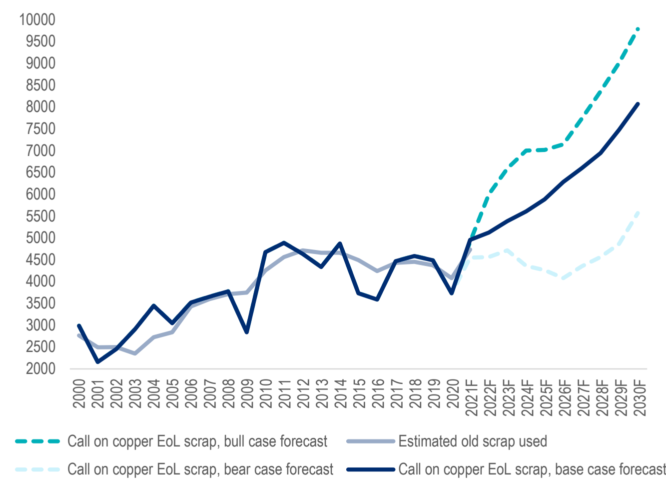
A rising call on scrap will likely place sustained pressure on the scrap industry to respond. The base and bull case call on scrap forecasts through 2030, shown in Figures 119-122 below, clearly indicate how daunting this challenge could be when taken in context of historical scrap supply. Specifically, we forecast that the call on scrap will increase to 8.1mt in 2030F, from around 5.0mt in 2021F in our baseline scenario (an increase in the call on scrap of 5.6%p.a.), and to 9.8mt in our bull case scenario (an increase in the call on scrap of 8.0%p.a.). Please also see the table in Figure 10 for details.

Figure 119. Base, bull and bear case consumption forecasts relative and our baseline mine supply forecasts ('000t)



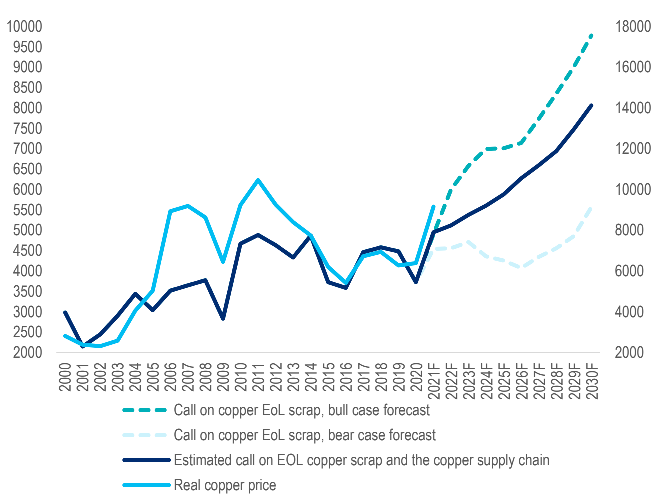
Source: Citi Research

Figure 120. Base, bull and bear call on scrap forecasts, with reference point being historical scrap used (as a proxy for scrap supply) ('000t)



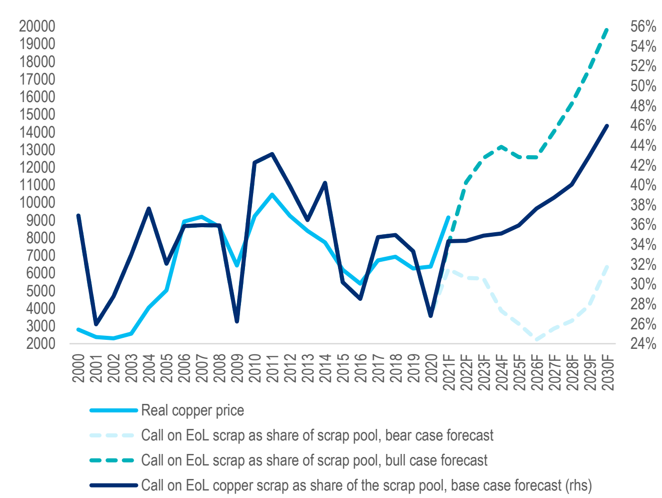
Source: Citi Research

Figure 121. Base, bull and bear call on scrap forecasts ('000t), with reference point being historical real copper prices (rhs)



Source: Citi Research

Figure 122. Base, bull and bear call on scrap forecasts (as share of the scrap pool, rhs), with reference point being historical real copper prices (lhs)

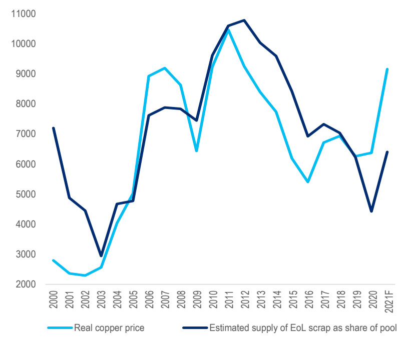


Source: Citi Research

What kind of scrap supply response and supply and demand balances will we see?

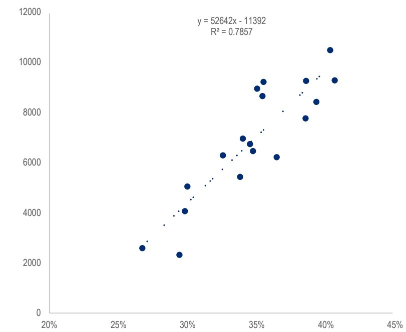
Here we take two approaches to forecast scrap supply, using the results of both approaches to help guide our price forecasting process. The first method we use is to provide base, bull and bear case scenarios for scrap supply based on spot prices, using different representative periods of price to scrap recovery relationships. The second is to imply the required price to clear the market, assuming the historical long run price to scrap recovery relationship is representative of future price to scrap recovery rates.

Figure 123. Prices have tended to drive scrap recovery rates...



Source: Citi Research

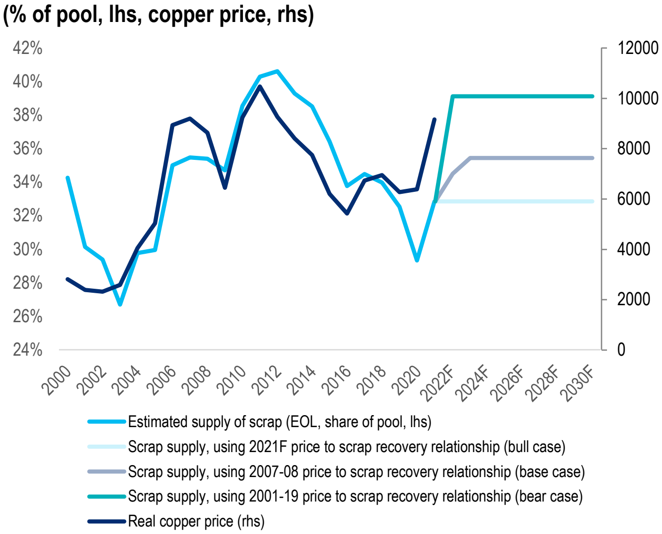
Figure 124. ...with an R-square of ~0.8 over the 2001-2019 period



Source: Citi Research

We present a base, bull, and bear case scenarios for scrap supply in Figures 125 ad 126, based on spot prices of ~$9,200/t copper, and different scrap recovery to price ratios, and compare them to our base case call on scrap in Figure 126 below. The baseline scrap supply scenario is based on a sustained repeat of 2007-2008 scrap pool recovery rates of around 35% and the bull case scrap supply scenario is based on a repeat of the broader 2001-2019 relationship (we outline in the next section why the 2010-2012 scrap recovery rates may not be repeated for the forseeable future). The bear case scrap supply scenario is based upon our estimate of the price to scrap recovery ratio in 2021 being held constant (i.e. sustained scrap supply chain issues over the coming decade). Our base case reflects the fact that rising scrap complexity and other scrap industry issues are likely to constrain scrap recovery rates relative to the 2010-12 period.

Figure 125. Three scenarios for scrap recovery rates at $9,200/t copper (% of pool, lhs, copper price, rhs)



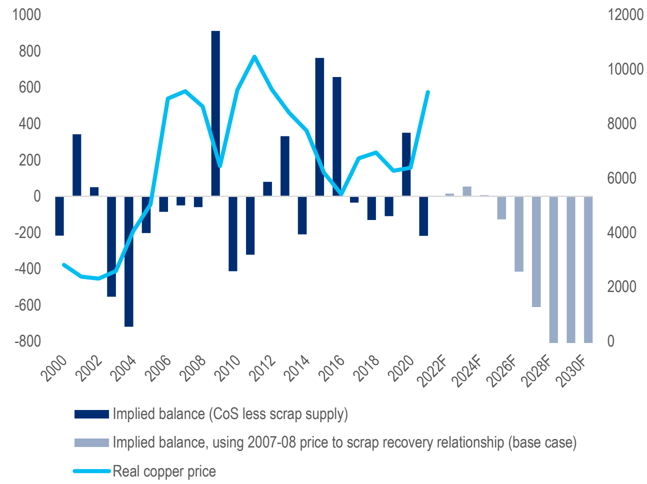
Source: Citi Research, Wood Mackenzie, ICA, Bloomberg

Figure 126. Three scenarios for scrap recovery rates at $9,200/t copper, compared to our base case call on scrap (levels, '000t)

Source: Citi Research, Wood Mackenzie, ICA, Bloomberg

By comparing the scrap supply in our baseline scenario to the call on scrap (as shown in Figure 126), we can calculate the implied future copper supply and demand balance assuming $9,200/t copper (please see Figures 127). Here we can see a broadly balanced market at current prices over the next few years, then sharply widening deficits from 2025 onwards. Our price forecasts assume that the speculative community brings some of the bullishness forward into 2023/2024. These findings underpin our long-term price upgrade to $9,000/t (from $7,500/t).

