Goldman Sachs | Commodities Research

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Green Metals

Solving Aluminium's Climate Paradox

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Aluminium as both a cause and a cure for climate change. At the heart of the coming surge in green aluminium demand lies a paradox: aluminium is a key input required to produce decarbonising technologies like EV's and solar power, yet its own production is very carbon intensive, generating 2% of all global emissions. This paradox begs the question: how can we secure enough aluminium to effectively decarbonise, while keeping the climate impact of the path to net zero to a minimum? In our view, the resolution of this paradox will drive a structural bull market in aluminium over the next half decade, driven by the necessity to grow supply to meet green demand while cutting emissions to prevent a climate catastrophe. Indeed, if copper's conductive properties place it at the heart of a sustainable energy system, aluminium's high emissions place it at the heart of the drive for industrial decarbonisation. Precisely because of its high emissions intensity, we see the key incremental driver of aluminium as material cost-inflation amid a sharp deceleration in primary metal production, rather than a comparative surge in green demand like copper. We have little doubt that investors should view aluminium as currently in the early stages of a multi-year bull market.

Decarbonisation is inflationary for aluminium. How then, can policymakers tip the aluminium industry toward a low-carbon equilibrium? In our view, the resolution of this climate paradox necessitates higher prices today. As the path to net zero requires a fundamental shift in production technology, policy must create a 'green margin' to simultaneously incentivise investment in expensive green production whilst meeting rising demand. Without decarbonised technologies offering greater profits than their carbon intensive counterparts, producers will not start the process of decarbonisation. Often, these policy incentives are designed to penalise more carbon intensive production, generating cost-inflation for dirty producers. For example in China, caps to aggregate aluminium supply will likely initially create a structural green deficit, forcing up aluminium prices so that only green capacity additions can take advantage of. In Europe, the emissions trading scheme will increasingly force producers to internalise the climate cost of aluminium by buying credits. Moreover, this cost inflation will be exported to producers from the rest of the world by a carbon border tax, likely to be rolled out next year, preventing the substitution of low carbon aluminium with cheaper, brown aluminium. In either case, aluminium prices must rise, in our view, as producers pass on higher carbon-related costs to consumers.

Climate policy is driving metal deficits today. Decarbonising aluminum supply requires capital, but ESG investment practises are shunning traditionally carbon intensive commodity production. Moreover, for those that wish to invest, they are facing a decade of growing policy risk, creating heightened uncertainty over future returns. Together with China's capacity cap, this growing policy risk premia has curtailed investment in additional aluminium capacity outside China. Indeed, aluminium is facing a classic 'revenge of the old economy scenario' – Western capacity actually peaked in the late 2000's and has shrunk ever since. There has been no new DM capex into incremental capacity, whilst broader RoW supply side additions ex-China curtail for now from early 2022. Whilst an aluminium smelter has a shorter construction timeline (brownfield ~2 years, greenfield 3-4 years) than a copper mine (brownfield 3-4 years, greenfield 6-8 years), from a starting point of essentially no growth appetite from the sector, the time lags still mean that supply growth is set to decelerate sharply into mid-decade. In fact, we expect the first half of the 2020's will see the lowest five-year period for global primary metal supply growth in close to 40 years. This will be set against a green reinforced demand environment, which will generate an extension through the 2020's of what has been a very strong decade for aluminium consumption in the 2010's. The net fundamental impact is that the aluminium market has now entered a phase of progressively larger deficits that in cumulative terms will amount to 3Mt by the end of 2023 and as high as 9Mt by mid-decade. From a starting point of estimated total global inventory close to 12Mt, this fundamental path will generate the tightest market conditions since the late-2000's when aluminium last sustainably traded above the $3,000/t level just as we expect over the next few years.

Policy shift provides structural support for an aluminium bull market. Underpinning our view for a decade of aluminium cost inflation is the fact that the world is now clearly focused on climate change. In the last 6 months alone, economies making up 67% of global GDP have announced polices that strengthen their commitment to solving climate change, from China's 2060 net zero pledge or Europe's carbon border tax proposal. In our view, this represents part of the structural shift in policy we have highlighted since the middle of the pandemic. In the last 30 years, systemic shifts in climate policy have been curtailed by the inability of policymakers to form a consensus on how to adequately protect the losers from such a shift. Yet with a renewed focus on redistribution, and a new awareness of the power of the state to tackle social need, we see this structural block against climate policy beginning to shift, as policy makers have become comfortable with pushing through sweeping changes during the pandemic. This willingness to 'act big' creates upside skew in the pace of decarbonisation, and hence aluminium prices. Moreover, as the world goes local, climate policy is increasingly being used as a tool of strategic competition, from European carbon border taxes to Biden's requirement for American made green technology. As we have often said, the trend of policymakers placing climate at the heart of domestic and foreign policy not only reduces the left-tail risks to green capex, but cements policy support at the centre of our structural bull thesis for commodities – and aluminium is no exception. Precisely because this shift in the aluminium market is driven by the structural break in macro policy, the last decade is a poor guide to the coming ten years. This fact is reinforced at the micro level where the market has shifted from an era of highly price elastic supply to one of limited supply responses underpinned by carbon based cost inflation creep. As a result, existing price models break down, generating the need to look beyond recent quantitative relationships when forecasting future returns.

Slow and steady will win the aluminium policy race. It is hard to understate the transformational effect this shift in climate policy will have on the aluminium market – on its physical emissions, distribution of global trade and pricing. First, physical emissions will likely continue to fall as new low carbon technologies such as inert-anodes and hydro powered smelters become ubiquitous. Second, production centers and trade routes will begin to bifurcate between those countries implementing strict emissions targets and carbon border taxes - led by Europe – and those who are both willing to produce and consume brown aluminium – likely led by India. Third, we believe that in the long run, cost-curve inflation generated by an industrial carbon price will dominate hard capacity caps as the driver of aluminium's decarbonisation policy. Capacity caps create convex price risks as deficits grow abruptly, generating volatility in prices often deemed unacceptable by policymakers. This is evident from the recent delays to implementing China's national steel production caps, and creates risk to the aluminum capacity cap if onshore prices rise too aggressively in coming years. A more controlled approach – as is occurring with the start of ETS phase 4 in Europe – prevents near term uncertainty over physical inflation. In fact, as China shifts from a commodity exporting economy to a high-value consumer economy, it will likely stop exporting commodity price deflation as it curtails total capacity to meet only domestic demand, strategically retaining its cheap energy advantage. The gradual curtailment in China's aluminium product exports will have an important further tightening effect on Western balances and reinforces the need for higher Western prices to drive supply investment.

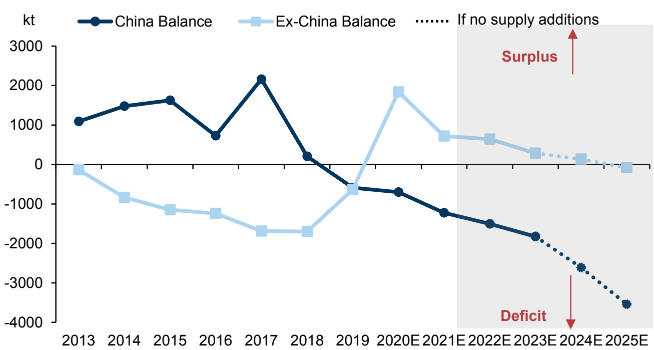
The real green premium lies in decarbonised margins. There has been much investor discussion of the pricing dislocations that climate policies may generate in the aluminium physical market. Most of these are focused on the idea that a green premium may develop as a differentiator between metal units on a carbon footprint basis. Whilst there is no doubt that modest carbon premiums already exist in the market and are closely tied to certain aluminium brand carbon footprint perceptions, the path from that to a broader and more substantial pricing dichotomy is less clear cut. The main challenge is that all LME deliverable ingots are fungible, so forcing consumers to pay materially more for a metal unit whose added value is defined by a historical production path rather than added value to the consumer is unreasonable. It is possible that the introduction of an exchange contract delineating aluminium by carbon content could generate some extra value. However, the clearest channel for a green premium in our view is via the additional margin that producers will gain from either existing green or prospective green margin benefits. This margin is generated when policy forces producers to pay more for carbon intensive production, but who are then forced to compete with cheap production methods of their decarbonised counterparts. We do however expect a strong environment for regional physical premium going forward irrespective of direct green component, reflecting overall deficit conditions, material inventory declines and regional dislocations, as well as China's increasing import requirements.

The metal research team would like to thank Annalisa Schiavon and Aditi Rai for their contribution to this report. Annalisa is an intern with the commodities research team.

Aluminium's coming bull market in 6 charts

Exhibit 1: Global aluminium market is set to trend into significant deficit over the next 3 years

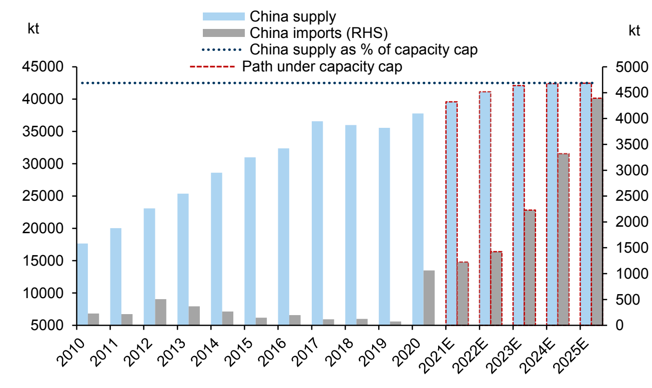
Aluminium China and Ex-China balance



Source: Woodmac, CRU, Goldman Sachs Global Investment Research

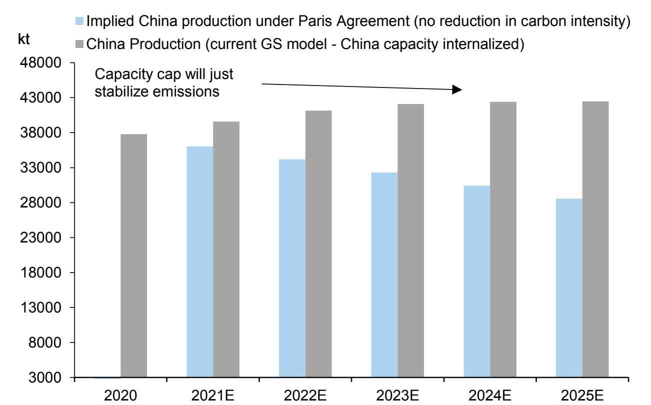
Exhibit 2: China's capacity cap will taper supply growth and support rising import volumes

China supply and imports under capacity cap



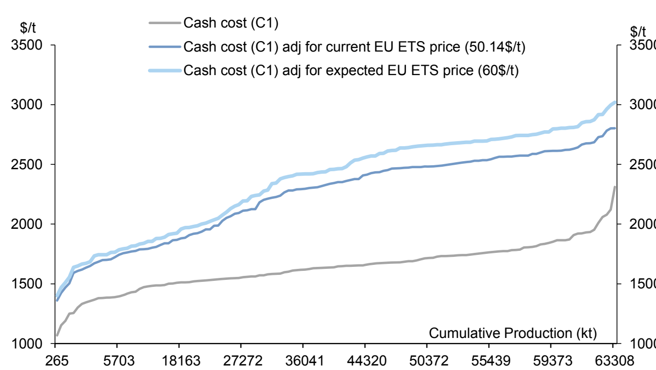
Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 3: But that will only be the beginning in China's sector adjustments given emissions targets



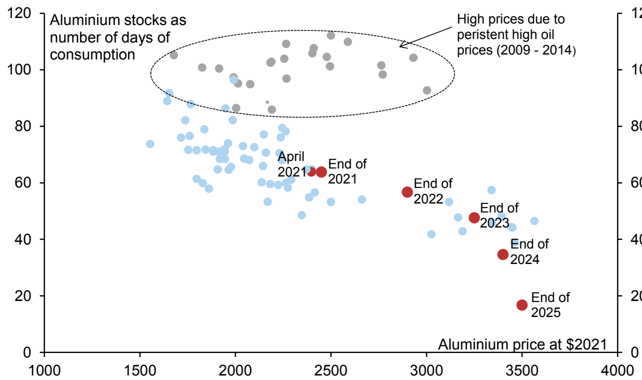
Source: Woodmac, IAI, Goldman Sachs Global Investment Research

Exhibit 4: Higher carbon prices will generate a progressive and significant inflationary effect on smelting costs



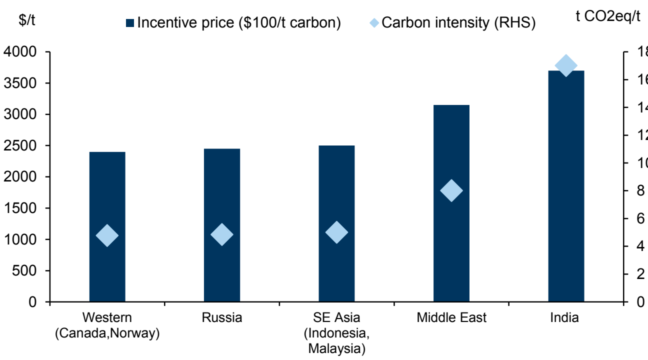
Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 5: Tightening path in balances points to significant tightness and higher prices over the next 2-3 years
Aluminum stocks as number of days of consumption vs aluminium price at $2021



Source: Wind, World Bank, Goldman Sachs Global Investment Research

Exhibit 6: Supply investments will eventually emerge but higher prices and decarb policy certainty are needed



Source: Woodmac, Goldman Sachs Global Investment Research

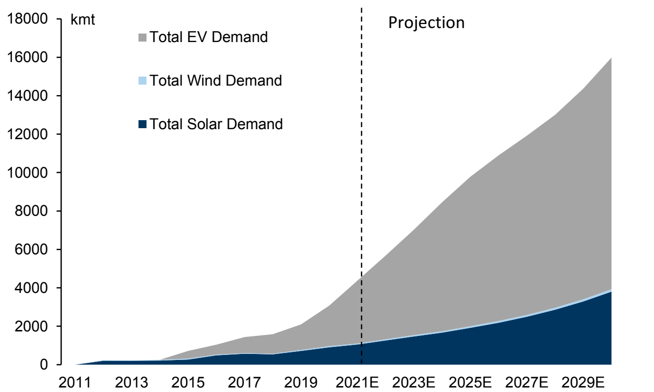
Deciphering Aluminium's Decarbonisation Trends

The green transition is undoubtedly the dominant production shift across industrial commodities in the 2020's. Aluminum's position in this shift is relatively unique amongst the base metals in the sense that it is both a key raw material for the technologies needed to achieve the green transition but also a commodity with a significant carbon footprint in its production process. Just like copper, aluminium is a metal with higher intensity of use in key green sectors such as EV's and solar, underpinned by its qualities as a light-weight metal with electrical conductivity and recyclability leave it well positioned for usage in the green economy. Understanding the demand side impact from the new consumption channels in the green economy is a critical step in gauging the fundamental impact from the transition. However, unlike copper, the significant carbon intensity involved in the primary aluminum production process also means the green transition will necessarily have a significant impact on supply-side dynamics. In this section we consider in detail both key channels of effect on the aluminium market, quantifying the green demand volumes and supply-side impact from current/prospective decarbonisation focused policies.