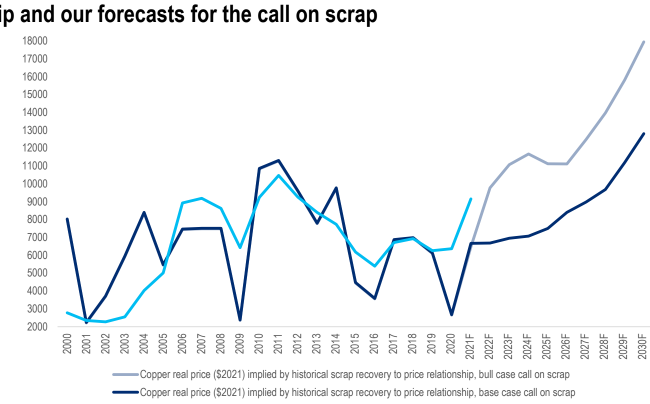
Figure 127. Our baseline scrap supply scenario assuming spot copper prices and the 2007-08 price to scrap recovery relationship points to widening deficits from 2025 onwards



Source: Citi Research, Bloomberg, ICA, Wood Mackenzie

The second method we take is to imply the copper prices required to meet the call on scrap over the coming decade, based on the 2001-2019 price to scrap recovery relationship. Here we find that historical price to scrap recovery relationships indicate that prices will need to average ~$9,000/t over the coming decade in our baseline call on scrap scenario (please see Figures 128 and 129), in order to see a sufficient scrap supply response in order to balance the market. To the degree there are scrap or other supply bottlenecks, prices will need to be higher. This approach implicitly assumes no copper deficits, rather it provides the prices required to incentivize a sufficient scrap response, based on the historical price to scrap recovery relationship. These findings also support our long-term price upgrade to $9,000/t (from $7,500/t).

Figure 128. We can imply copper prices required to balance the market based on this relationship and our forecasts for the call on scrap



Source: Citi Research

Figure 129. Implied copper prices based on the historical relationship are in the region of ~$9k/t over the coming decade in our base case

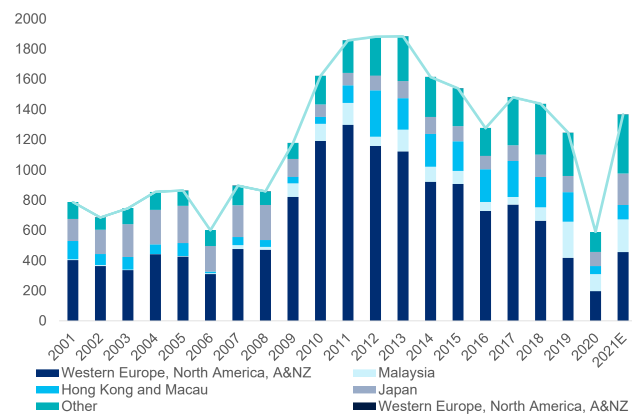
	2021F-2030F	2026F-2030F
Copper average impled price ($2021) using historical scrap recovery to price relationship, bull case call on scrap	12174	14286
Copper average impled price ($2021) using historical scrap recovery to price relationship, base case call on scrap	8617	10230

Source: Citi Research

Factors potentially limiting a scrap supply response

- **Historical recovery rates may not be representative of future recovery rates.** In particular, the scrap market recovery rates as a share of the scrap pool during 2009-2012 may not representative of near term potential recovery rates, since they likely in part reflect de-stocking and/or excess labour in the developed markets post the Global Financial Crisis (please see Figure 130).

Figure 130. A large increase in scrap supply from Western Europe, North America and Australia during and immediately post the Global Financial Crisis may have reflected one off de-stocking of scrap supply chain inventories (or higher recovery rates due to an excess of labour in these regions)



Source: Citi Research

- **Rising scrap nationalism** may disrupt scrap supply chains over the coming years.

- **Rising scrap complexity**, particularly in shorter-life products such as consumer electronics.

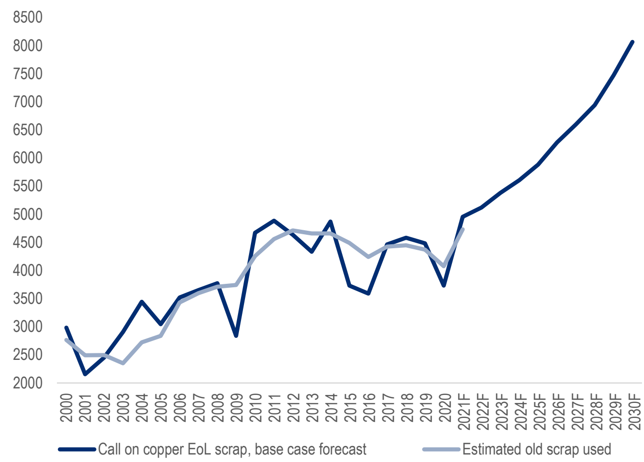
- **Recent literature indicates that industry surveys point to difficulties and skepticism regarding raising scrap recovery rates** – please see “Current challenges in copper recycling: aligning insights from material flow analysis with technological research developments and industry issues in Europe and North America”, Loibl A, Tercero Espinoza, L (2021).

- **Rising concerns regarding pollution from scrap processing is limiting processing capacity.** For example, China’s ability to offshore its scrap processing industry, following moves from China’s authorities to crack down on scrap processing-led pollution has had major issues. After offshoring some processing to Malaysia, Malaysia has recently imposed strict rules on scrap processing, meaning a new hub will need to be found.

Factors suggesting a scrap response will be sufficient to stop deficits from occurring

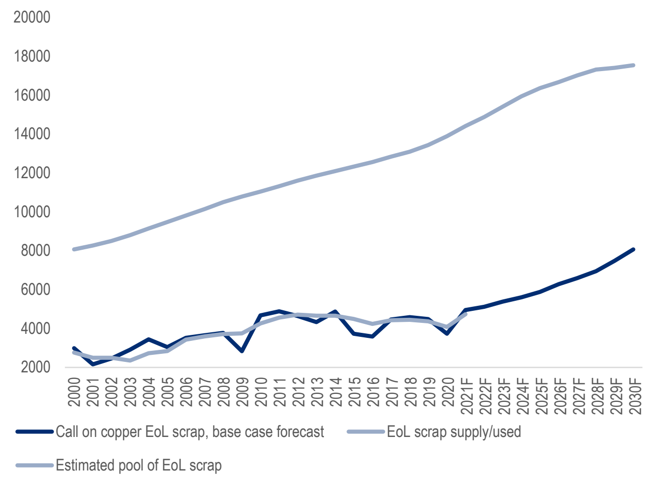
- **There appears ample room to raise recovery rates when one compares the size of the scrap pool flows (~14mt) to recoveries (~5mt) (please see Figure 132).** Though the call on scrap over the next decade is roughly equal to the total volume used over the past 15 years (Figure 131), recovery rates are only around 1/3rd of the pool of scrap.

Figure 131. The volume of scrap required over the next decade is roughly equal to the total volume used over the past 15 years…



Source: Citi Research

Figure 132. …however the scrap pool flows that might be reclaimed are very high and so there seems ample room to increase recoveries



Source: Citi Research

- **Potential government support** and broader investment in scrap market development given its relative low carbon footprint.
- **Scrap industry revenues and profits are very high at these prices and will inevitably result in investment in expanding capacity and R&D.** The end of life scrap is roughly a 5mt market, which at $9k copper is a $45bn industry, up from a $25-30bn industry during 2019 (pre-COVID). The bulk of this increase in revenues will likely be profits and ultimately this will start to get re-invested. The highly fragmented nature of the industry may slow this process down, however.
- **Technical improvements** with respect to shredding/sorting may improve recovery rates over time.

Appendix I: Inventories, curve shape, and convenience yields, the theory

In this Appendix we show that the commodity futures curve is a function of the cost of carry less the convenience yield of holding a physical for a certain time. The convenience yield is the net benefit of holding the physical commodity relative to the corresponding commodity futures contract convex function of, and is intrinsically linked to, inventories, where inventories, in turn, mostly reflect changes in the balance of supply and demand fundamentals.

Figures 133 and 134 are stylized charts detailing the interaction between the physical market (S), the futures market (F), financing (r) and warehousing costs (w), and the convenience yield (y). We note that Figures 130 and 131 are consistent with Equation (5) and its components. For a full worked example of how a market finds equilibrium in a deficit market with and without frictions (taking you from Pt A to Pt C in Figure 8, please see Appendix A).

The theory of storage[4] suggests that holders of a physical commodity receive a stream of implicit benefits called the "convenience yield", reflecting the flexibilities provided to the holder. For consumers and producers these flexibilities include reducing costs associated with varying production levels and avoiding stockouts in response to supply and demand shocks, and for traders this includes the ability to meet consumers' changing requirements. The value of holding stocks - the convenience yield - is expected to rise as inventories decline, and the convenience yield is expected to fall as inventories rise. As such, the convenience yield and inventories are intrinsically linked, with inventories usually predominant amongst other factors.

The no arbitrage relationship between the spot and forward prices, including the convenience yield and storage costs is:

$$F_t - w_{t,T} = S_t.e^{(r_{t,T}-y_{t,T})^{(T-t)}} \qquad (1)$$

Re-arranging 1 for the convenience yield, y, gives:

$$y_{t,T} = \frac{LnS_t - In(F_t - w_{t,T})}{T-t} + r_{t,T} \qquad (2)$$

Where $y_{t,T} = the\ convenience\ yield\ earned\ by\ the\ holder\ from\ time\ t\ to\ T$

$w_{t,T} = the\ cost\ of\ physically\ storing\ a\ unit\ of\ the\ commodity\ from\ t\ to\ T$

$S_t = the\ spot\ price\ of\ the\ commodity\ at\ t$

$F_t = the\ forward\ price\ for\ delivery\ of\ a\ commodity\ at\ time\ T > t$

$r_{t,T} = the\ cost\ of\ borrowing\ from\ time\ t\ to\ T\ (continuous\ compounding)$

Assuming stock is held for one year gives:

$$y = LnS - In(F - w) + r \qquad (3)$$

The simplified linear approximation of this is:

$$y = S - F + w + r.S \qquad (4)$$

This can be written as:

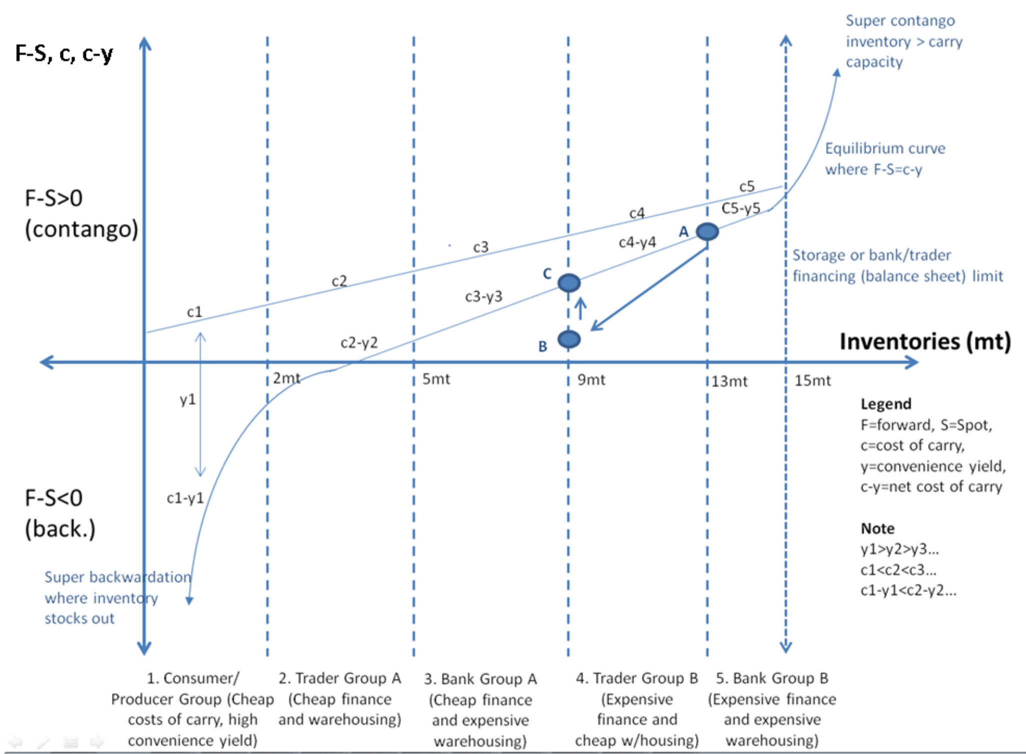
$$F - S = c - y, where\ c = w + r.S \qquad (5)$$

Where c=cost of carry (physical storage plus financing

). Specifically, the costs of carry are the marginal costs of carry – financing (the cost of capital to the individual holder, in the example below Traders A and B and Banks A and B) and warehousing/storage costs – as this is what sets the shape of the curve.

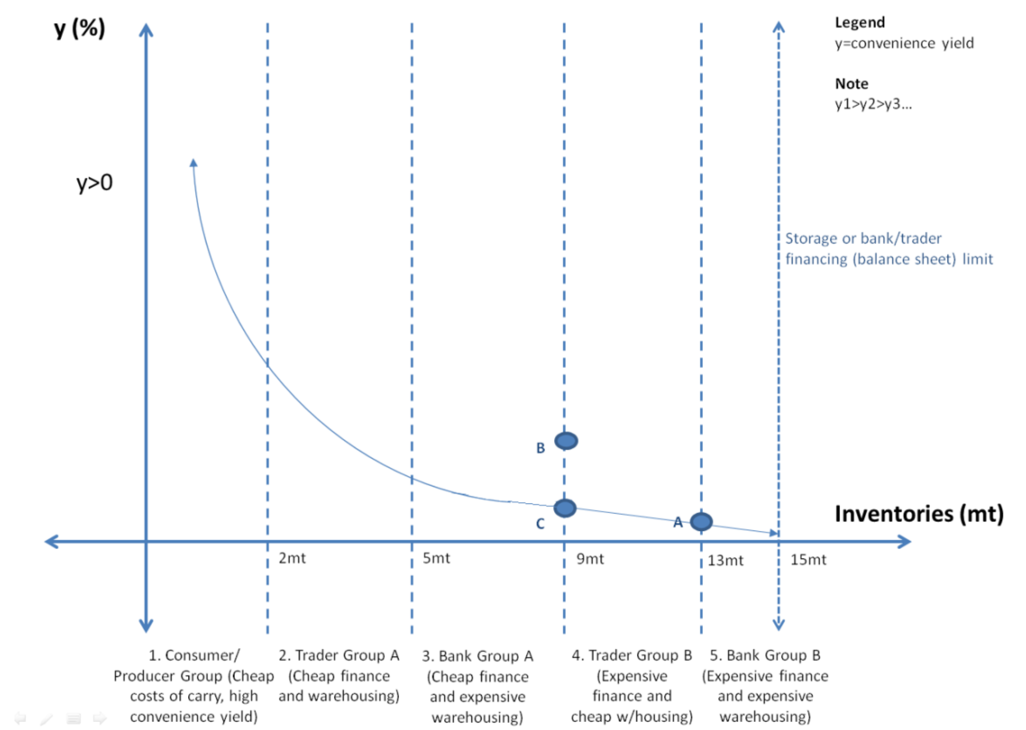
[4] The theory of storage has been developed and discussed by Working (1949) and Brennan (1958, 1991).

Figure 133. The relationship between the physical and futures markets, the cost of carry, and the convenience yield (see Appendices A, B and C for details)



Source: Citi Research

Figure 134. The theoretical relationship between the convenience yield and inventories (see Appendices A, B and C for details)



Source: Citi Research

From equation (5) and Figures 133 and 134, we can observe the following about the drivers of commodity curve shape:

- **The shape of the curve (F-S) is positively related to storage costs (w) and interest costs (r) as a share of spot prices (S), all else equal**
  - Storage and financing costs tend to be positively correlated with inventory levels, which can exacerbate contangos in bear markets, especially where storage capacity is tested, or where bank and trader balance sheet financing capacity is stretched

- **The shape of the curve (F-S) is negatively related with the convenience yield (y) and thus positively related with periods of rising inventories (supply > demand), all else equal**
  - Global growth tends to be negatively correlated with inventories (placing downward pressure on curve structure) and positively correlated with interest rates (placing upward pressure on curve structure), meaning the two can be moving in opposite directions

- **Lower (higher) costs of carry mean a smaller (higher) convenience yield is required to drive see a backwardation (contango), all else equal**
  - This is important at present for the base metals, as the cost of financing and storage is for many participants quite low, meaning that it won't take much of an increase in convenience yields (i.e decline in inventories or expected inventories) to see some metals forwards (nickel, copper) move into backwardation.

- **One should be very wary of using curve shape to imply inventory levels without adjusting for carry costs, as a contango market can – in contrast to some commonly held beliefs – be consistent with an underlying deficit in the physical market** (i.e. a contango market structure can be consistent with bullish underlying or expected fundamentals). The converse can also be true for backwardated markets. Both dynamics can be seen by reviewing a deficit market (drawing inventories) from high levels in Figure 134.

Appendix II: Spot and futures dynamics

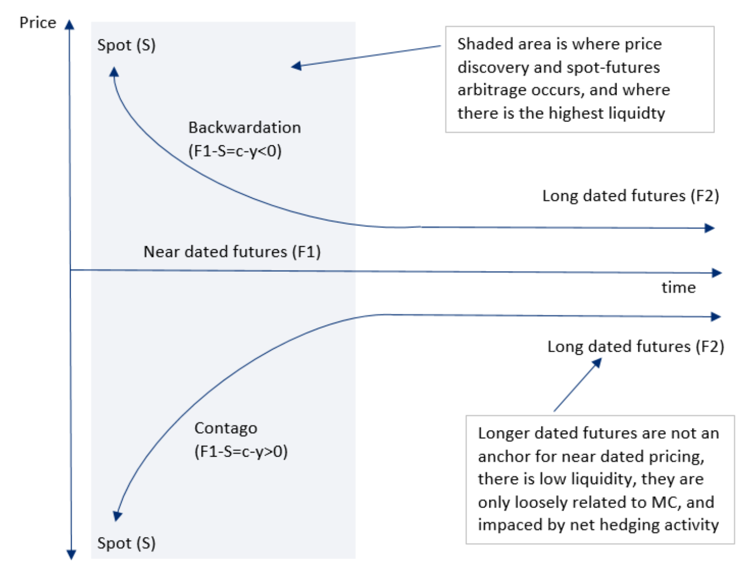
In this Appendix, we discuss the some stylized facts about copper spot and futures pricing dynamics (please see Figure 135).

We make three key assertions here:

1. **That the spot price is principally set by price formation within the nearby futures**, and then the arbitrage between spot and futures via the convenience yield (spread) relationship explained in Appendix I.
2. **That the back end of the curve is not a pricing anchor.** There is no theoretical need for it to be, nor any empirical evidence of it being so.