Green electrification set to generate an additional 12Mt of aluminum demand by 2030

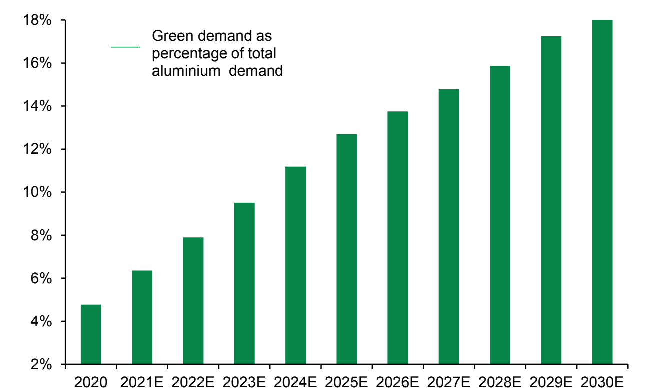
The past 12 months has seen a significant shift towards clearer commitments to stricter emissions targets from the world's largest emitters. China, accounting for 27% of global CO2 emissions, pledged to reach peak carbon by 2030 and net zero emissions by 2060, Biden set a target of 50-52% reduction of GHG emissions by 2030 and the EU has committed 37% of the 750bn Recovery Fund to the green transition. Switching to the green technologies needed to achieve these emission reduction targets also requires a great amount of metals. Using a bottom-up methodology, as we employed with copper, we have attempted to quantify the green implications for aluminium demand. Our analysis shows that in aggregate 'green' aluminium amounted to 3Mt in 2020, just 4% of total global aluminium demand. However, our modeling suggests a rapid acceleration in green demand growth from here rising to 9.8Mt by 2025 (12% total global demand) and then 16Mt in 2030 (19% of total global demand). We estimate that green demand will grow at an average annual growth rate of 18% y/y in the 2020s, generating 1.3Mt per year of growth in demand volumes.

Exhibit 7: Global green aluminium demand to rise by 13Mt over the decade, increasing by 18% y/y on average
Aluminium demand, per year, by green sector



Source: IEA, IRENA, Goldman Sachs Global Investment Research

Exhibit 8: Green demand will rise to 18% of total global demand by 2030
Green aluminium demand as percentage of total aluminium demand



Source: Woodmac, Goldman Sachs Global Investment Research

How Aluminium's elemental properties make it uniquely suited to the green transition.

Aluminium is the most abundant metallic element in the Earth's crust and the most used non-ferrous metal. This widespread adoption is due to its physical, chemical and mechanical properties that make it central in the green transition.

• **Low specific weight.** For its level of reactivity, aluminium nuclei are lighter that the ones of the other metals, giving aluminium a low density.

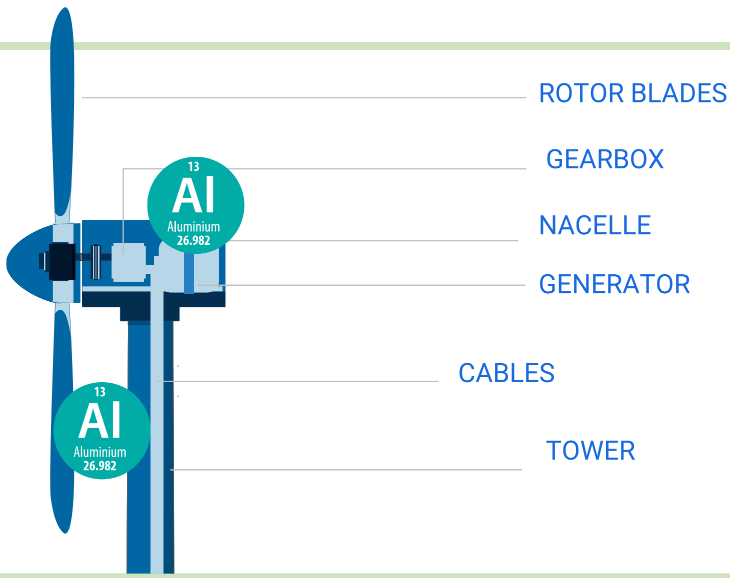
- **Durability:** When mixed with a number of alloys such as magnesium, silicon and zinc, wrought aluminum can have a tensile strength three times that of steel, making it key for applications such as electric vehicles, planes, or offshore wind turbines.

• **Electrical conductivity.** Like copper, silver and gold, aluminium valence electrons are not bound strongly to its nucleus, allowing for a free flow over the metal lattice.

• **Recyclability.** Aluminium can be recycled indefinitely as it does not lose its key elemental properties in the process. In fact, the recycling process is so straightforward, 75% of aluminium ever produced is still in circulation today.

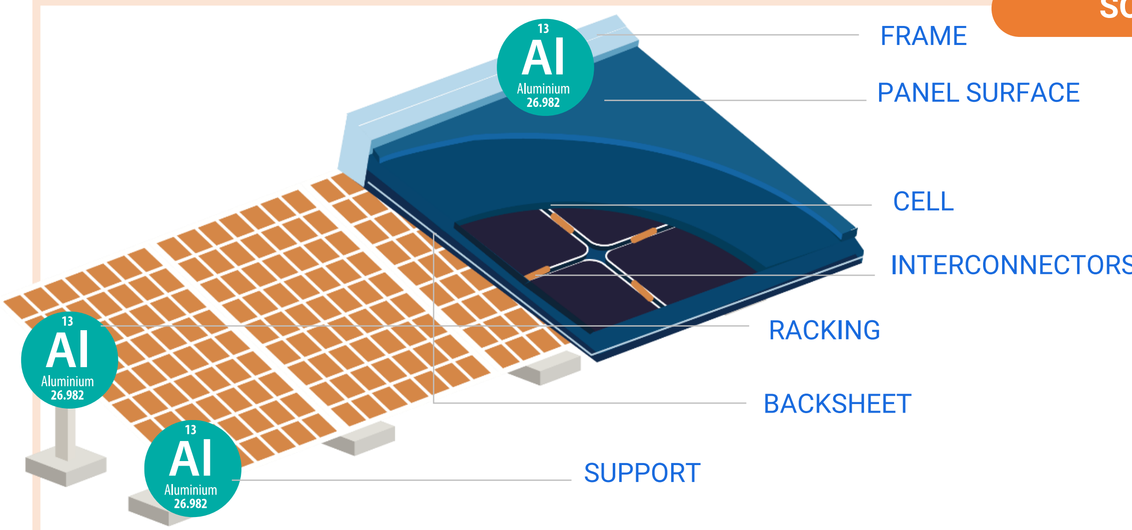
How Al Will Power the Next Generation of Clean Tech

WIND TURBINE



Wind power demand for aluminium is expected to grow by 7% annually for the next decade, with upside risk from further policy support to offshore farms.

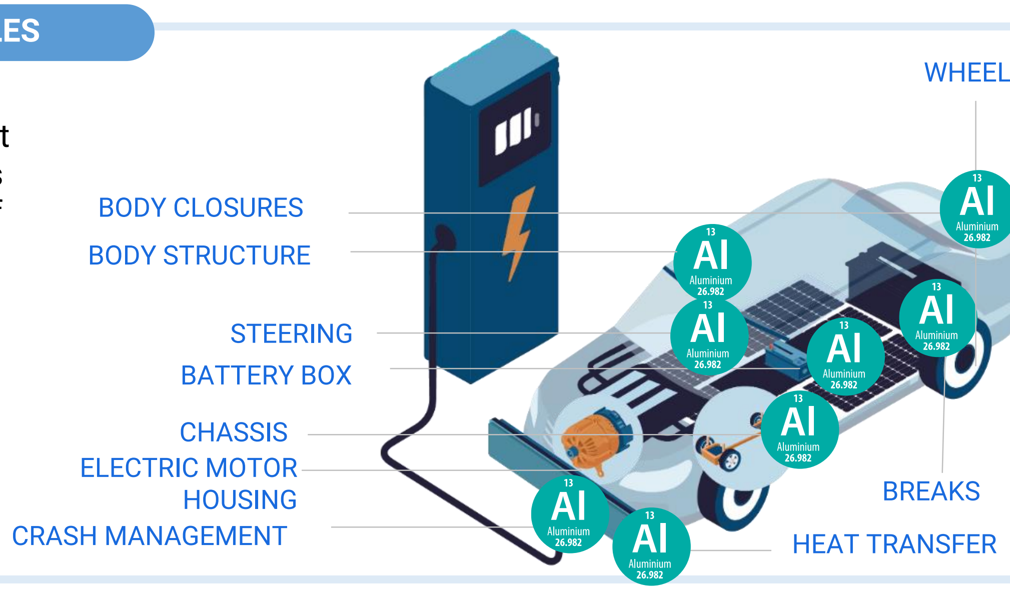
SOLAR PANELS



Solar will account for 20% of aluminium green demand as the metal is crucial to protect and support the PV systems.

ELECTRIC VEHICLES

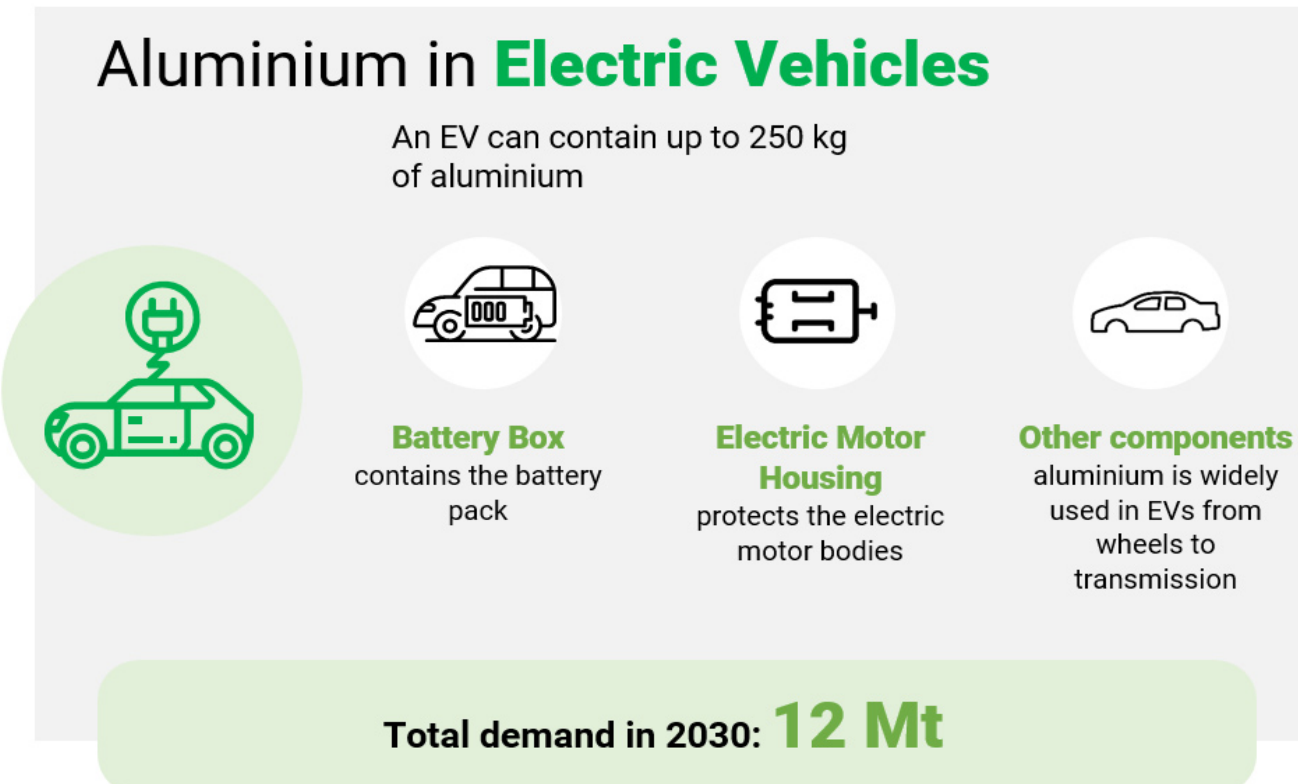
In a hunt for lighter weight and higher efficiency, EVs will be the main drivers of aluminium green demand with an annual volume of 12 Mt by 2030.



Source: World Bank, IAI, Goldman Sachs Global Investment Research

Electric Vehicles - the engine of green aluminium demand

EVs will be the main driver of aluminium green demand as the sector displays continuous expansion on the back of mounting support by governments and improving economics. Indeed, we see aluminium demand from EVs accelerating throughout this decade, with EVs accounting for over 65% of the total green demand. We forecast EV-related demand to amount to 12Mt of aluminium by 2030 (vs. 2.1Mt in 2020), growing at a rate of 20% a year for the remainder of the decade.

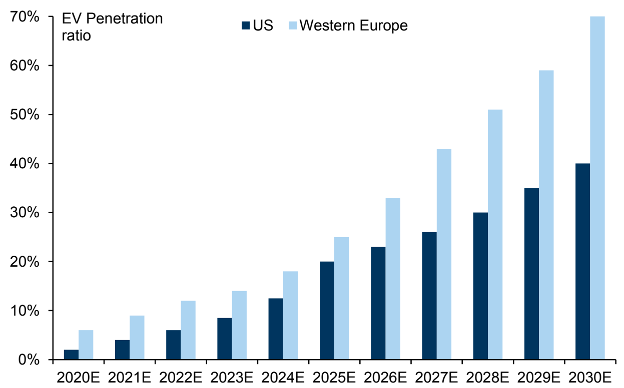


Source: European Aluminium Association, IAI, Goldman Sachs Global Investment Research

An EV contains on average 250kg of aluminium, 70kg more than an ICE vehicle. Aluminium is used for a number of different components, related both to electrification (battery casing, electric motor housing) and to more traditional uses as wheels, transmission, chassis, body closures and structure, breaks and steering. Despite the last years' trend of increasing aluminium in cars, to improve fuel efficiency and reduce emissions, our analysts suggested that as we move to widespread EV adoption OEMs can turn to steel to meet the demand of more price conscious consumers. To take into account this potential scenario we assume aluminium intensity decreases by 20% by 2030.