3. **That the long run curve shape is "just the tail of the dog"** since it is often an extrapolation of short-term demand trends, which in turn influence the markets estimate on long-run marginal cost.

Figure 135. Price formation occurs in the spot market and nearer dated portion of the futures curve, regulated by spot-futures parity



Source: Citi Research

To make this relationship clearer we break down each constituent of the curve:

<u>**Spot pricing: "a function of nearby futures and the convenience yield"**</u>

- **The price for material today, in a certain region (i.e. LME + regional premium)**
- **A f(supply (production and inventories), demand (consumption and inventories), marginal cost), and importantly, a function of futures prices where s/d is price inelastic (given spot-futures arbitrage)** . The concept that futures and the convenience yield determine spot pricing is in our view the logical conclusion of the fact that liquidity (i.e. participation in price formulation) is higher in the futures market.
- **Somewhat liquid**
- **Participants (physical traders, producers, consumers)** – conventional 'futures' speculators are negligible participants in spot trading given the loss of leverage (margining is swapped for a realised asset value) and the implied interaction with logistics. In fact, by definition trading in spot suggests the entity would overlap with physical traders.

<u>Nearer dated futures (1 day-1 year): "the central point of price formation"</u>

- **Price for material in an exchange warehouse for a certain day in the future**
- **A f(Short run demand e, supply e and marginal cost estimate)** . These three factors are expected to drive near dated speculation and hedging decisions alike. Short run demand sentiment is driven by many macro and micro variables. Further momentum trading may 'piggy back' on existing trends and exaggerate the moves for a time until suitably opposed by physical arbitrage between futures and spot.
- **Highly liquid**
- **Participants include:**
    - concentrate, scrap, blister, refined, semi-fabricated, fabricated inventory hedging / financing occurs, by producers, consumers and traders
    - speculators
    - consumer and producer output and consumption expectation hedging
- **Arbitrage with spot via the convenience yield relationship** – i.e. if futures are bid by speculative flows away from spot by an amount above the convenience yield for holding metal then a trader will sell futures and buy spot to lock in the higher differential, and in doing so bring prices more in line.
- **Helps with spot market efficiency –** Consumers can preserve cash flow by hedging via future dated contracts rather than stockpiling at today's prices. Likewise, traders and producers have optionality on when to sell material as they can hedge most of the value until a date when required i.e. due to logistical delivery.

<u>Back end futures: not the anchor for pricing, "just the tail of the dog"</u>

- **The price for material in an exchange warehouse for a certain day in the distant future**
- **low liquidity, naturally conviction is lower further out, and risk taking lower as a result.** Low liquidity begets low liquidity as this environment leads to high transaction costs and high bid-ask spreads.
- **A f(front end of curve, net producer/consumer hedging, speculative positioning, long run marginal cost estimate 'LR MCe')**. This makes sense given long dated hedging will usually be around a level considered to be a good long-term profit margin for a producer, or in some sense 'cheap' in absolute terms for a consumer which most likely makes reference to if producers are profitable or not. Limited speculative activity this far out will likely take a similar view possibly extending from marginal cost to 'incentive pricing' which for metals is largely a function of the cash cost of production.

In fact, we assert that the LR MCe, and with it back end curve pricing are in fact often pro-cyclical with the current cycle. In this sense the back end of the curve is "the tail of the dog" rather than its anchor. We can break down the markets attempt to estimate Long Run Marginal Cost 'LR MCe' as a function of f(LR demand expectations, supply curve, technology) given that future demand sets future supply need and with it the marginal producer. Absent then of a clearly visible significant technological supply/demand driver (rare let along with foresight), or a large structural non-cyclical demand driver (even decarbonisation leaves ~70% to cyclical elements), market sentiment towards the LR MCe is most likely largely influenced conditions as long run demand expectations rarely see past the current cycle. Tellingly no major cyclical downturn has ever resulted in a sell off only at the front without the back end also coming down to some extent also.

Appendix III: Refined supply and demand balance

Of course, the refined balance has its place, and here we publish our latest estimates (please see Figure 136). The refined demand forecasts are a scaled down version of our consumption forecasts outlined in this report (to reflect the old scrap not used by refineries).

Figure 136. Refined copper supply and demand balance – 2019-2025F

kt	2019	2020	2021f	2022f	2023f	2024f	2025f
Mine Production	**20,764**	**20,793**	**21,154**	**21,662**	**22,514**	**23,300**	**24,001**
% Change	*-0.1%*	*0.1%*	*1.7%*	*2.4%*	*3.9%*	*3.5%*	*3.0%*
Including Total Disr. Allowance (%)		*0.0%*	*2.0%*	*6.0%*	*7.1%*	*7.2%*	*6.5%*
Concentrate and blister balance	*-162*	*-160*	*0*	*0*	*0*	*0*	*-1*
Refinery scrap	*3,548*	*3,459*	*3,850*	*4,100*	*4,350*	*4,450*	*4,450*
Refined Production	**23,888**	**23,811**	**24,389**	**25,147**	**26,236**	**27,111**	**27,790**
% Change	*2.5%*	*-0.3%*	*2.4%*	*3.1%*	*4.3%*	*3.3%*	*2.5%*
Refined Consumption	**23,824**	**23,231**	**24,546**	**25,180**	**26,230**	**27,181**	**28,103**
% Change	*1.5%*	*-2.5%*	*5.7%*	*2.6%*	*4.2%*	*3.6%*	*3.4%*
Surplus/Deficit	**64**	**580**	**-157**	**-34**	**6**	**-70**	**-313**
Price (US$/t)	6,010	6,178	9,165	9,250	9,000	9,500	9,800
Price (US$/lb)	2.7	2.8	4.2	4.2	4.1	4.3	4.4

Source: Citi Research

Equity Implications

Equity outlook favourable, especially on a 12,000$/t price from 2024 onwards as a bull case

We assess companies with exposure to copper which we expected to benefit from our stronger for longer view on the metal. In addition to running the valuation metrics on our base case forecast, we highlight our bull case price of $12,000/t where there could be a 30% upside to the NPV of our copper stocks on average (vs a current P/NPV of 0.8x the copper stocks are currently trading at)

We analyse companies on the following metrics metrics: 1) Production growth; 2) Mine lives; 3) Bull/bear scenarios on EBITDA/NPV; 4) What commodity prices are priced into stocks; 5) Earnings growth and PE valuation; 6) Return on equity and price-to-book valuation; and 7) Copper exposure in revenue mix.

Valuations attractive

Copper equities are trading at 4.3x EV/EBITDA for '22 and 4.7x for '23. The copper sub-sector is expected to deliver 12-14% FCF yield over the next three years. Strong cash generation should open way for additional capital management by the miners and potentially lead to a sector re-rating.

The copper equities are at 0.82x NPV at our base case 9,000$/t L.T copper price, 0.63x NPV at our bull case 12,000$/t.

Key stock ideas

We have Buy ratings on the following stocks that have varying degree of copper exposure: **Europe** – Glencore, Anglo American, Rio Tinto; **Americas** – Freeport, First Quantum, GMexico, Teck Resources; **Australia** – Oz Minerals, Sandfire, Rio Tinto; **Asia** – China Moly, MMG, Zijin. We have Sell ratings on Boliden and KGHM in Europe.