Exhibit 9: 2030 EV penetration ratio will be 70% and 40% in Europe and the US

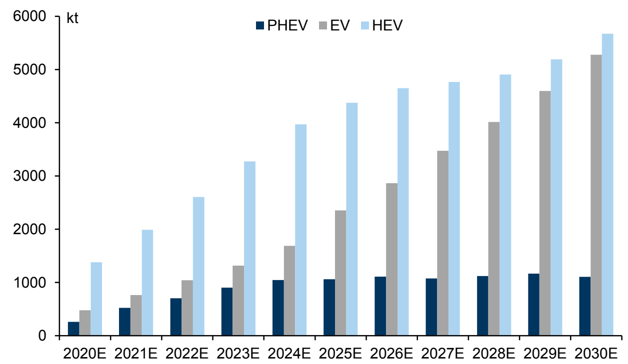
EV penetration ratio



Source: Goldman Sachs Global Investment Research

Exhibit 10: We see aluminium demand from EVs growing to 12Mt by the end of the decade

Aluminium demand from EVs



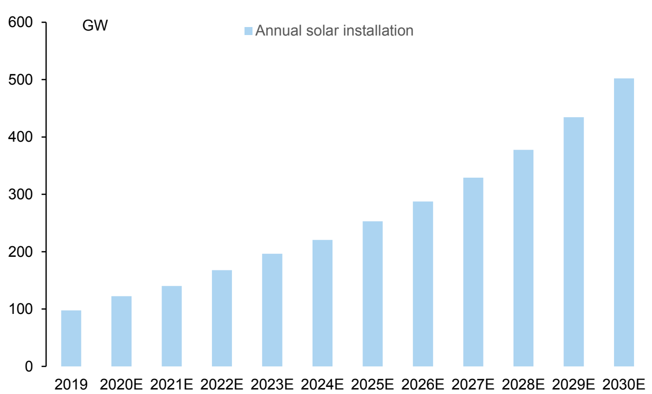
Source: Goldman Sachs Global Investment Research

Renewables - Solar dominates wind intensity

According to EIA projections energy consumption will increase by 50% over the next 30 years and at the same time countries will have to reduce emissions to comply with policy targets. To achieve the latter and also meet the demand, countries are transitioning to a greener energy supply driving increasing metals demand for solar and wind installations. Aluminium is at the core of construction and structure of solar panels and around 90% of the demand coming from renewables is from solar systems. We expect the demand from solar to grow on average by 15% in the next decade and reach 3.7Mt by 2030 in light of solar annual installations that we expect to increase on average by 16% thanks to solar competitiveness against fossil fuel energy sources. The Middle East will be a key region driving this demand, as cheap-oil producer countries transition to cheap-solar energy production. We expect 12% of the demand to come from this region by 2025, second only to China that will account for 30% of it by 2030.

Exhibit 11: Solar growth will be the main driver in aluminium demand from renewables

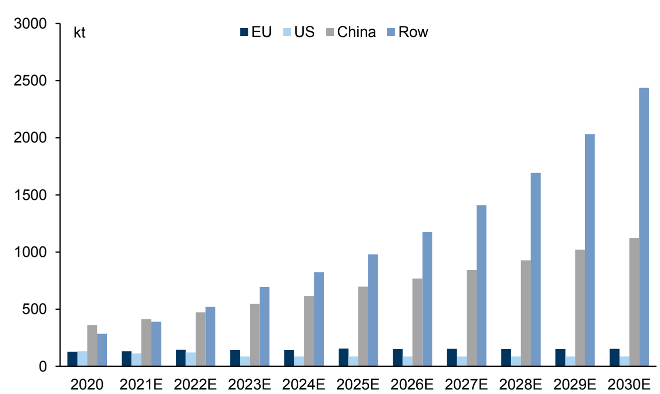
Solar annual installations



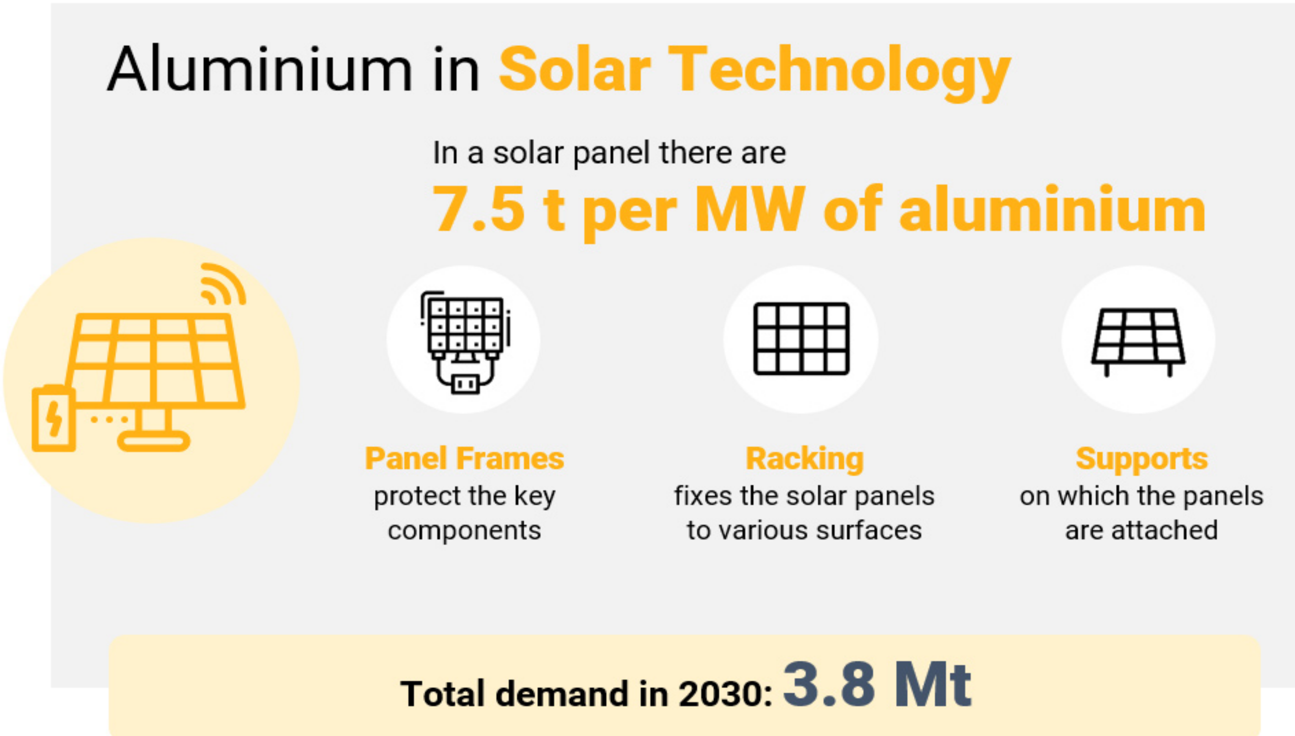
Source: Goldman Sachs Global Investment Research

Exhibit 12: Aluminium solar demand to reach 3.8Mt by 2030

Aluminium demand from solar PV panels, by region

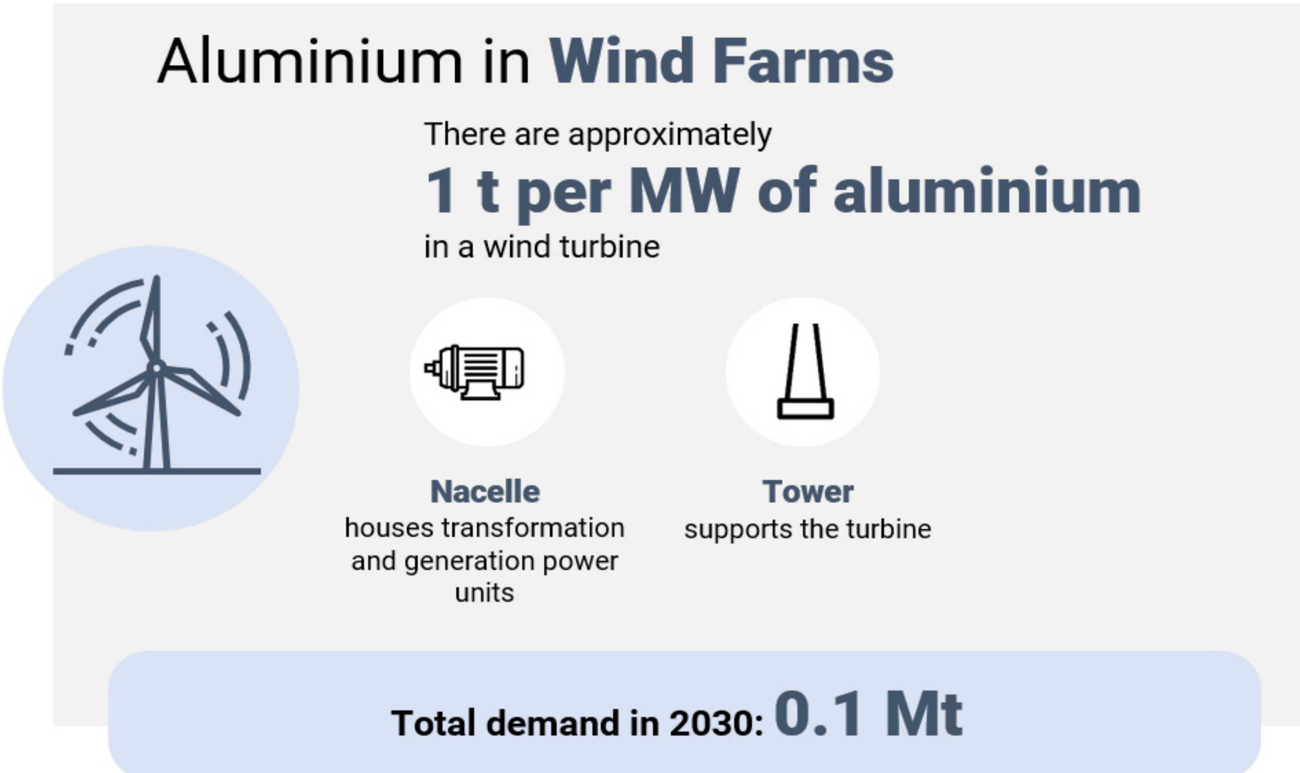


Source: IAI, IEA, IRENA, Goldman Sachs Global Investment Research



Source: European Aluminium Association, IAI, JRC, Goldman Sachs Global Investment Research

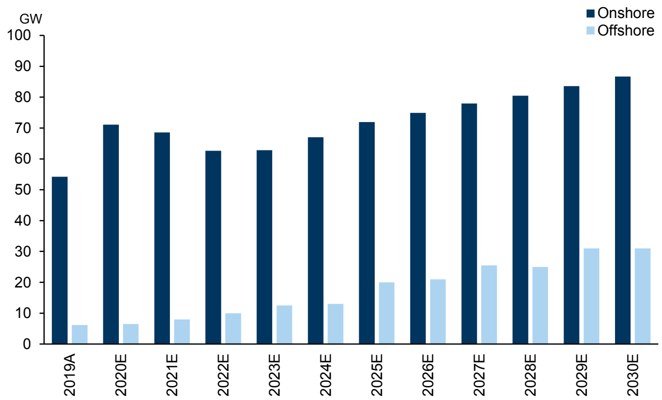
Aluminium accounts for more than 85% of solar PV panels components (7.5kt/GW) and it is used for the module frame, the racking and the mounting systems. These same components can be obtained from steel, however aluminium has gained in the years the highest market share and it is unlikely to lose its position thanks to its higher strength-to-weight ratio, lighter weight and higher resistance to corrosion that turns out to be crucial for systems that should last over 25 years. Nevertheless, we test the sensitivity of the demand on three different scenarios, assuming a decreasing intensity for solar panels in utility installations (steel would not be used on residential ones as it is too heavy). The analysis shows a decrease in demand by 4% with a 30% decrease in intensity by 2030, 6% with 40% decrease and 7% if intensity decreases by 50%.



Source: European Aluminium Association, IAI, JRC, Goldman Sachs Global Investment Research

Wind power will have a very limited impact on aluminium demand as turbines have a material intensity that ranges just between 0.8kt per GW and 1kt per GW. We see the total demand coming from wind to reach 0.1Mt by 2030 growing at a rate of 7% annually. Accounting just for up to 2% of total raw materials of a wind turbine, aluminium is used for the nacelle that protects the energy transformation and generation components and in the tower. Aluminium demand from wind doesn't face any clear upside or downside risk of substitution from copper and steel respectively. Nevertheless, governments' incentives and policies can represent an upside risk for the demand. Last April the US committed to doubling offshore wind production by 2030, the NEA in China stated that wind, together with solar, should account for 16.5% of total society power consumption in 2025 and in 2020 the EU presented the EU Strategy on Offshore Renewable Energy to increase offshore wind capacity to 300GW by 2030.

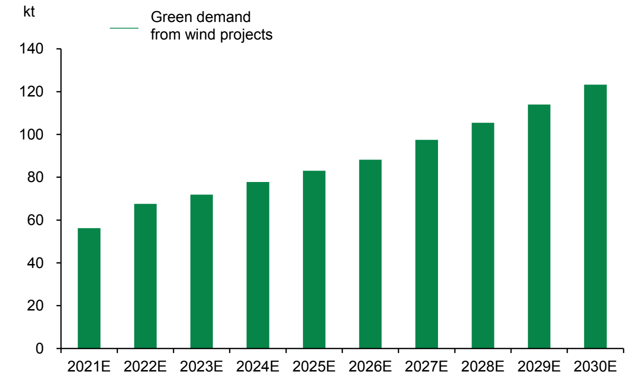
Exhibit 13: Wind installations out to 2030



Source: Goldman Sachs Global Investment Research

Exhibit 14: Aluminium demand from wind to grow by 7% in the next decade

Aluminium demand coming from wind



Source: IAI, IEA, IRENA, Goldman Sachs Global Investment Research

GS Global green aluminium demand model

Exhibit 15: Quantifying green aluminium demand by sector and region

('000's tonnes)	2020	2021E	2022E	2023E	2024E	2025E	2026E	2027E	2028E	2029E	2030E
Solar											
EU	127.1	132.8	145.1	143.3	143.3	154.9	152.4	154.3	152.4	152.4	154.3
% change	*15%*	*4%*	*9%*	*-1%*	*0%*	*8%*	*-2%*	*1%*	*-1%*	*0%*	*1%*
US	132.0	114.0	121.5	87.0	87.0	87.0	87.0	87.0	87.0	87.0	87.0
% change	26%	-14%	7%	-28%	0%	0%	0%	0%	0%	0%	0%
China	361.5	412.5	472.5	547.5	615.0	697.5	767.3	844.0	928.4	1021.2	1123.3
% change	66%	14%	15%	16%	12%	13%	10%	10%	10%	10%	10%
Row	285.5	391.1	520.5	694.7	823.5	979.6	1,175.5	1,410.6	1,692.8	2,031.3	2,437.6
% change	0%	37%	33%	33%	19%	19%	20%	20%	20%	20%	20%
Total Solar Demand	**906**	**1,050**	**1,260**	**1,472**	**1,669**	**1,919**	**2,182**	**2,496**	**2,861**	**3,292**	**3,802**
Wind											
EU	11	12	14	12	12	13	13	15	15	15	16
% change	21%	10%	18%	-14%	-6%	10%	1%	17%	0%	0%	9%
US	9	8	8	9	10	8	8	9	9	9	9
% change	26%	-10%	2%	12%	14%	-17%	0%	11%	0%	0%	0%
China	35	27	35	38	42	46	49	52	57	62	66
% change	77%	-23%	29%	11%	10%	9%	6%	7%	9%	9%	6%
Row	9	10	11	12	14	16	18	21	24	28	32
% change	-24%	13%	13%	13%	14%	14%	14%	14%	15%	15%	15%
Total Wind Demand	**63**	**56**	**68**	**72**	**78**	**83**	**88**	**97**	**105**	**114**	**123**
Electric Vehicles											
EU	1,159	1,810	2,124	2,387	2,731	2,783	3,087	3,131	3,123	3,161	3,149
% change	132%	56%	17%	12%	14%	2%	11%	1%	0%	1%	0%
US	166	296	427	604	874	1,209	1,294	1,375	1,484	1,620	1,747
% change	5%	78%	44%	41%	45%	38%	7%	6%	8%	9%	8%
China	296	581	1,094	1,640	2,077	2,604	2,851	3,078	3,308	3,544	3,806
% change	2%	97%	88%	50%	27%	25%	9%	8%	7%	7%	7%
Row	494	588	709	861	1,023	1,191	1,393	1,738	2,126	2,632	3,357
% change	29%	19%	21%	21%	19%	16%	17%	25%	22%	24%	28%
Total EV Demand	**2,115**	**3,275**	**4,353**	**5,492**	**6,705**	**7,787**	**8,625**	**9,321**	**10,040**	**10,956**	**12,059**
By Region											
EU Renewable Demand	1,297	1,955	2,283	2,543	2,886	2,951	3,253	3,300	3,290	3,328	3,320
US Renewable Demand	307	418	556	700	971	1,304	1,389	1,471	1,580	1,716	1,843
China Renewable Demand	692	1,021	1,601	2,226	2,734	3,348	3,667	3,974	4,293	4,628	4,996
RoW Renewable Demand	788	988	1,241	1,568	1,860	2,186	2,587	3,169	3,843	4,691	5,826
Global Aluminium Demand	**3,084**	**4,382**	**5,681**	**7,037**	**8,452**	**9,789**	**10,895**	**11,914**	**13,006**	**14,362**	**15,985**
% change	*47%*	*42%*	*30%*	*24%*	*20%*	*16%*	*11%*	*9%*	*9%*	*10%*	*11%*

Source: IAI, CRU, IEA, IRENA, Goldman Sachs Global Investment Research

Decarbonisation will drive a structural shift in aluminium supply

The aluminum production process is carbon intensive, yet without aluminum decarbonisation can't happen. The green transition requires then, in our view, firstly a decarbonisation of metal supply required for the green transition of the rest of the economy. Decarbonizing aluminium supply requires investment and implies higher costs for aluminium smelters. Our analysts estimate that to relocate Chinese capacity to hydro-rich provinces an additional Rmb35bn of capex would be required to switch from coal-captive power to the grid. Such a switch would drive up the unit cost of production by Rmb870/t. Moreover, moving from a carbon anode to an inert anode for the electrolysis (it currently accounts for 10% of smelters' emissions) would translate into high licensing costs for smelters. With a market increasingly dominated by ESG investments and until recently low margins in aluminium sector, we expect that policy makers will be the ultimate driver of aluminium decarbonisation by incentivizing producers to switch production technologies.

Primary aluminium and its carbon footprint

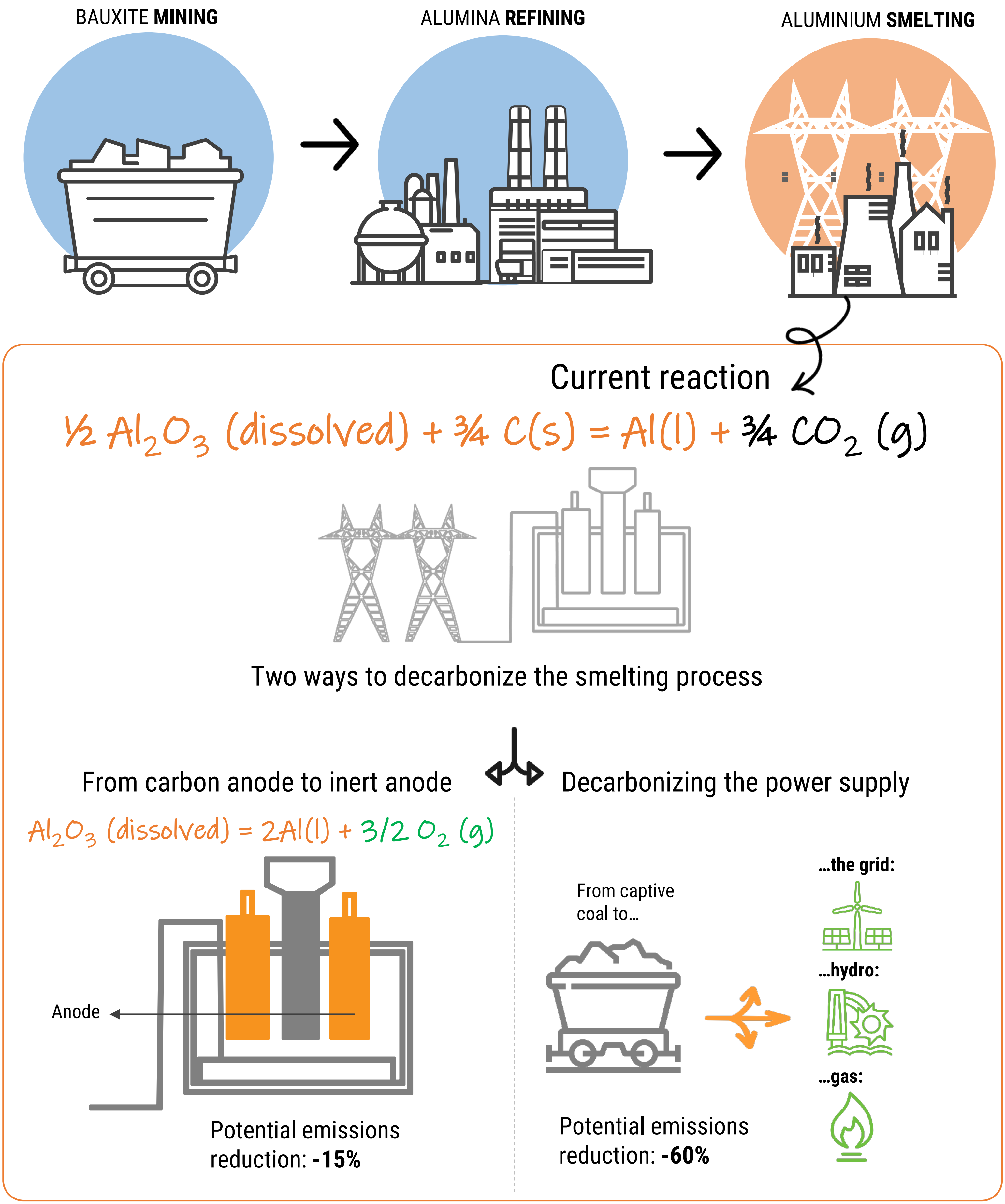
Primary aluminium production emits on average 16.5 CO_2e/t and aluminium smelting is responsible for 77% of it. Smelting is done via the Hall-Héroult process that involves obtaining aluminium from alumina through electrolysis. In the electrolytic cell three processes happen: reduction of alumina into aluminium, formation of CO_2 and heat transfer enable the products to achieve a state such that they can be removed from the cell.

Indirect emissions accounts for 80% of CO_2e produced during the smelting process. The chemical reaction happening in the electrolytic cell requires on average 14.2 KWh/kg of aluminium. Hence, the source of electricity determines most of the overall carbon footprint of aluminium. Carbon intensity is 11.6 CO_2et/t for coal-powered energy, 7 for natural gas, 0.3 for hydro and 0.17 for nuclear.

Direct emissions from the electrolysis of alumina accounts for 10% of the total. During the Hall-Héroult process carbon anodes react with the oxygen released from alumina, forming predominantly CO_2. As long as carbon anodes are used CO_2 emissions, between 1.4 and 1.6 CO_2/t, cannot be avoided.

Smelting process produces further direct emissions from the anode effects. The anode effect is triggered by a decrease in the alumina concentration and determines high voltage, interruption of the aluminium production and production of perfluorocarbons (PFCs) for an amount corresponding to 0.6 t CO_2e/t (4.7% of primary aluminium production emissions).

Aluminium to net zero

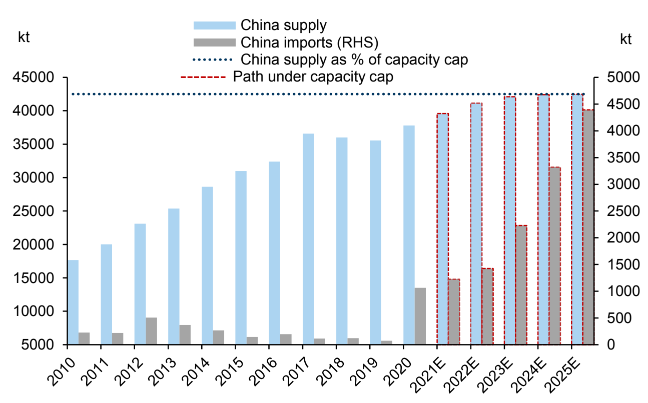


Source: IAI, European Aluminium Association, Goldman Sachs Global Investment Research

Policy makers can incentivize the transition on the aluminium supply side in two ways. First, by limiting coal powered production and thus creating a scarcity of aluminium to be filled by green producers or second, by making it uncompetitive by internalizing the cost of emissions in the cost of production. China is currently following the first path. In 2017 Beijing put in place a cap on smelting capacity at 45Mty alongside strict old-for-new replacement capacity rules. At the time there was only 41Mty but over the course of the past four years that figure has risen to close to 45Mty (as defined as capacity in operation). China's production will hit 40Mt in 2021, so there still remains some ability for smelters to flex production towards their maximum operating rate which we see being hit by 2024 (~43Mty output). After that point, we project that onshore primary production will flat line and that additional China supply will either come from secondary smelting capacity additions or via the primary metal import channel.

We believe that this capacity cap will be hard and that from the end of this year, any onshore primary smelting capacity additions will have to be in place of closing older capacity and likely directed to locations where greener power sources are available. A progressive increase in power prices and eventually carbon pricing will act as a push factor alongside an elevated aluminium price for producers to swap to greener operations. We have already seen energy reduction targets resulting in certain provinces forcing cuts on the smelting sector and this is likely to continue as progressively lower energy consumption targets have to be met. There has already been a significant build out of replacement capacity in Yunnan province (from 1.5Mty in 2017 to 4.7Mty this year) reflecting the high levels of hydro generating power capacity in the province. We expect a continued trend of green replacement capacity though this will not represent net capacity growth and importantly, will be restrained by the pace of green power expansion.

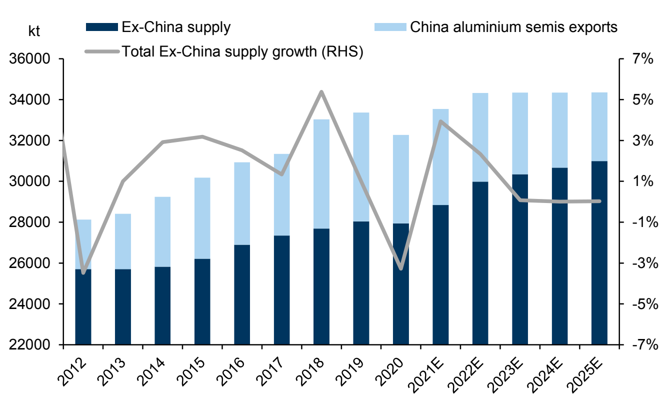
Exhibit 16: China's capacity cap is set to restrain supply growth and support higher import volumes



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 17: Ex-China supply growth will not be enough to cover for China deceleration

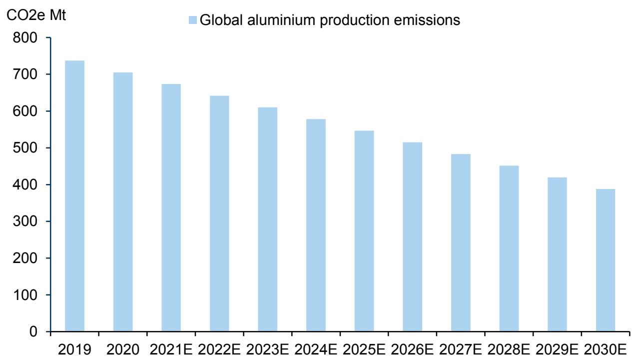
Ex-China supply and China semis exports



Source: Woodmac, Goldman Sachs Global Investment Research

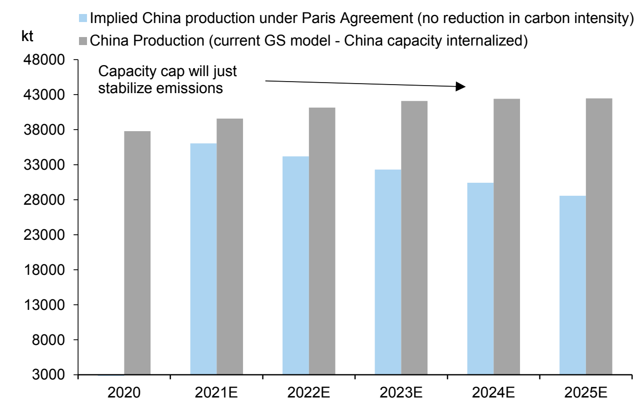
There are several implications for this particular policy instrument. First, it doesn't penalise more polluting aluminium smelters more than less polluting ones, making the majority of the technological transformation likely to happen on the extensive margin, not intensive. This means Chinese aluminium prices likely have to rise higher and more aggressively than the more tailored carbon tax approach. To illustrate why, we build a simple model analysing the "policy induced deficit" in the onshore and global markets under China current policy, and the policy needed to meet Paris Agreement targets. Assuming no change in average carbon intensity of production, we see that the growth of structural deficits would rapidly destock the onshore market and if the Paris Agreement was to be met it would likely leave the Chinese market in a deficit of 14Mt by 2025. The fast destocking implied by this policy instrument leads to scarcity pricing and increasing volatility. Indeed, spot prices would change dramatically given the absence of enough inventories to respond to the shock.