Figure 137. Copper miners' valuation comps

	Ccy	Local Price	Target Price	Rating	Mcap (US$ m)	YTD Perf %	12m Perf %	P / E			EV / EBITDA			FCF Yield			Dividend Yield			P / Book			ROE			ROIC		
								2021E	2022E	2023E	2021E	2022E	2023E	2021E	2022E	2023E	2021E	2022E	2023E	2021E	2022E	2023E	2021E	2022E	2023E	2021E	2022E	2023E
Copper Miners																													
Anglo American PLC	£	26.0	40.0	Buy	47,993	10%	43%	4.4	4.7	7.0	2.5	2.7	3.4	22.5%	16.6%	17.4%	11.6%	8.6%	5.8%	1.4	1.2	1.1	35.1%	27.9%	16.7%	30.0%	23.0%	16.5%
Antofagasta	£	13.6	16.0	Neutral	18,222	-6%	38%	11.3	11.4	13.1	4.3	4.4	4.7	9.7%	12.7%	14.6%	5.3%	3.1%	2.7%	2.1	1.9	1.8	19.4%	17.6%	14.1%	22.4%	20.7%	18.3%
Boliden AB	SKr	281.4	285.0	Sell	8,805	-3%	9%	8.9	9.3	10.5	4.7	4.6	4.8	8.1%	6.9%	7.2%	6.6%	6.4%	6.0%	1.5	1.4	1.4	18.0%	15.8%	13.3%	15.5%	14.1%	12.1%
China Molybdenum	$	4.9	8.3	Buy	2,445	-4%	72%	13.6	12.4	13.0	8.1	7.5	7.5	7.7%	1.6%	1.8%	3.7%	4.0%	3.9%	2.1	1.9	1.8	15.8%	16.0%	14.1%	9.5%	9.8%	8.9%
First Quantum Minerals Ltd	$	24.4	32.0	BuyHigh Risk	13,378	7%	115%	12.7	8.4	9.8	6.0	5.0	5.2	10.7%	16.2%	12.6%				1.3	1.1	1.0	11.2%	14.5%	10.8%	9.4%	11.5%	9.7%
Freeport McMoRan	$	32.2	42.0	Buy	47,272	24%	105%	11.2	10.5	15.8	6.0	5.2	5.6	11.5%	10.3%	9.3%	0.9%	0.9%	0.9%	3.3	2.5	2.2	34.8%	26.9%	14.6%	16.4%	16.6%	13.4%
Glencore PLC	£	3.7	4.0	Buy	66,524	59%	125%	9.7	9.4	10.5	4.1	4.3	4.4	11.7%	13.1%	14.6%	4.8%	4.6%	4.8%	1.8	1.6	1.5	17.2%	16.2%	13.2%	12.0%	10.9%	10.1%
Grupo Mexico	$	80.5	98.0	Buy	30,462	-5%	47%	7.3	8.1	8.6	3.8	3.9	3.7	13.9%	14.7%	14.6%	6.9%	6.2%	5.8%	2.0	1.7	1.5	29.4%	22.3%	18.2%	24.5%	22.2%	20.7%
Jiangxi Copper	$	13.9	18.7	Neutral	2,477	14%	57%	7.9	7.8	9.1	5.9	5.8	5.9	-11.5%	18.0%	10.5%	2.0%	2.0%	1.7%	0.6	0.6	0.5	8.1%	7.6%	6.2%	7.4%	7.0%	6.1%
KGHM Polska Miedz SA	Zl	156.9	185.0	Sell	7,902	-14%	34%	7.0	7.6	11.1	3.8	4.0	5.0	5.4%	8.3%	4.0%	2.2%	2.9%	3.2%	1.2	1.1	1.0	18.1%	14.6%	9.3%	15.8%	13.5%	8.9%
MMG	$	3.3	4.1	Buy	3,673	-2%	66%	5.0	6.5	6.8	4.4	4.5	4.3	38.4%	44.3%	40.8%				1.9	1.5	1.2	49.0%	24.8%	18.9%	12.1%	10.1%	9.9%
OZ Minerals Ltd	$	21.8	27.5	Buy	5,382	17%	57%	13.1	14.0	11.6	6.4	6.7	6.2	3.4%	1.6%	2.3%	1.4%	1.0%	1.0%	2.0	1.8	1.7	16.3%	13.8%	15.2%	13.3%	11.4%	12.7%
Rio Tinto PLC	£	48.1	62.0	Buy	107,843	-9%	7%	4.6	5.9	7.7	2.8	3.2	4.1	18.9%	15.5%	11.5%	18.8%	14.8%	11.3%	2.5	2.3	2.2	54.1%	39.8%	28.7%	34.9%	28.0%	20.0%
Sandfire Resources Limited	$	5.2	7.3	BuyHigh Risk	1,315	3%	31%	5.7	6.7	8.1	2.4	2.3	2.5	26.1%	19.4%	22.0%	5.7%	4.2%	3.9%	0.9	0.9	0.8	19.6%	14.4%	10.3%	26.5%	14.9%	10.3%
Southern Copper Company	$	56.2	70.0	Neutral	43,478	-14%	23%	11.7	13.4	14.2	6.4	7.1	7.2	6.8%	7.0%	7.3%	5.5%	3.7%	3.5%	5.1	4.3	3.7	47.1%	34.7%	28.0%	30.6%	25.8%	24.3%
Teck Resources	$	32.4	40.0	Buy	13,490	40%	84%	6.1	5.8	11.4	4.0	3.4	4.0	6.7%	16.6%	18.3%	0.9%	0.9%	0.9%	0.7	0.7	0.6	12.7%	12.4%	5.8%	8.3%	8.7%	5.9%
Zijin Mining	$	9.4	14.7	Buy	6,816	5%	79%	13.2	10.1	10.6	7.4	5.8	5.7	3.7%	11.0%	13.3%	3.8%	5.0%	5.7%	3.0	2.6	2.4	24.4%	28.1%	23.7%	14.4%	16.3%	15.7%
					427,477	**10%**	**55%**	**8.1**	**8.4**	**10.3**	**4.2**	**4.3**	**4.7**	**13.8%**	**13.3%**	**12.5%**	**8.5%**	**6.8%**	**5.6%**	**2.4**	**2.1**	**1.9**	**34.5%**	**27.0%**	**19.4%**	**23.5%**	**20.1%**	**16.2%**

Source: dataCentral, Citi Research; Pricing as of 6 Oct at 5AM UK

Production growth – Teck, China Moly, Zijin and Anglo offer attractive growth

Teck, China Molybdenum, Zijin and Anglo American are expected to deliver double-digit % production CAGR for 2020-24E from project delivery. OZ Minerals, Sandfire and Freeport are expected to deliver attractive volumes growth.

On an aggregate basis, copper miners delivered 2.2% annualized growth over 2015-20 and the growth is expected to accelerate to 4.3% over the next four years with QB2 (Teck) and Quellaveco (Anglo American) as key projects.

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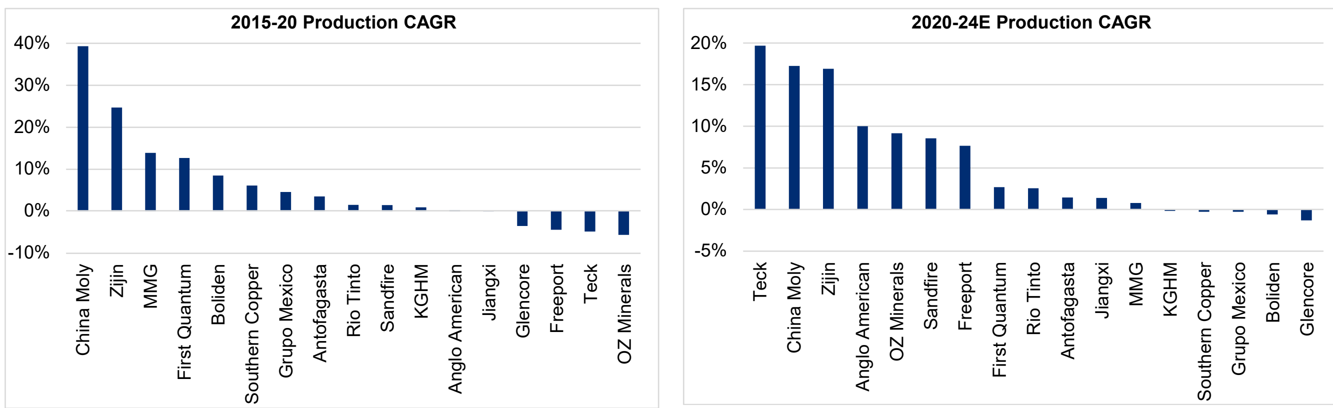
Figure 138. Production growth over time



Source: Company reports, Citi Research estimates

Figure 139. Production profiles by company

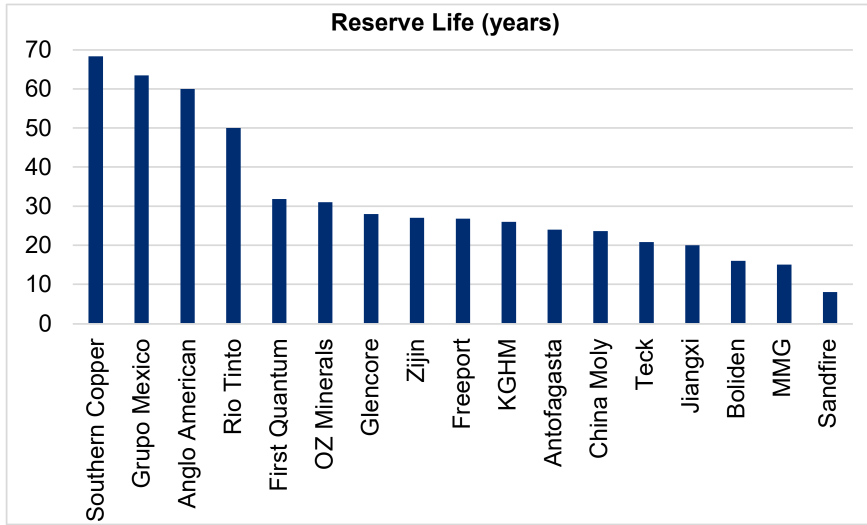
Copper Production (kt)	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	15-20 CAGR	20-24E CAGR
Anglo American	638	577	579	668	638	647	666	735	945	948	0.3%	10.0%
Antofagasta	616	710	704	725	770	734	720	750	800	777	3.6%	1.4%
Boliden	85	110	143	140	121	128	111	119	122	125	8.5%	-0.6%
China Moly	40	60	249	200	207	210	237	253	275	396	39.3%	17.3%
First Quantum	428	539	574	606	705	779	809	822	849	866	12.7%	2.7%
Freeport	1,822	2,108	1,696	1,730	1,473	1,455	1,735	1,996	1,991	1,955	-4.4%	7.7%
Glencore	1,502	1,426	1,310	1,454	1,371	1,258	1,218	1,175	1,200	1,193	-3.5%	-1.3%
Grupo Mexico	906	1,054	1,011	1,002	1,119	1,133	1,091	1,090	1,120	1,120	4.6%	-0.3%
Jiangxi	209	210	210	208	209	209	209	215	217	221	0.0%	1.4%
KGHM	672	677	656	634	702	704	737	699	699	699	0.9%	-0.2%
MMG	200	503	600	467	452	385	367	395	453	397	13.9%	0.8%
OZ Minerals	130	117	126	123	109	98	128	137	147	139	-5.6%	9.2%
Rio Tinto	497	514	473	646	583	537	493	552	584	594	1.6%	2.6%
Sandfire	67	68	67	65	71	72	71	101	96	100	1.5%	8.6%
Southern Copper	743	900	877	884	994	1,001	961	960	990	990	6.2%	-0.3%
Teck	357	324	287	294	297	279	280	345	561	573	-4.8%	19.7%
Zijin	150	155	208	249	370	453	532	712	822	847	24.7%	16.9%
Aggregate	*9,063*	*10,053*	*9,770*	*10,094*	*10,191*	*10,081*	*10,363*	*11,056*	*11,872*	*11,940*	*2.2%*	*4.3%*

Source: Company Reports and Citi Research Estimates

Mine lives – SCCO, GMexico, Anglo and Rio have long reserve lives

Southern Copper has the highest reserves life while GMexico, Anglo, Rio have close to 50 years of reserves life. Sandfire has the lowest reserves life of 8 years.