Exhibit 18: Aluminium sector is still far away from net zero
Global aluminium production emissions - Paris Agreement Targets implied path



Source: IAI, Woodmac, Goldman Sachs Global Investment Research

Exhibit 19: China cap will only be the beginning in China's sector adjustments given emissions targets
Current China aluminium production and implied path under Paris Agreement Targets

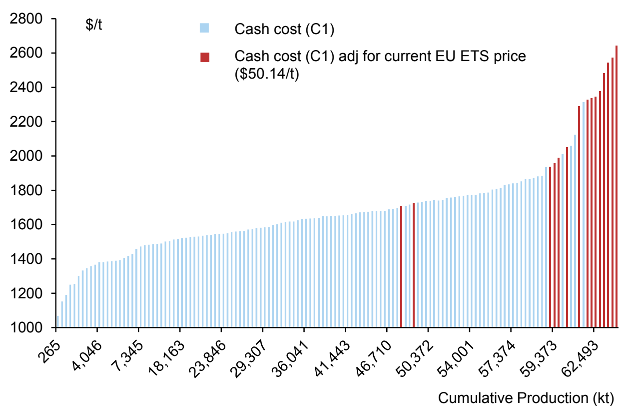


Source: Woodmac, IAI, Goldman Sachs Global Investment Research

Europe is taking a different approach with the EUA scheme. By incorporating a carbon price into the cost structure of producers, it accounts for the spread in pollution from different production technologies. This approach leads to three outcomes, the most polluting technologies become uncompetitive, European producers lose competitiveness in the international stage and the risk of carbon leakage increases. European policymakers are planning a carbon border tax to prevent the last two from happening. Under the current draft aluminium importers would have to buy CBAM (Carbon Border Adjustment Mechanism) certificates, with the price being based on the closing prices of European carbon auctions. We highlight the impact of this tax by adjusting the unit cost of European producers for the current EU ETS price. Internalizing emissions cost inflates the average European production cost from 1766$/t to 2160$/t, and moves 100% of European smelters costs above the 90th percentile of the distribution. We then analyse the impact of a carbon-price level consistent with meeting Paris Agreement Targets. The range needed according to the High-Level Commission on Carbon Price would be at least 40 – 80$/t by 2020 and 50 – 100$/t by 2030. A global carbon tax would result in the 90th percentile of the cost curve moving from ~$1,700/t to $2450/t – $3,200/t under the first scenario and to $2615/t – $3600/t under the second.

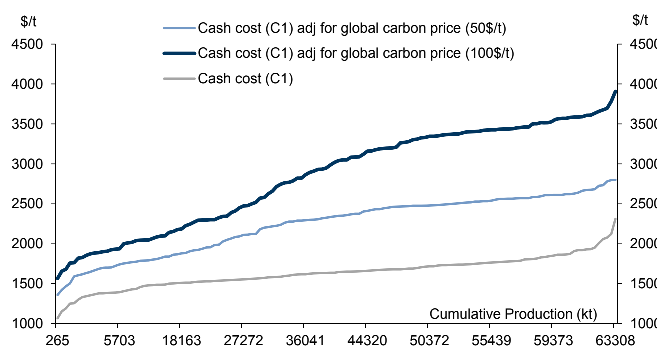
Ultimately we see the second approach dominating aluminium decarbonisation. It allows for incremental change in production technologies without triggering scarcity-driven prices and volatility as cost inflation has higher persistence over time. Moreover, ETS are growing outside Europe. On January 2021 China's national ETS came online, including for the moment just the power sector but with the scope of expanding it to the other seven sectors, including aluminium and in the US, Biden's administration will likely face mounting pressure on creating a carbon emissions market in the coming years. Despite policymakers' commitment to decarbonisation, aluminium transition faces some risks. First is China releasing the capacity cap as prices dramatically increase. We have seen that being suggested for steel production in Tangshan province after the latest rally. Second is a carbon trade war between Europe, US and China that would push up aluminium prices without incentivizing the transition. Biden's administration and China, along with other countries, have already pointed out how the CBAM could trigger WTO challenges and retaliatory taxes.

Exhibit 20: Carbon price moves European smelters above the 90th percentile of the cost curve
Aluminium cost curve adjusted for current EU ETS price



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 21: Higher carbon prices will generate a progessive and significant inflationary effect on smelting costs
Cost curve adjusted for global carbon price needed to meet Paris Agreement targets



Source: Woodmac, Goldman Sachs Global Investment Research

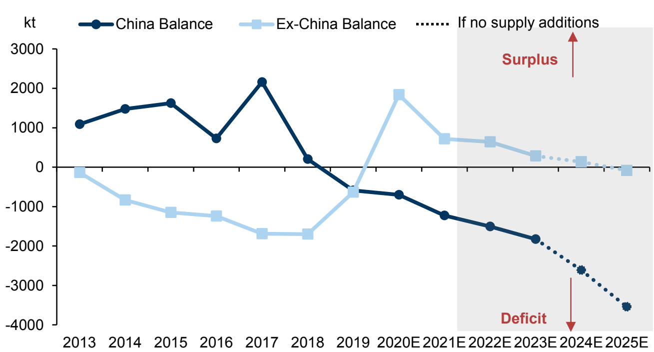
Balance impact: Caught between cost inflation and scarcity pricing

The fundamental impact on the aluminium market from the decarbonisation is nothing short of transformative. A combination of China's capacity cap being hit this year, no material ex-China capacity additions from 2022 and a green reinforced demand dynamic provide a clear tightening path for the commodity. We now see the aluminium market entering a phase of progressively larger deficits over the next 3 years which will generate a cumulative deficit just under 3Mt by 2023. Whilst global inventories start this phase at relatively elevated levels – we estimate total stocks are close to 12Mt – a near halving by the end of 2023 represents a material reduction in buffer versus the past decade for this market. If there are no softening adjustments between now and then, the current deficits in 2024 (2.4Mt) and then 2025 (3.6Mt) imply significant tightness in conditions. As with copper, the prospect of near term steady tightening trends combined with mid-decade scarcity risks, supports a necessary surge in pricing now to stimulate fundamental adjustments.

The shorter cycle of aluminium supply responses (2-3 years' smelter construction) than copper (6-8 years mine construction) however mean the fundamental path from mid-decade is less certain given a higher risk that supply adjustments can occur and have a softening impact on that time frame. However, for that to happen, prices need to both counteract inflationary forces from carbon costing, scarcity risks from deficit markets as well as compensate producers for investments made in a high uncertain decarbonisation policy environment. In this context, there is a very strong case for significantly higher price levels to transpire. We have little doubt that investors should view aluminium in the early stages of a multi-year bull market. Whilst supply responses are likely to emerge on this path higher, they will take several years to implement and in the interim a significant phase of tightening in fundamentals will likely occur.

Exhibit 22: Global aluminium market is set to trend into significant deficit over the next 3 years

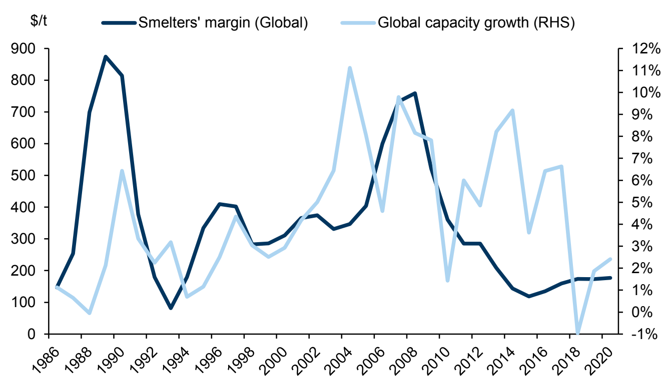
Aluminium China and Ex-China balance



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 23: Weak smelter margins in the 2010's mean a near depletion of capacity additions in the early 2020's

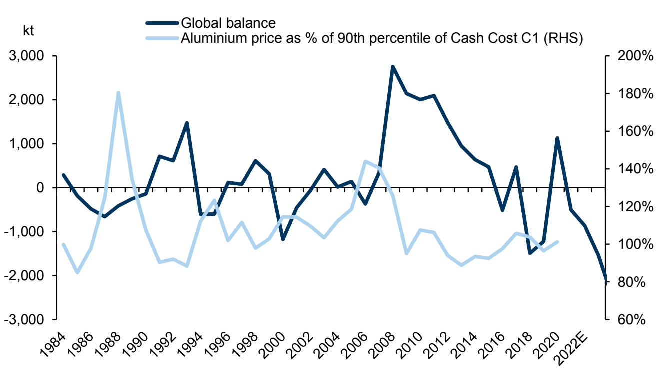
Global aluminium smelters' margin and capacity growth



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 24: During tight markets aluminium price trades well above the cost curve

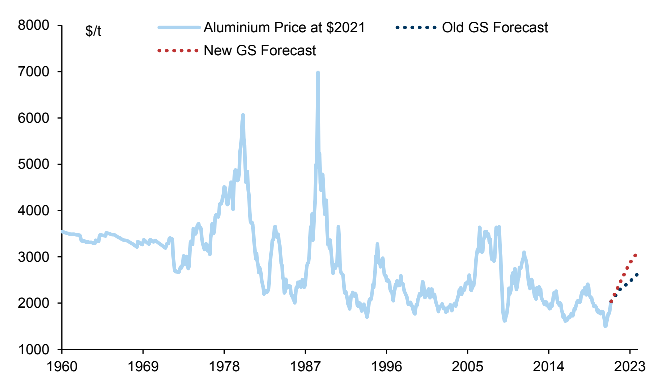
Global aluminium balance and aluminium price as percentage of 90th percentile of cost curve



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 25: Our price forecast is within the historical path

Historical and forecasted aluminium price at $2021



Source: World Bank, Goldman Sachs Global Investment Research

China's capacity cap materially constrains aluminium supply dynamics into mid-2020's

The critical fundamental development supporting this tightening path relates to Beijing's imposition of a hard 45Mty capacity cap on the aluminium smelting sector. This will be hit by the end of the year and we believe will be hard in nature. T he reason this is so critical a development relates to the fact that the most persistent bearish feature of the aluminium market over the past decade has been the impact from the rapid build out of smelting capacity in China that began in the 2000's. China's total primary smelting capacity expanded from just 3Mty in 2000 to 21Mty by 2010 and then 44Mty by the end of last year. Whilst that expansion was very much underpinned by demand requirements, provincial level emphasis on regional development as well as export opportunities ultimately resulted in significant spare capacity. From just 100kty (3%) spare capacity in 2000 that increased to 4Mty (20%) spare capacity in 2010 and then 8Mty (19%) by 2020. This fundamental trend has meant that China's supply dynamic has over the past decade become highly price elastic and ultimately a persistent source of softness on price rallies. This has defined aluminium's inability to sustain deficits and price premiums to the cost curve. Removing this feature of the market, ultimately shifts China primary aluminium supply function to a price elastic function. We view this as most important development in the bullish path for the metal.

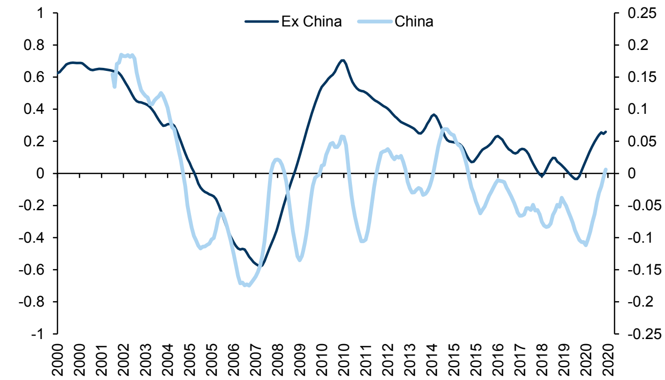
There are three critical aspects to the impact on aluminium market dynamics from China's capacity cap. First and foremost, net capacity additions mean the capacity cap will be hit this year. This means that China's primary metal output growth will naturally decelerate over the next three years. From an expected starting point of 40Mt in 2021 (+5% y/y), growth will decelerate to just 2% by 2023 (42.1Mt) as utilisation rates are maxed out. Second, set against a decelerating but higher demand growth rate, China's primary metal import requirement will expand. From a domestic deficit of 703kt in 2020 and 1Mt in 2021, this will expand to close to 2Mt by 2023. This a critical tightening channel on the ex-China market, which will sustain competition for units, draw inventories and support regional premiums. Third, we also expect China's aluminium semis exports to progressively decline resulting from less unit availability and Beijing's probable removal of economic incentives on this trade channel. China's semis export peaked at 5.4Mt in 2018 and had fallen to 4.3Mt in 2020. We expect a decline towards 3Mt by 2023. Alongside China's increasing primary metal import requirements, the trend lower in semis exports will generate another progressive tightening effect on the ex-China market.

Exhibit 26: China supply growth to decelerate 2% by 2023

Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 27: Moderation in aluminium supply sensitivity to price set to continue

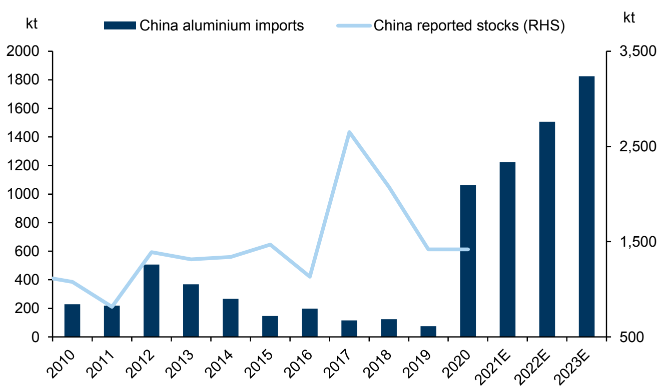
Rolling correlation of annual aluminium supply growth and aluminium LME 3mth price, China (RHS)



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 28: China imports set to increase in the the coming years as stocks deplete

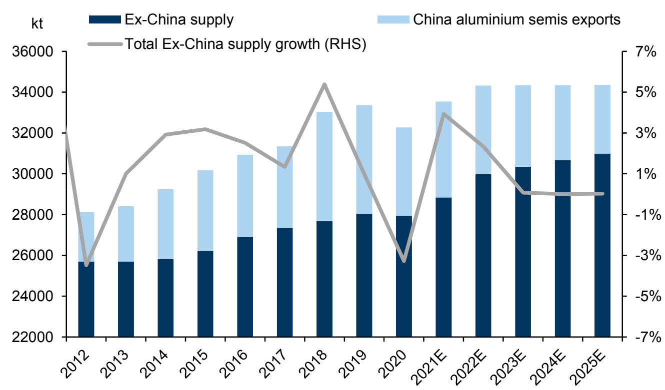
China aluminium imports and reported stocks



Source: Woodmac, Wind, Goldman Sachs Global Investment Research

Exhibit 29: Ex-China supply growth will not be enough to cover for China deceleration

Ex-China aluminum supply and China semis exports



Source: Woodmac, Goldman Sachs Global Investment Research

Ex-China supply to decelerate sharply from 2023 as ramp-ups and restarts taper

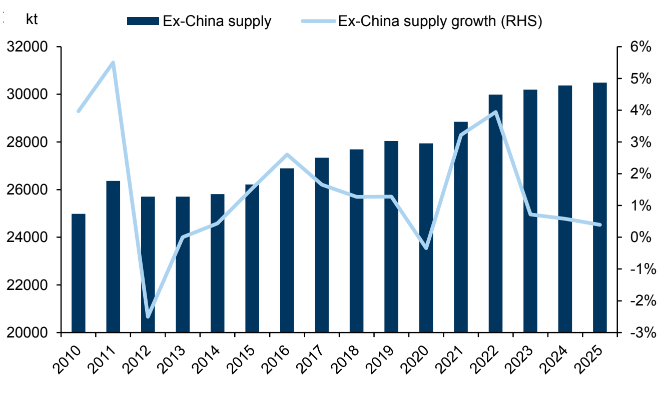
The other critical aspect to aluminium supply dynamics regards the ex-China market. While China's shift toward price inelastic supply function is based on current policy, market discipline has governed a longer running restraint on ex-China capacity and supply growth. Whilst China's primary production grew at annual average rate of 19% y/y in the 2000's and 11% y/y in the 2010's, ex-China output grew at an average of just 1% and 2% y/y respectively during those two decades. On a forward looking basis, the ramp-up of new capacity and some planned restarts will temporarily bolster ex-China supply growth over the 2021-22 period, with close to 2Mt growth (averaging ~3.5% average annual growth). However, from 2023 onwards ex-China supply growth completely dissipates and on current known capacity, just 500kt of output growth will follow over the three-year period to 2025. Given the lead times on ex-China capacity additions are longer than in China (4-5 years versus 2-3 years), the ability for producers to materially adjust that sharp drop off in supply growth from 2023 is limited.

We would note that given a very strong demand growth phase during 2021-22 (+6%,

+3.8Mt), the ex-China market will progressively tighten from what was a near 2Mt surplus in 2020 to just a 642kt surplus in 2022 before deficits begin into mid-decade. Ultimately given China's progressively larger deficit and assuming this is largely solved via the import channel, on a post-trade basis the ex-China primary market will trend from a deficit of 500kt this year to 865kt in 2022 and then 1.5Mt in 2023, then absent supply additions, even larger deficits of 2.4Mt in 2024 and 3.6Mt in 2025. Compounded by a trend of lower semis exports from China, we believe there will be a material tightening trend in the ex-China market that will drive down primary metal inventories to multi year lows. There is no immediate shortage of inventory currently in the ex-China market with an estimated 8-9Mt of stocks. However, the accumulated deficits between now and 2025, suggest those stocks will be reduced by as much as 70% by mid-decade.

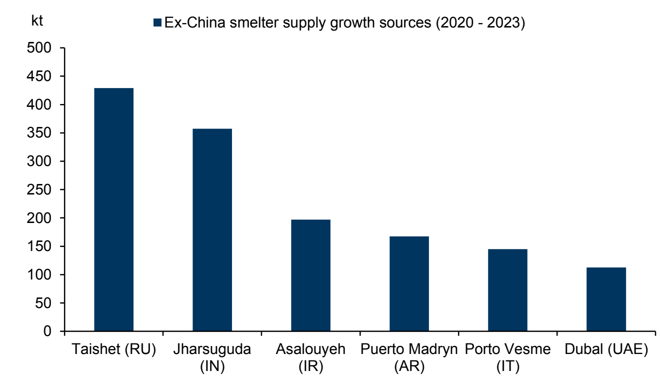
Exhibit 30: Ex-China aluminium supply growth will briefly accelerate the next two years

Ex-China aluminium supply volumes and growth



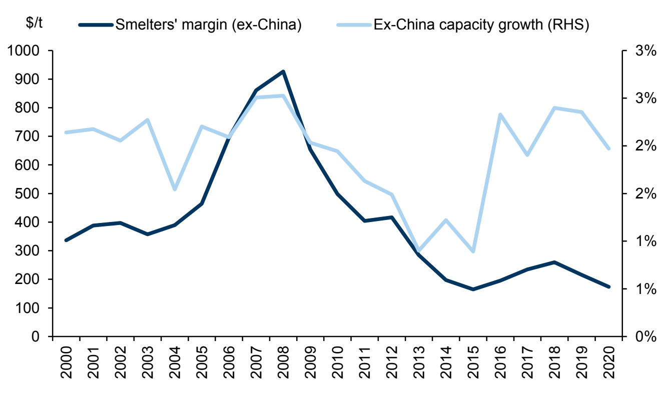
Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 31: Limited pipeline of ex-China capacity ramp-ups over next 2 years then growth pipeline depletes



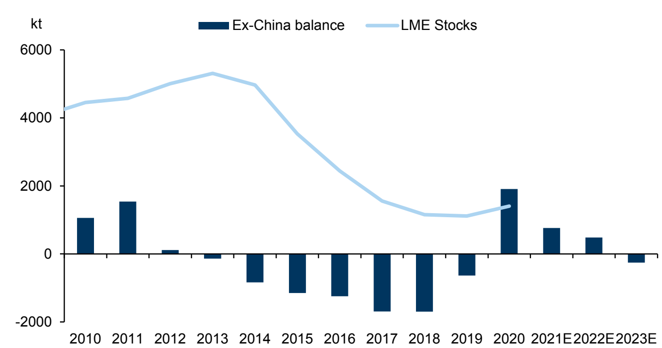
Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 32: Ex-China capacity additions have lagged margin incentives by 4-5 years, suggesting any response to current price signal will not emerge until mid-decade



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 33: Tightening path in ex-China primary balance alongisde China imports point to LME stock rundown



Source: Woodmac, Wind, Goldman Sachs Global Investment Research

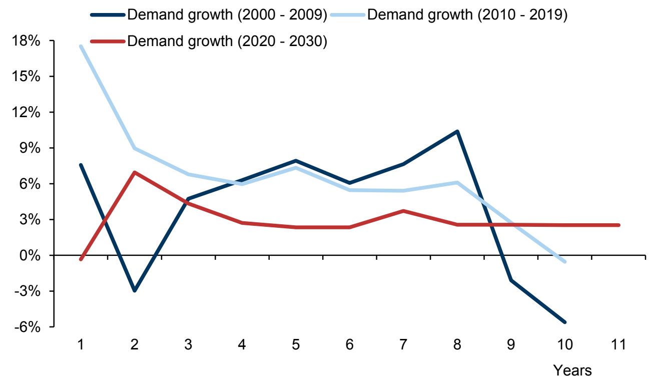
Green electrification sustains global demand trend rather than accelerate

The emphasis on the impact from decarbonisation policies has so far been on the constraining influence on the primary aluminium supply-side. Incrementally we view that as the most impactful trend into the 2020's. That is not to say that aluminium demand is not positively impacted by green channels in the way that other metals such as copper and nickel are, but rather aluminium has seen a very robust demand setting progressively transpire over the past decade. Unlike the other base metals, global aluminium demand growth rates actually accelerated in the 2010's (+6% pa average growth rate) versus the 2000's (+5% pa average growth rate). China demand growth decelerated as with most base metals (from +19% y/y in 2000's to +9% in the 2010's) but it was in the ex-China market where demand accelerated (+2.5% in the 2010's vs +1% in the 2000's). The key factor driving that relatively strong demand trend primarily related to light weighting in the auto sector, a trend that evolved during that decade as part of a broader emphasis on fuel efficiency standards in Western economies. One could argue this was an initial green demand effect, well before copper and nickel benefited from green demand channels such as EV's and renewables.

Looking ahead, we expect a continuation rather than acceleration in aluminium demand growth conditions through the course of the 2020's. As with the broad industrial metals complex, we expect a strong stimulus supported global demand recovery trend in 2021 (+7% y/y) and 2022 (+4% y/y) before a trend rate between 2-3% y/y pa through the remainder of the decade. This is only modestly ahead of average demand growth rate in the 2010's (+2.5% y/y) but that should be understood as a continuation in a robust trend. In aggregate terms, we project close to 20Mt growth in global primary demand over the course of the decade, which will be split 13Mt for green demand growth and 7Mt for non-green demand growth. As we have discussed earlier, EV's and solar will be the dominant demand driver. From a regional perspective, we would note after two decades where China generated the overwhelming majority of demand growth (90% in 2000's, 88% in 2010's), we expect a less China-centric demand growth composition in the 2020's (with China only generating 47% of the growth over the decade). This is an important feature of the demand dynamics which points to a broader set of macro and policy drivers than the China-centric drivers of the past 20 years.

Exhibit 34: Aluminium demand will steadily grow through the decade

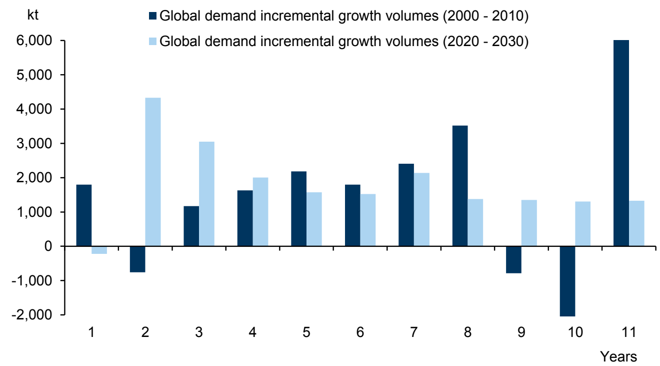
Global aluminium demand growth, by decade



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 35: Global aluminium volume growth in 2020's is expected to be on a par with the previous supercycle in the 2000's

Global demand volumes, by decade

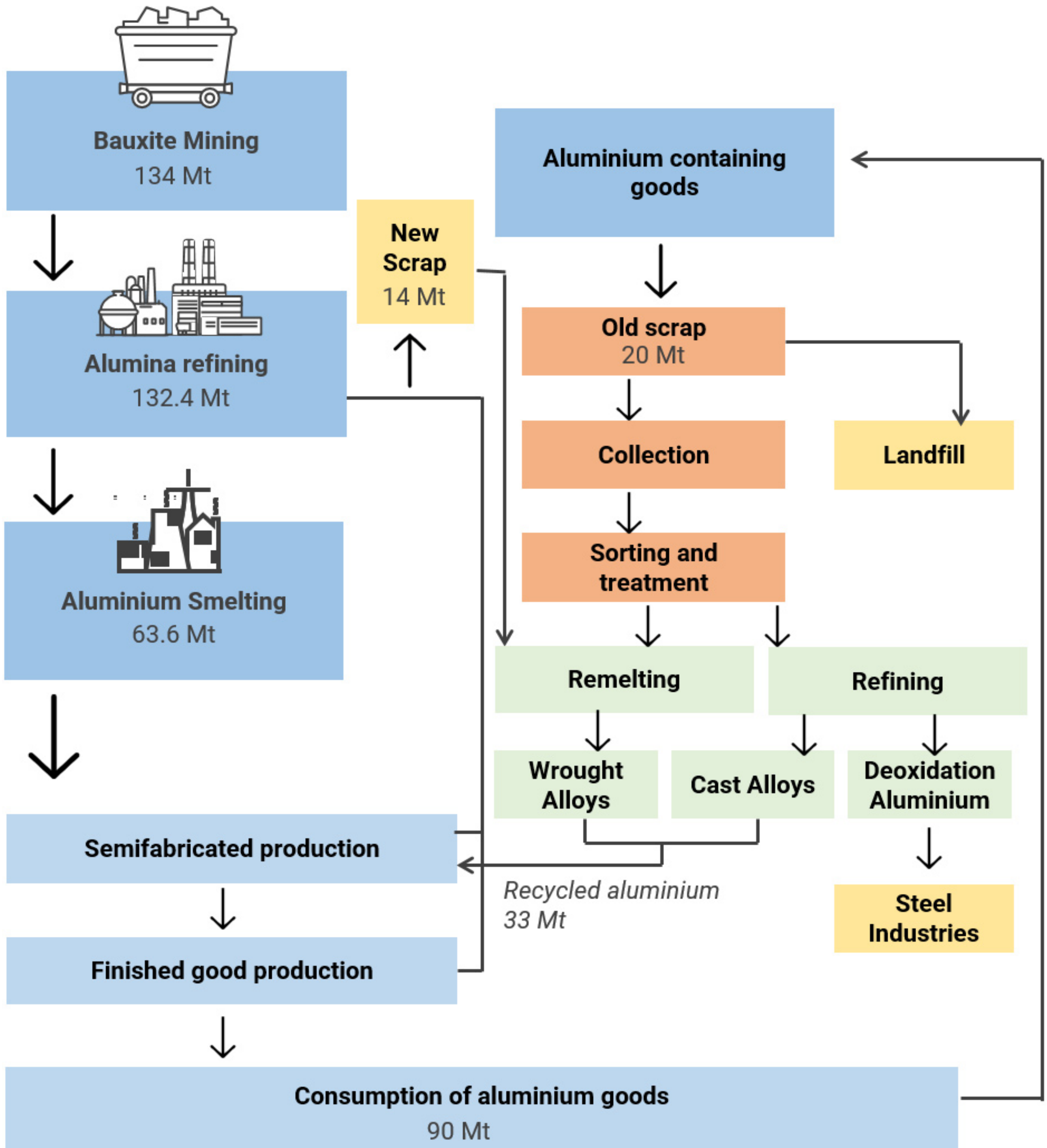


Source: Woodmac, Goldman Sachs Global Investment Research

Scrap supply constrained by China's end of life trends, accelerating influence into mid decade and beyond

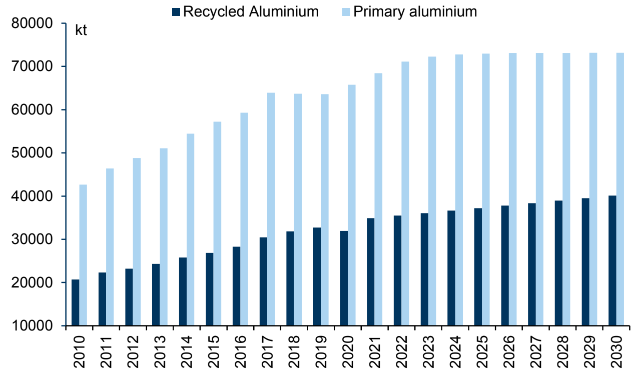
Policy makers' last instrument to decarbonise aluminium production is to incentivize aluminium recycling as it requires 5% of the energy used by smelters, emitting just 0.5 CO2eq t/t. The secondary production in 2019 was around 33Mt, 30% of total global supply and satisfied 25% of the global aluminium demand. Of the total supply globally 60% comes from post-consumer scrap, however the share varies highly by region and determines the different potential of each country to grow in the future. In China the share of old scrap accounts only for 40% of total scrap against rates close to 70% in Europe and in North America. The fact that old scrap is a function of past aluminium-containing goods consumption both explains why western countries have a higher share of old scrap and also is the foundation of the potential growth of recycled aluminium coming from old scrap in China. Aluminium goods have on average a high service life (construction, autos), meaning that the supply for secondary production will be generated only years after primary aluminium consumption. Looking at the last 20 years of China aluminium consumption and considering that those goods are arriving now at the end of their life, in the next years an increase in old scrap can be expected, translating into an increase of secondary production. In Europe and North America the potential of an increase in the supply is smaller as the industry in these regions is already mature with high recycling rates and efficiency. The marginal improvement is therefore more difficult as it is linked mostly to technical challenges in the sorting and treatment process rather than to scrap availability. In these regions recycling can be increased by disincentivising scrap exports. Europe and North America export 13% and 24% of the generated scrap however this trend is expected to decrease as policymakers commit to a more circular economy, therefore pushing to recycle metal in the region to lower the overall emissions.