Figure 140. Mine lives based on reserves



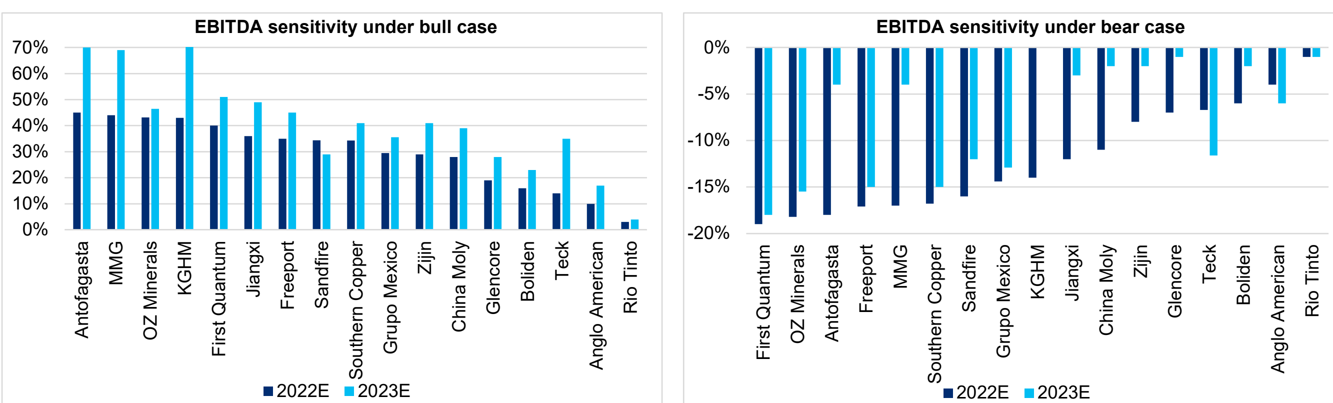
Source: Citi Research, Company Reports

Bull / Bear scenarios on EBITDA and NPVs – pure-plays offer most leverage

Understandably, pure-play miners have the most upside/downside sensitivity to copper prices.

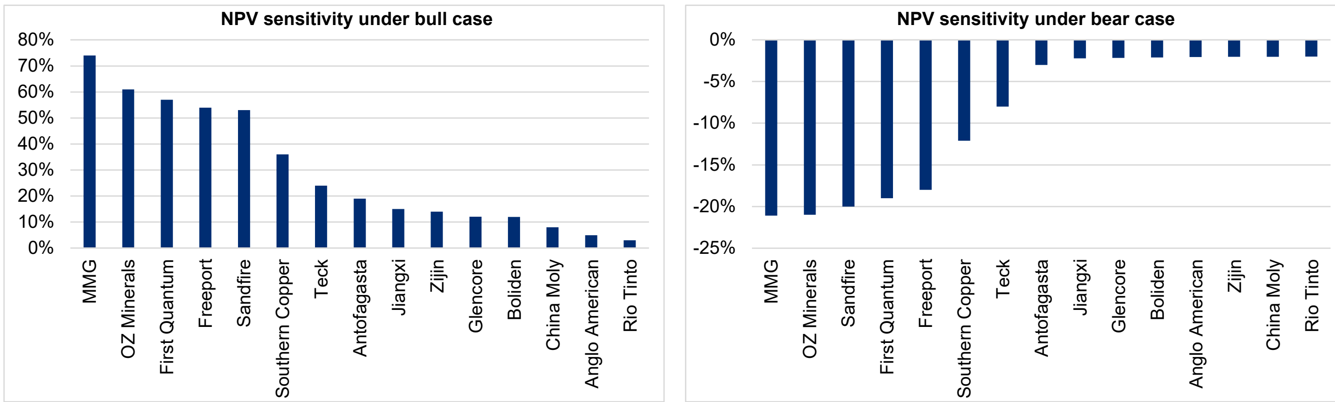
We run $12,000/t scenario for bull case and $8,000/t for bear case. Antofagasta, MMG, OZ Minerals, Sandfire, KGHM, First Quantum and Freeport have the highest sensitivity to change in copper price.

Figure 141. EBITDA sensitivity on bull/bear case on copper



Source: Citi Research

Figure 142. NPV sensitivity on bull/bear case on copper

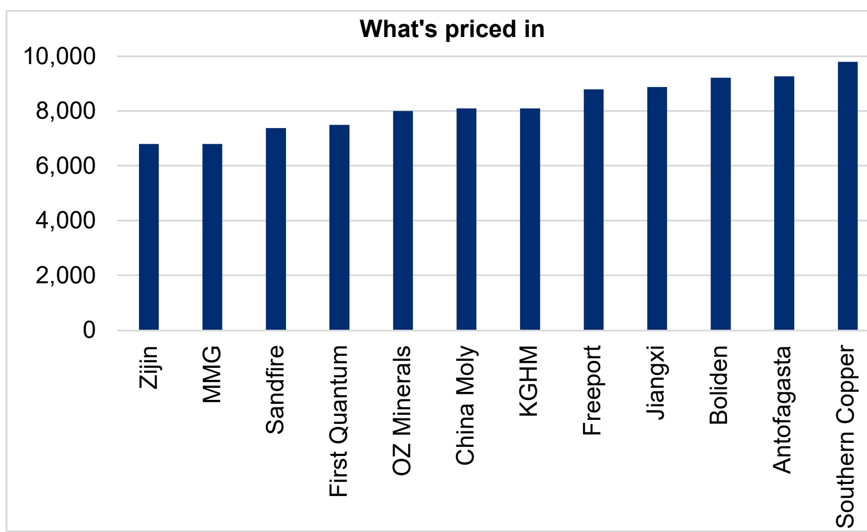


Source: Citi Research

What copper prices are factored into stocks? – $7,000-9,000/t

Copper stocks are generally pricing in $7,000-9,000/t (with an average of around $8,050/t) of copper price against spot copper price of $9,200/t. Among pure-plays, MMG and Sandfire are pricing in the lowest copper price into the valuations while Southern Copper is factoring in the highest. Antofagasta and Boliden are pricing in around spot copper which indicates that the stocks are fairly valued with respect to the copper price.

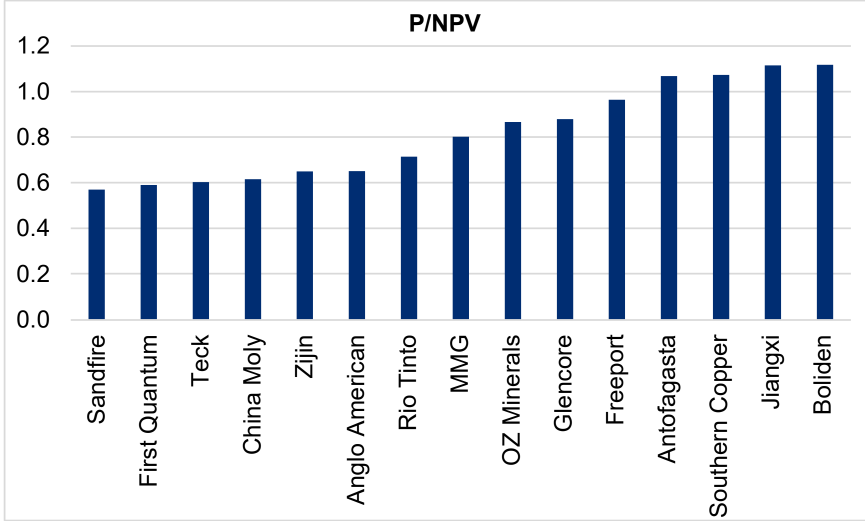
Figure 143. What copper prices are factored into stocks ($/t)



Source: Citi Research

In terms of price-to-NPV valuation, Sandfire and First Quantum are trading at undemanding valuations while Antofagasta, Southern Copper, Boliden and Jiangxi appear well priced.

Figure 144. P/NPV valuation



Source: Citi Research

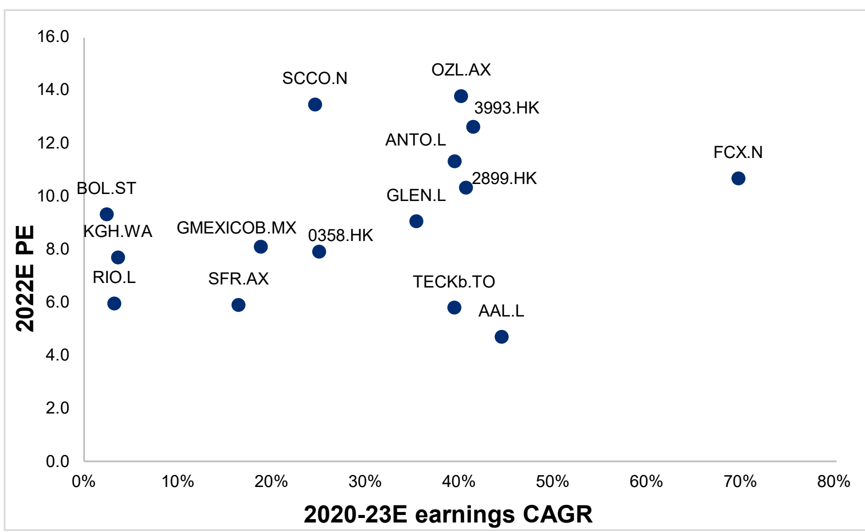
Earnings growth and PE valuation – pure-plays valued better

Most of the copper stocks are likely to deliver strong earnings growth led by strong copper prices translating into higher earnings. However low '20 base results in outsized growth rates for some of the names.

Copper equities are trading at 8.4x '22 and 10.3x '23 earnings.

Pure-play copper miners are trading at reasonably rich valuations relative to their diversified peers. Anglo American, Teck and Rio are trading at undemanding valuations on earnings.

Figure 145. Earnings growth vs PE valuation

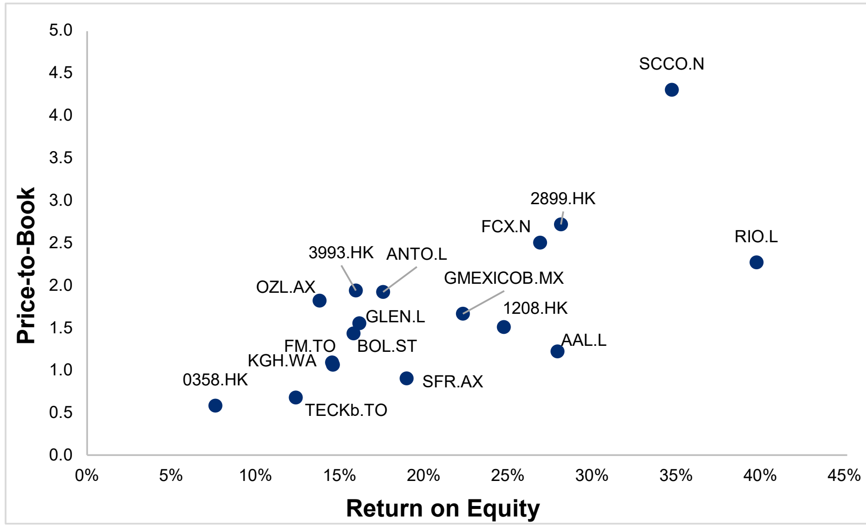


Source: Company Reports and Citi Research Estimates

Return on equity and price-to-book valuation – attractive ROE profiles

Copper miners are expected to deliver 20-25% ROE with the stocks trading at 1.5-2.0x price-to-book, on average, on our estimates.

Figure 146. Return on equity vs Price-to-Book valuation

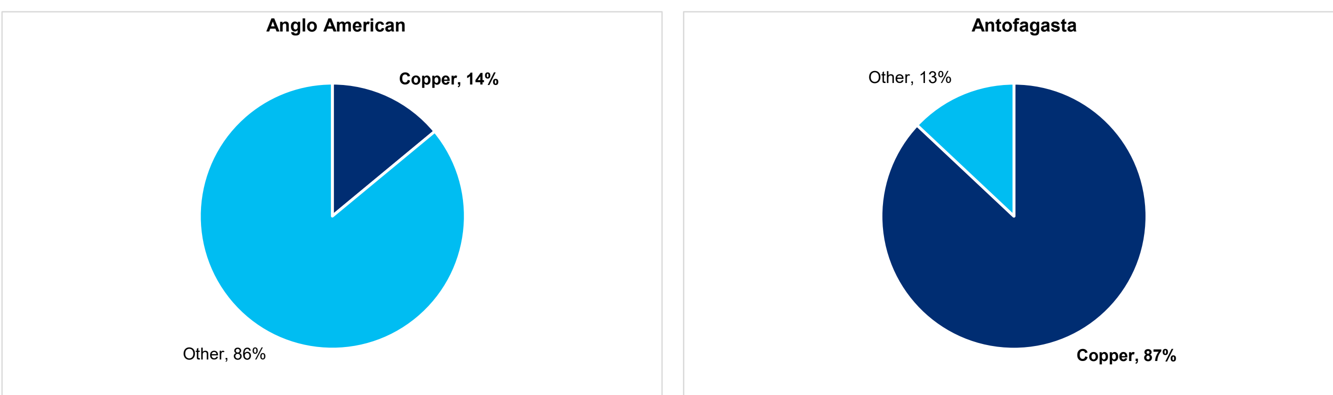


Source: Company Reports and Citi Research Estimates

Copper exposure in revenue mix – FCX and ANTO provide clean copper exposure

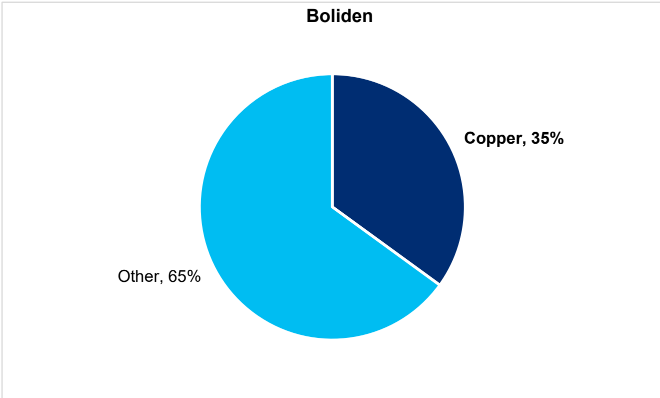
Freeport, Antofagasta, First Quantum, Southern Copper, Jiangxi, MMG and Sandfire have more than 75% of revenues coming from copper and are therefore best plays to get copper exposure. Even among them, Freeport and Antofagasta are well regarded by global investors to get clean copper price exposure.