Recycled aluminium accounts for 30% of total production
Scrap Flow model (2019 IAI data)



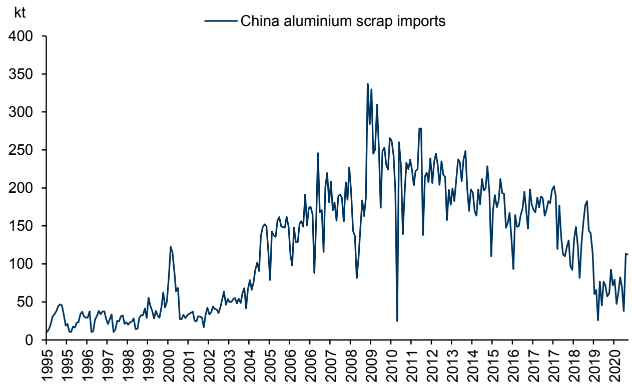
Source: IAI, Woodmac, Goldman Sachs Global Investment Research

Exhibit 36: Recyled aluminum will increase, substituting ~500kt pa of primary aluminium
Aluminium production under IAI recycled aluminium assumption



Source: IAI, Goldman Sachs Global Investment Research

Exhibit 37: China's scrap imports have fallen sharply on quality rules, strong origin market demand
China aluminium scrap imports



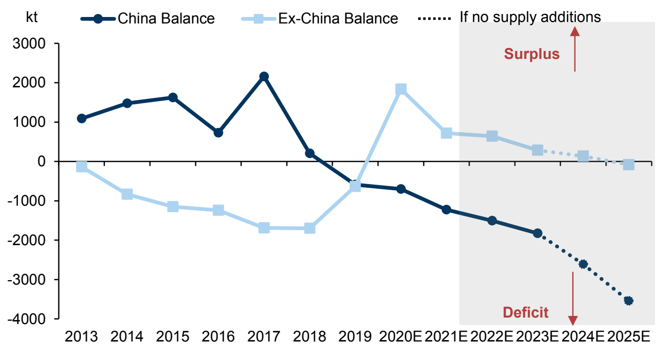
Source: Wind, Goldman Sachs Global Investment Research

Deficits through to mid-decade set to drive scarcity risks and sustained cost curve premiums

We expect the aluminium market to move into a phase of significant increasing sized deficits over the next 5 years. Over the 2021 to 2025 period we now project a cumulative deficit of 9Mt, the largest phase of cumulative tightening effect ever seen in this market. The last time the aluminium market faced a similar period of large and sustained deficits was from 1985 to 1990, when 5 years of consecutive deficit nearly halved global stocks and supported a near 150% increase in price. Visible market stocks in the aluminium market currently amount to just 2.7Mt which would deplete by mid-2023 if they were the only stock buffer. The reality is that the aluminium market also has a significant level of off-warrants. We estimate this non-visible holding ex-China at close to 5Mt alongside 1.5Mt producer stocks, which means pre-consumer primary metal stocks amount to between 9-10Mt. In that context, our balance projection point to a halving in inventory levels by early 2024 and potential depletion by the end of 2025.

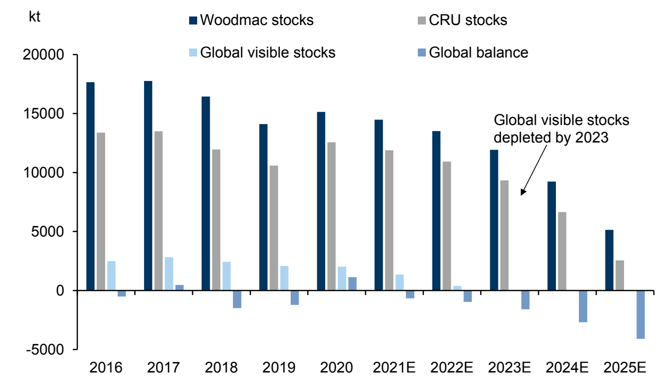
Whilst there are some risks that supply responses emerge to soften the 2024/25 balances, there appears to be a very low risk the balances can materially change given the absence of any fresh investment and a minimum 2-3 year for brownfield additions, 4-5 years for greenfield. Given this sustained and sequential accumulation in deficits during the first half of the 2020's, we expect a sustained trend higher in price.

Exhibit 38: Global aluminium market is set to trend into significant deficit over the next 3 years
China and ex-China aluminium balances



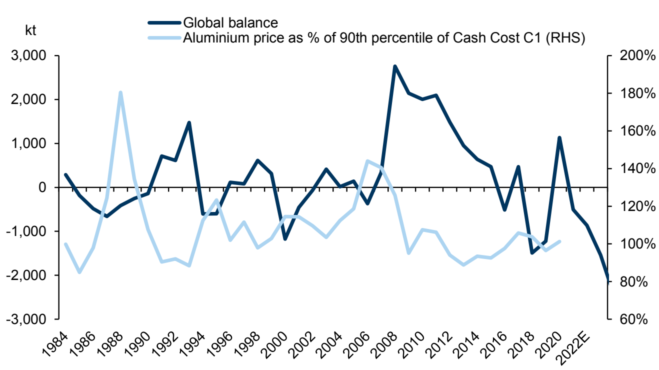
Source: Woodmac, CRU, Goldman Sachs Global Investment Research

Exhibit 39: Forecasted deficits imply inventories run down
Aluminium stocks under different calculations and path implied by global balance and aluminium global balance



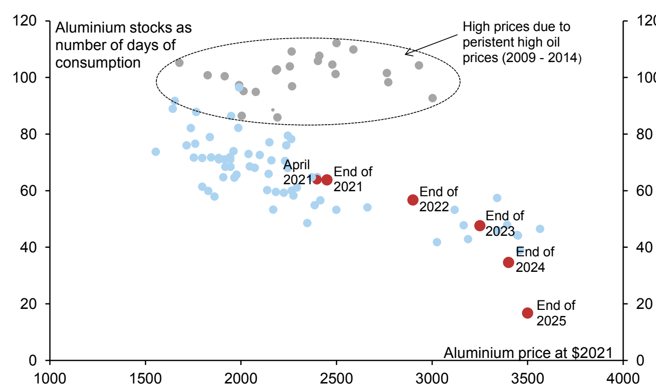
Source: Woodmac, CRU, Wind, Goldman Sachs Global Investment Research

Exhibit 40: During tight markets aluminium price trades well above the cost curve
Aluminium global balance and aluminium price as percentage of 90th percentile of cost curve



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 41: Tightening path in balances points to significant tightness and higher prices over the next 2-3 years
Stock as number of weeks of consumption versus aluminium price at $2021



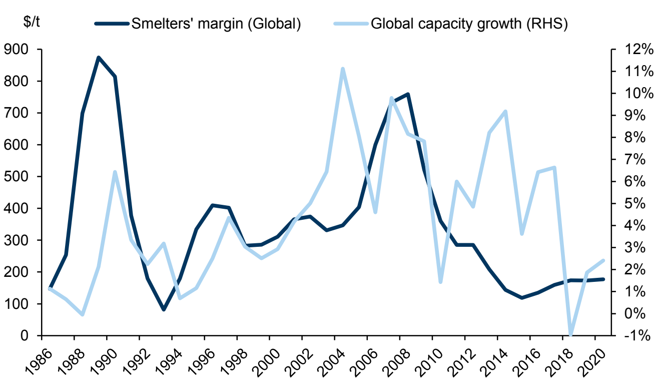
Source: Wind, World Bank, CRU, Goldman Sachs Global Investment Research

LT deficits will have to be resolved by new capacity investment, carbon adjusted incentive prices point to aluminium trending well above $3000/t

As with our copper analysis, our current medium-to-long term projections for the copper balance point to deficits developing by the second half of the 2020's. From the 4Mt deficit projected for 2025, that then more than doubles by 2030 to 10Mt. The reality is that such long term deficits cannot occur because they imply instant inventory depletion and an inability for the market to function. Rather, the reason these deficits will not occur is because the higher price environment we project will stimulate supply responses that will ultimately generate enough incremental supply. In that context, we think the incentive price needed to bring on supply is being underestimated by most of the market because of the significant carbon inflation premium that producers are building into their economics. If carbon costs were not a consideration then the incentive price for the majority of brownfield and greenfield capacity would stand below current LME price levels. However, the reality is that no projects have been approved and feedback from Western producers, suggests no appetite to invest in new capacity at current price levels. We think this reflects the anticipation of significantly higher carbon costs. Capturing that effect by discounting a long term carbon price of $100/t into the incentive price calculation, we estimate incentive price levels for green Western capacity close to $2,500/t, then escalating above $3,000/t for capacity in the Middle East and Asia.

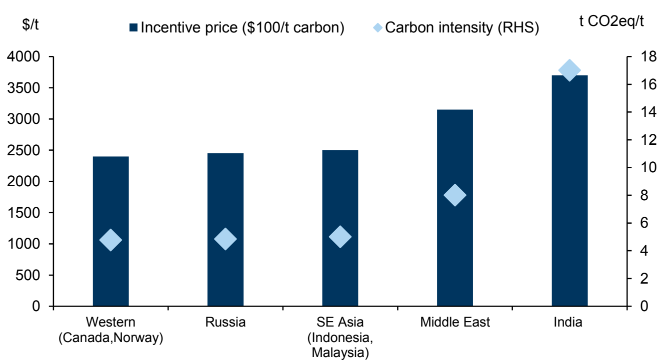
The reality is there is a significant level of uncertainty what the carbon price will be and precise level of impact by region, but with the skew to the upside in the era of decarbonisation, that uncertainty premium to project and operating economics weighs against investment at current price levels. There is little doubt however that significant investment in new capacity will eventually have to occur given the depletion level deficits currently projected for the second half of the decade. In this context, we think there are three key areas of focus in terms of probable investment. First, given we assume China will no longer allow net primary capacity additions, any net growth will have to offshore and that is most likely to be in SE Asia locations such as Indonesia and Malaysia. We would note that already Tsingshan are investing in a 2Mty smelting in Indonesia with Chalco providing some advisory role. Indonesia have implied that there will be no further new coal fired generating capacity, which likely constrains the pace of build out. Second, we would expect probable production expansion in locations such as India and Middle East though the base case suggests that the earliest such additions would impact supply would be in the second half of the decade. Third and final, in the West the most likely supply addition will either be brownfield additions at green capacity and potentially some small scale restarts.

Exhibit 42: Before 2000, smelters' response to high margins had lagged
Global aluminium smelters'margin and capacity growth



Source: Woodmac, Goldman Sachs Global Investment Research

Exhibit 43: Supply investments will eventually emerge but higher prices and decarb policy certainty are needed
Incentive prices, by region



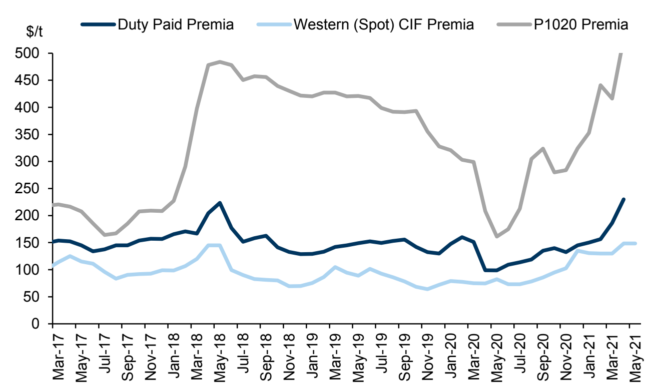
Source: Woodmac, Goldman Sachs Global Investment Research

Regional physical premia will be well-supported, but logic less clear on explicit green premia component

There has been much investor discussion of the pricing dislocations that climate policies may generate in the aluminium physical market. Most of these are focused on the idea that a green premium may develop as a differentiator between metal units on a carbon footprint basis. Whilst there is no doubt that modest carbon premiums already exist in the market and are closely tied to certain aluminium brand values, the path from that to a broader and more substantial pricing dichotomy is less clear cut. The main challenge is that all LME deliverable ingots are fungible, so forcing consumers to pay materially more for a metal unit whose added value is defined by its historical production path rather than added value to the consumer is counter-intuitive. It is possible that the introduction of an exchange contract delineating aluminium by carbon content could generate some extra value. However, the clearest channel for a green premium in our view is via the additional margin that producers will gain from either existing green or prospective green margin benefits. This margin is generated when policy forces producers to pay more for carbon intensive production, but who are forced to compete with cheap production methods of their decarbonised counterparts. We do however expect a strong environment for regional physical premium going forward irrespective of direct green component, reflecting in particular overall deficit conditions, material inventory declines and regional dislocations, as well as China's increasing import requirements.