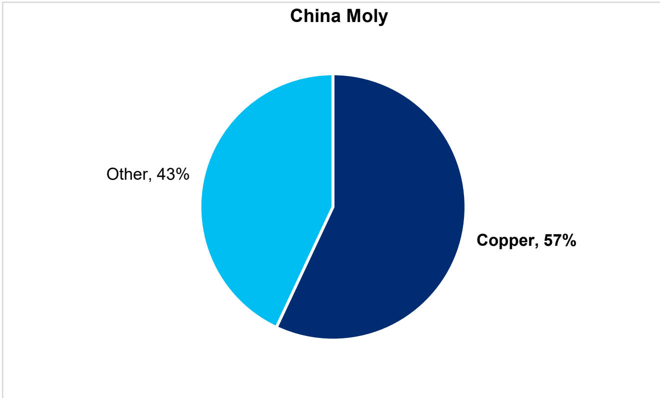
Figure 147. Copper in revenue mix



Source: Company reports, Citi Research

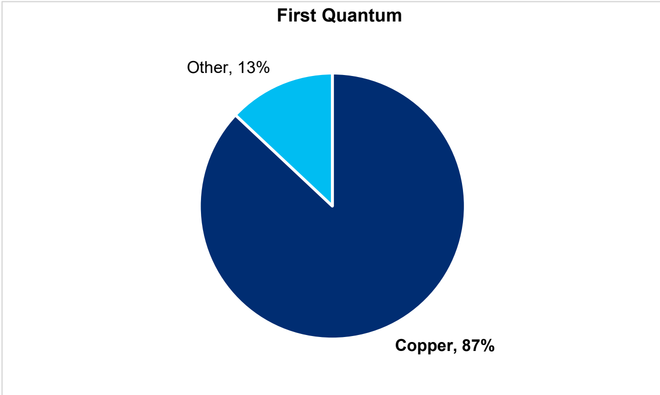
Figure 148. Copper in revenue mix

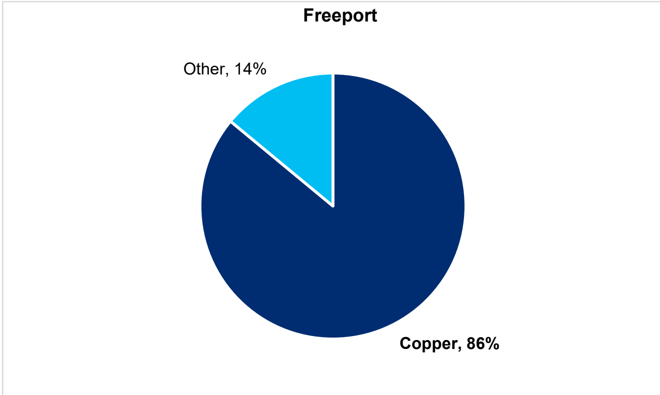




Source: Company reports, Citi Research

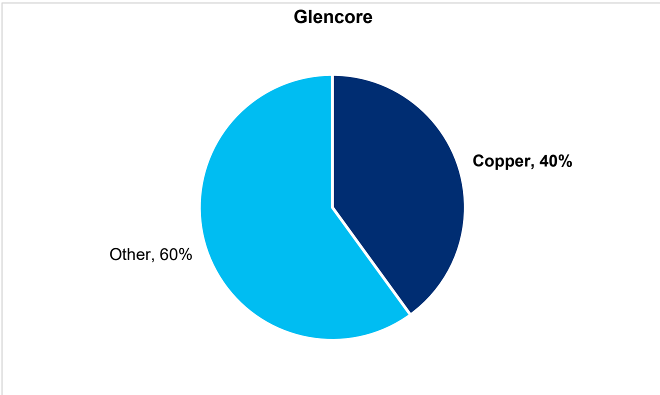
Figure 149. Copper in revenue mix

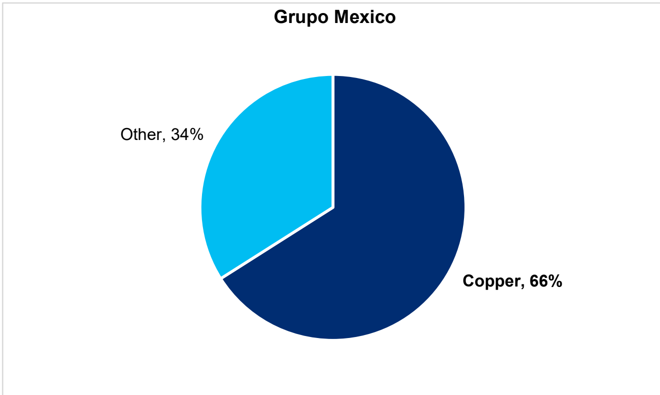




Source: Company reports, Citi Research

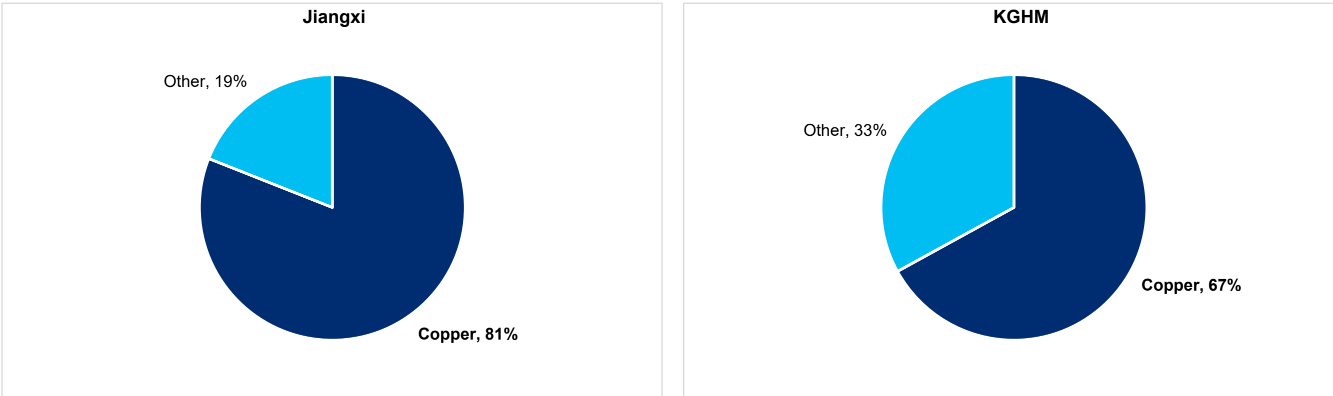
Figure 150. Copper in revenue mix





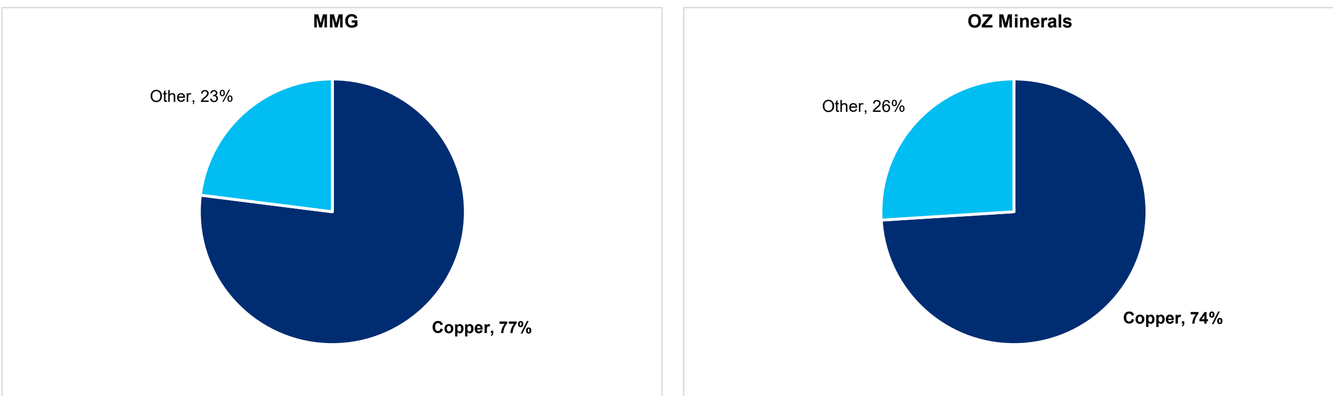
Source: Company reports, Citi Research

Figure 151. Copper in revenue mix



Source: Company reports, Citi Research

Figure 152. Copper in revenue mix

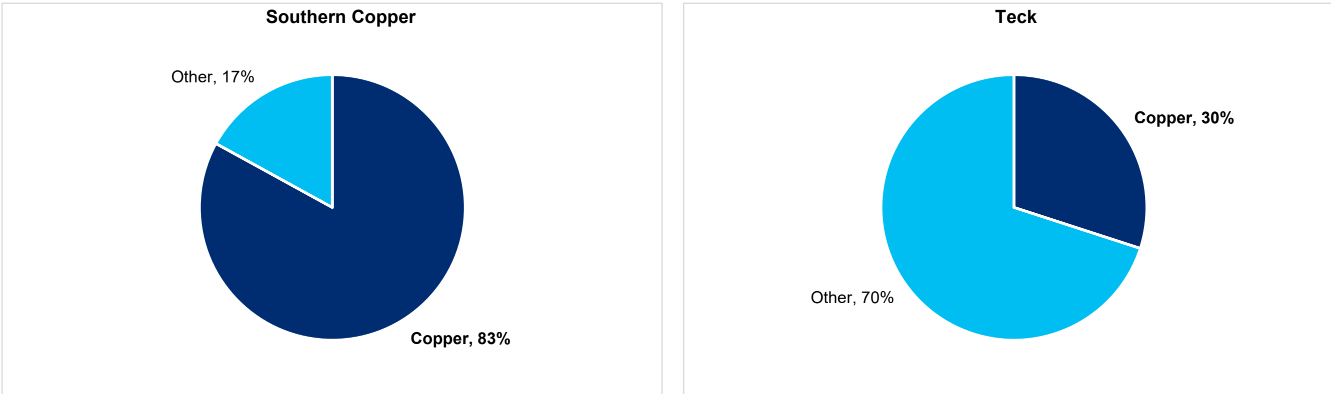


Source: Company reports, Citi Research

Figure 153. Copper in revenue mix

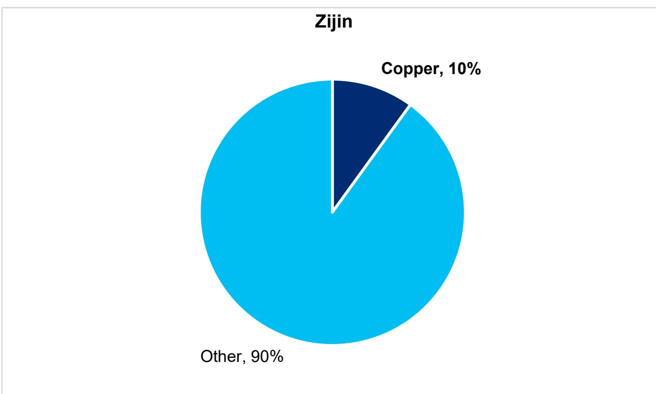
Source: Company reports, Citi Research

Figure 154. Copper in revenue mix



Source: Company reports, Citi Research

Figure 155. Copper in revenue mix



Source: Company reports, Citi Research

Companies Mentioned:

Rio Tinto Ltd (RIO.AX; A$96.54; 1; 07 Oct 21; 16:00) | OZ Minerals Ltd (OZL.AX; A$21.92; 1; 07 Oct 21; 16:00) | Teck Resources (TECKb.TO; C$30.91; 1; 06 Oct 21; 16:00) | First Quantum Minerals Ltd (FM.TO; C$23.88; 1H; 06 Oct 21; 16:00) | Antofagasta (ANTO.L; £13.5; 2; 07 Oct 21; 16:30) | Rio Tinto PLC (RIO.L; £49.51; 1; 07 Oct 21; 16:30) | Anglo American PLC (AAL.L; £26.57; 1; 07 Oct 21; 16:30) | Boliden AB (BOL.ST; SKr295.4; 3; 07 Oct 21; 17:30) | Southern Copper Company (SCCO.N; US$56.2; 2; 06 Oct 21; 16:00) | Grupo Mexico (GMEXICOB.MX; P$80.82; 1; 06 Oct 21; 14:00) | Jiangxi Copper (0358.HK; HK$14.04; 2; 07 Oct 21; 16:10) | MMG (1208.HK; HK$3.37; 1; 07 Oct 21; 16:10) | Freeport McMoRan (FCX.N; US$31.71; 1; 06 Oct 21; 16:00) | KGHM Polska Miedz SA (KGH.WA; Zl155.5; 3; 07 Oct 21; 17:00) | Zijin Mining (2899.HK; HK$9.46; 1; 07 Oct 21; 16:10) | Sandfire Resources Limited (SFR.AX; A$5.05; 1H; 07 Oct 21; 16:00) | China Molybdenum (3993.HK; HK$4.85; 1; 07 Oct 21; 16:10) | Glencore PLC (GLEN.L; £3.58; 1; 07 Oct 21; 16:30)

Please see sources for figures below:

Fig 25-26: Citi Research, Bloomberg, SMM, Cohilco Wood Mackenzie
Fig 27-37: Citi Research, Bloomberg, Wood Mackenzie, ICA, ICSG, BGRIMM
Fig 84-85: Citi Research, Bloomberg, SMM, Cohilco Wood Mackenzie
Fig 86-91: Citi Research, Bloomberg
Fig 92-110: Citi Research, Company Reports, Wood Mackenzie, ICSG, BGRIMM
Fig 111-114: Citi Research, Wood Mackenzie
Fig 115-125: Citi Research, ICA, Bloomberg, ICSG, Wood Mackenzie
Fig 127-129: Citi Research, ICSG, Wood Mackenzie, BGRIMM
Fig 133: Citi Research, ICSG, ICA, Bloomberg, Wood Mackenzie, BGRIMM

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Appendix A-1

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