Exhibit 44: Western aluminium premia supported by the tight market

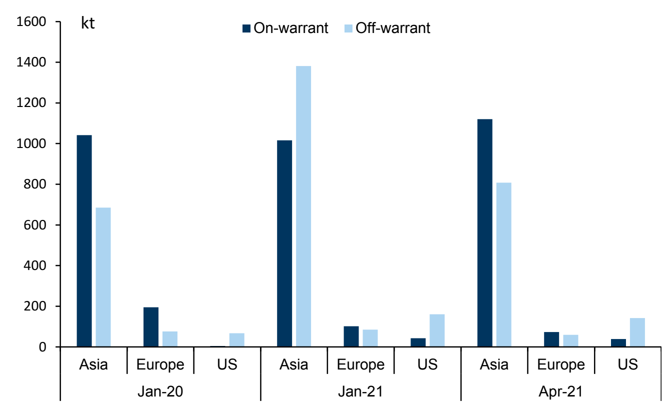
Western aluminium premia



Source: CRU, Goldman Sachs Global Investment Research

Exhibit 45: Low LME stocks in the West

On-warrant and off-warrant LME stocks



Source: Woodmac, Goldman Sachs Global Investment Research

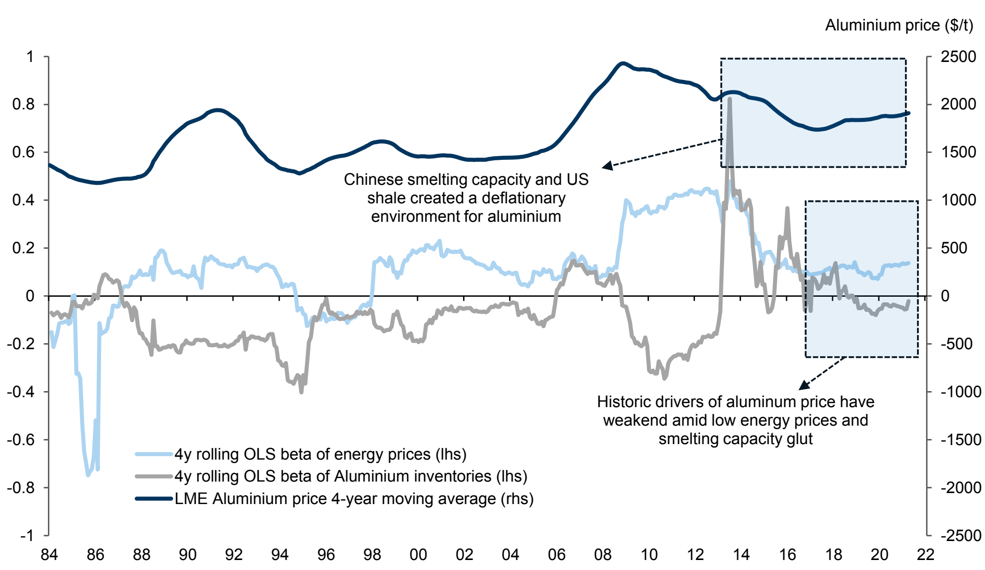
Capturing price risk through a structural break

In this note, we have outlined how the aluminium market is undergoing a shift in micro fundamentals, from a stagnant cost curve to deficit pricing. This shift is set against an entirely new macro backdrop, where policymakers are pushing for an unprecedented overhaul in industrial production. As a result, we believe that the recent past is a poor predictor of how the aluminium market will behave in the future.

We analyse the impact of such structural breaks on the predictive power of a standard aluminium pricing model, and show that it falls substantially in the period directly after the break occurs. Intuitively, this is because the data fed into such models reflects the state of macro fundamentals before their change. It is only after an extended period of time that enough data capturing the new state of the world can be collected to produce accurate models. As Exhibit 47 shows the Mean Square Error – a measure of a models' out of sample accuracy – of a standard price model for aluminium rises after periods where capacity constraints begin to bind after a period of cost inflation. This is precisely the situation we are in today. Moreover, Exhibit 46 indicates just how unique the last decade has been in the history of the aluminium market. After extensive capacity capex – particularly in China – led to a glut of smelting capacity, aluminium has been anchored to the cost curve. Moreover this cost curve was deflating as US shale oil and greater coal to gas switching in Europe led to falling energy prices from 2014-2020. As these constraints failed to bind on the aluminium market over the last decade, modelling the price dynamics of a structural constrained market becomes infeasible.

Exhibit 46: A decade of aluminum deflation amid cheap energy and a capacity glut has limited the elasticity of traditional price drivers

Betas from rolling regression of oil price and inventories on aluminum price, where all the variables are in log differences

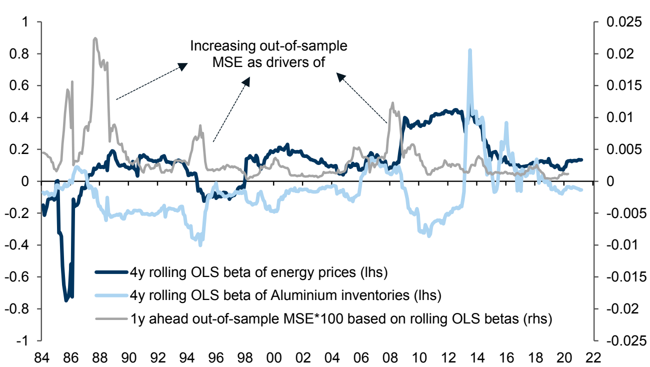


Source: Wind, Goldman Sachs Global Investment Research

How then, should we think about price risks in aluminium going forward? We tackle the problem both quantitatively and qualitatively. First, we look at the aluminium market over the last 50 years, and consider those periods that have similar macro and micro fundamentals to what we expect over the coming 3 years. On a micro basis, we look at those times when aluminium prices rose above the cost curve – that is when inventories were relatively tight, and had a relatively stronger beta on aluminium price than cost-curve inflation. Then, we cross reference these with periods of similar strong, fiscally and monetary expansionary policy – like the late 1980's at the end of the arms race and the war on acid rain, or the mid 2000's with the rise of China and low US interest rates. We construct a truncated price model from those periods, taking an average of rolling beta estimates and using these to project prices forward into the coming decade. Comparing the results of this analysis with a price model constructed from data over the last decade gives us a direct quantitative estimate of the risk surrounding our forecast based on the structural break. Both estimates are conditioned on the same underlying assumptions on the balance and path of oil prices, yet the model based on the most recent data highlights the likely price path in an environment of unsupportive macro policy and structural overcapacity. The other shows a much stronger price response to our underlying assumptions, consistent with the theory highlighted above.

Exhibit 47: Model accuracy worsens during periods of structural change

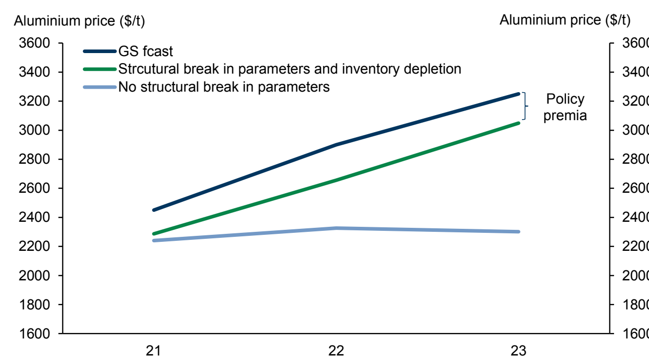
Energy prices refer to brent crude oil price, and we use LME aluminium stocks series for aluminium inventories.



Source: Wind, Goldman Sachs Global Investment Research

Exhibit 48: The past is not always a good predictor of the future

Structural break in parameters price path is created by taking average of betas from rolling OLS regressions over late 1980s and mid 2000s, and no structural break in parameters price path is created by taking betas from a fixed OLS regression over the last decade



For rolling OLS regressions of oil prices and stock of aluminium on aluminium price where all the varibles are in log differences, we use a window size of 4 years.

Source: Wind, CRU, Goldman Sachs Global Investment Research

Second, we consider the qualitative factors that are generating the structural break in the drivers of aluminium's price – the political economy of climate change. Considering aluminum's central role in industrial decarbonisation and that decarbonisation's role in driving the coming bull market, mapping out the potential risks to policy is crucial. In our view, the majority of the risk remains skewed firmly to the upside. For the last 30 years, economists have characterised climate policy as a free rider problem – without other economies curbing emissions, why should any country shoulder the cost of decarbonisation? Yet this is misleading – climate policy is not an issue of free riding, but of redistribution. Without the capacity to adequately compensate the losers – often low-income households – the required political coalition can never form to generate a systemic shift in policy. With a renewed focus on redistribution, and a new awareness of the power of the state to tackle social need, we see this structural block against climate policy beginning to shift, as policy makers become comfortable with pushing through sweeping changes.

Despite the fact that since the start of the pandemic, countries accounting for 67% of GDP have announced stronger policies to fight climate change, no country yet has a policy platform that fully aligns the path of emissions to the Paris Agreement's Targets. For example, President Biden's announcement of 50-52% emission reduction by 2030 is about 5 to 10% points lower than the target consistent with a 1.5°C pathway. EU's commitment to "at least 55%" net emission reduction by 2030, should be between 58% and 70% and China's path, despite commitment to peak carbon in 2030, falls far outside its "fair share" range. With growing domestic political consensus over the need for stronger action, and considerable room to tighten further, it remains likely that further announcements of decarbonisation policy will occur before COP26 in Glasgow this November.

The widespread adoption of carbon trading schemes, already well-established in Europe, being rolled out in China and just emerging in the US remain a key upside policy risk to aluminium. In fact, we see the launch of the Chinese ETS as the main upside risk for onshore aluminium in coming years. Despite a recent scale back of its decarbonisation plan to ensure no negative impact on the economy after the pandemic, in the medium term Chinese environmental officials appear likely to push for a tightening of the new ETS, both by extending the reach to high carbon-intensity sectors, including aluminium, and by modifying the allocation of allowances to create a progressive tightening.

Not all the risks remain to the upside however. Indeed, in recent weeks Chinese policymakers have rolled back capacity caps to steel producers after growing onshore inflation. With Beijing pressuring smelters to cut copper speculative positions, policy support for decarbonisation may well be tempered by the reality of a sudden shift to higher prices. The tension between climate policy, inflation and growth extends beyond China. Additionally, decarbonisation in India could hang in the balance as economic growth has become a top priority post pandemic. While the US-India Climate and Clean Energy Agenda 2030 partnership is intended to provide the much need space for increasing green practices in India, the country has still not provided a clear roadmap for a transition away from coal. Also, India's environment minister has said the country "won't raise its climate ambitions under pressure", and India has called the EU border tax scheme "unfair and discriminatory" in a joint statement with Brazil, South Africa and China.

GS Aluminium Supply and Demand Model

Exhibit 49: GS Global Aluminium Supply and Demand Model

('000 tonnes)	2013	2014	2015	2016	2017	2018	2019	2020	2021E	2022E	2023E	2024E	2025E
Consumption - DM													
US	4928	5128	5391	5490	5547	5519	5382	4978	5421	5692	5823	5939	6088
% change y/y	*1.8%*	*4.0%*	*5.1%*	*1.8%*	*0.5%*	*-0.5%*	*-2.5%*	*-7.5%*	*8.9%*	*5.0%*	*2.3%*	*2.0%*	*2.5%*
Europe	8093	8234	8359	8606	8924	9102	8920	8028	8630	9036	9280	9493	9683
% change y/y	*1.2%*	*1.7%*	*1.5%*	*3.0%*	*3.7%*	*2.0%*	*-2.0%*	*-10.0%*	*7.5%*	*4.7%*	*2.7%*	*2.3%*	*2.0%*
Japan	1997	2108	2012	2080	2154	2180	2071	1833	1983	2079	2131	2177	2226
% change y/y	*-7.8%*	*5.5%*	*-4.5%*	*3.4%*	*3.6%*	*1.2%*	*-5.0%*	*-11.5%*	*8.2%*	*4.9%*	*2.5%*	*2.2%*	*2.3%*
Other DM	2794	2945	3010	3088	3167	3164	3069	2772	3000	3145	3224	3293	3367
% change y/y	*0.2%*	*5.4%*	*2.2%*	*2.6%*	*2.6%*	*-0.1%*	*-3.0%*	*-9.7%*	*8.2%*	*4.9%*	*2.5%*	*2.2%*	*2.3%*
Sub- DM	17812	18415	18772	19264	19792	19966	19442	17611	19034	19952	20458	20903	21364
% change y/y	*0.1%*	*3.4%*	*1.9%*	*2.6%*	*2.7%*	*0.9%*	*-2.6%*	*-9.4%*	*8.1%*	*4.8%*	*2.5%*	*2.2%*	*2.2%*
Consumption - EM													
China	24282	27147	29373	31664	34419	35796	36154	38500	40810	42646	43926	45024	46015
% change y/y	*11.8%*	*11.8%*	*8.2%*	*7.8%*	*8.7%*	*4.0%*	*1.0%*	*6.5%*	*6.0%*	*4.5%*	*3.0%*	*2.5%*	*2.2%*
Other EM	8028	8236	8592	8874	9237	9422	9233	8495	9093	9638	9905	10136	10360
% change y/y	*3.0%*	*2.6%*	*4.3%*	*3.3%*	*4.1%*	*2.0%*	*-2.0%*	*-8.0%*	*7.0%*	*6.0%*	*2.8%*	*2.3%*	*2.2%*
Sub- EM	32310	35383	37966	40538	43656	45218	45387	46995	49903	52285	53831	55160	56374
% change y/y	*9.5%*	*9.5%*	*7.3%*	*6.8%*	*7.7%*	*3.6%*	*0.4%*	*3.5%*	*6.2%*	*4.8%*	*3.0%*	*2.5%*	*2.2%*
Global Consumption	50122	53798	56738	59802	63449	65184	64829	64606	68937	71987	73989	75563	77089
% change y/y	*6.0%*	*7.3%*	*5.5%*	*5.4%*	*6.1%*	*2.7%*	*-0.5%*	*-0.3%*	*6.7%*	*4.4%*	*2.8%*	*2.1%*	*2.0%*
Global Production													
China Production	25372	28623	30995	32393	36580	36002	35563	37797	39586	41140	42100	42412	42469
% change y/y	*9.9%*	*12.8%*	*8.3%*	*4.5%*	*12.9%*	*-1.6%*	*-1.2%*	*6.3%*	*4.7%*	*3.9%*	*2.3%*	*0.7%*	*0.1%*
Ex-China Production	25704	25816	26213	26895	27340	27688	28042	27945	28845	29982	30347	30673	30993
% change y/y	*0.0%*	*0.4%*	*1.5%*	*2.6%*	*1.7%*	*1.3%*	*1.3%*	*-0.3%*	*3.2%*	*3.9%*	*1.2%*	*1.1%*	*1.0%*
Total Production	51075	54439	57208	59288	63920	63689	63605	65742	68431	71122	72448	73085	73462
% change y/y	*4.7%*	*6.6%*	*5.1%*	*3.6%*	*7.8%*	*-0.4%*	*-0.1%*	*3.4%*	*4.1%*	*3.9%*	*1.9%*	*0.9%*	*0.5%*
Global Balance	**953**	**641**	**470**	**-514**	**471**	**-1494**	**-1224**	**1136**	**-506**	**-865**	**-1541**	**-2479**	**-3627**
Cash Prices (annual average)													
Current Dollars ($/t)	1846	1868	1662	1605	1968	2111	1748	1712	2450	2900	3250	3400	3500
Current Dollars (c/lb)	84	85	75	73	89	96	79	78	111	132	147	154	159

Source: Woodmac, CRU, Goldman Sachs Global Investment Research

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Reg AC

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