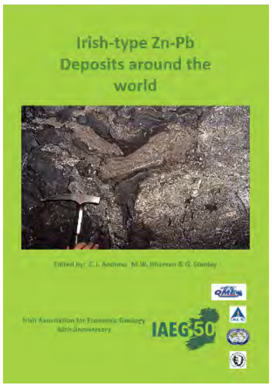

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Zinc supply and influences from geology

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Zinc supply and influences from geology

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Abstract: Zinc consumption growth is driven by urbanization and industrialization primarily in developing economies through the galvanization of steel and die casting with end use in the construction, automobile, and machinery parts industries. While global consumption will increase from 13.6Mt in 2022 to 19.8Mt in 2050, growth will slow to 1.2% through structural change in global consumption patterns and decreasing zinc intensities in first use and end use products. To meet this growth in demand, refined zinc supply and mine supply production will need to increase. In the short term, refined zinc capacity at smelters can increase by improvements in utilization rates, and we forecast this to be sufficient until the end of the decade. Later, demand will have to be met with new capacity coming online. The requirement for new zinc mine supply by 2032 is expected to reach 5.6Mt and will necessitate a healthy project pipeline and available finance to construct it. Whilst there is no shortage of projects that could step in, the average lead time from exploration to construction is 14 years and dependent on a variety of risk factors. Recent junior and development company financing has shown strong activity since late 2020 and the size of funding is loosely correlated to the stage of development at which the project is currently in. This suggests that right now, zinc projects are of interest to investors irrespective of which stage of development they are in. Project capital intensities have been increasing from their historical average and competitiveness of projects remains linked to their envisaged cash (C1) operating cost. Geology affects a mine's cashflow in various ways. Projects coming into production have been more polymetallic in nature in recent years, which tends to help to reduce cashflow risk through diversification. Geology also impacts concentrate quality which has implications for product marketing and therefore future revenue. For SedEx, Irish-type and MVT deposits, concentrates typically produced are sought after products by smelters around the World.

Keywords: Zinc metal supply and demand, consumption, mine production, new supply, growth forecasts, future mines, zinc concentrates.

Demand

Global zinc consumption is forecasted to grow by 1.6% until 2032 and slow to 1.2% until 2050. This equates to zinc consumption growing from 13.6Mt in 2022 to 19.8Mt in 2050.

Zinc consumption is primarily driven by urbanization and industrialization which are both somewhat tied to demographic changes. From a first usage perspective, about 60% of refined zinc is used in galvanising steel for corrosion protection and ends up predominantly being consumed in the construction and vehicle manufacturing industries. The remainder is used for die casting alloys and brass fabrication, in chemicals and in semi manufactured products.

In the recent past, economic liberalization in China and other Asian countries resulted in an acceleration in urbanization and industrialization. Between 2000 and 2021, large investments in infrastructure and manufacturing in China helped drive zinc consumption growth by around 2.4% p.a. This points to the fact that the process of urbanization and industrialization is largely propelled by developing rather than developed economies.

The restructuring of the Chinese economy from one driven by investment in infrastructure and exports to one driven by domestic consumption means that Chinese economic growth will become less zinc intensive. Whilst long term urbanization and industrialization in other Asian economies will continue at a faster pace, growth of global zinc consumption will slow to a forecast 1.2% p.a. between 2023 and 2050. Developed economies, which have largely passed the process of urbanization and industrialization, are facing ageing and shrinking populations and will see diminishing growth. Over this period the share of global consumption accounted for by today's developing economies is projected to rise from 72% in 2022 to 79% in 2050, with China's share set to decline from 50% of global demand to 39% over the same period.

Structural shifts will continue to decrease zinc's intensity of use. The long-term shift in the pattern of zinc's first use consumption has been from one dominated by zinc die-casting alloys and brass before the 1980s to galvanized steel and has in a sharp reduction in zinc's intensity of use. Post fabrication galvanising continues to face competition from paints, whilst zinc-magnesium-aluminium ("ZAM") coatings for continuous

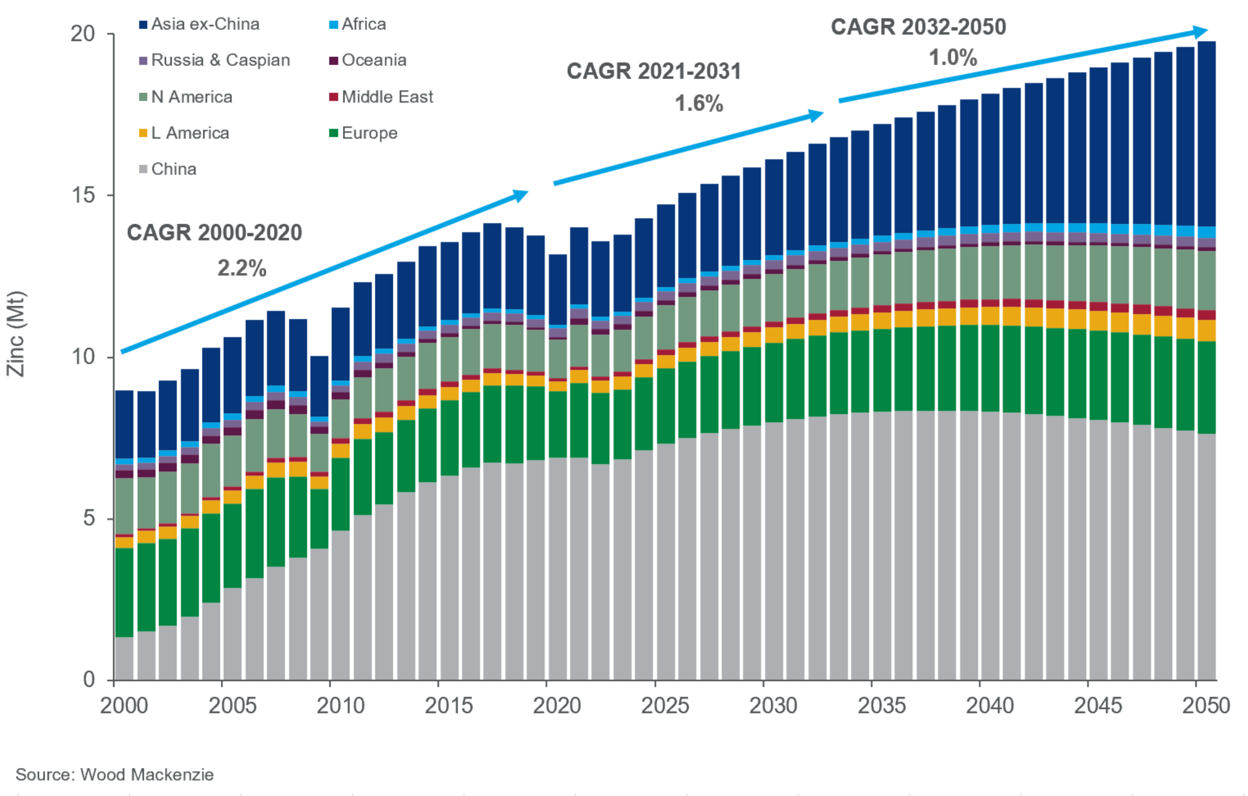


Figure 1: *Global zinc consumption by region.*

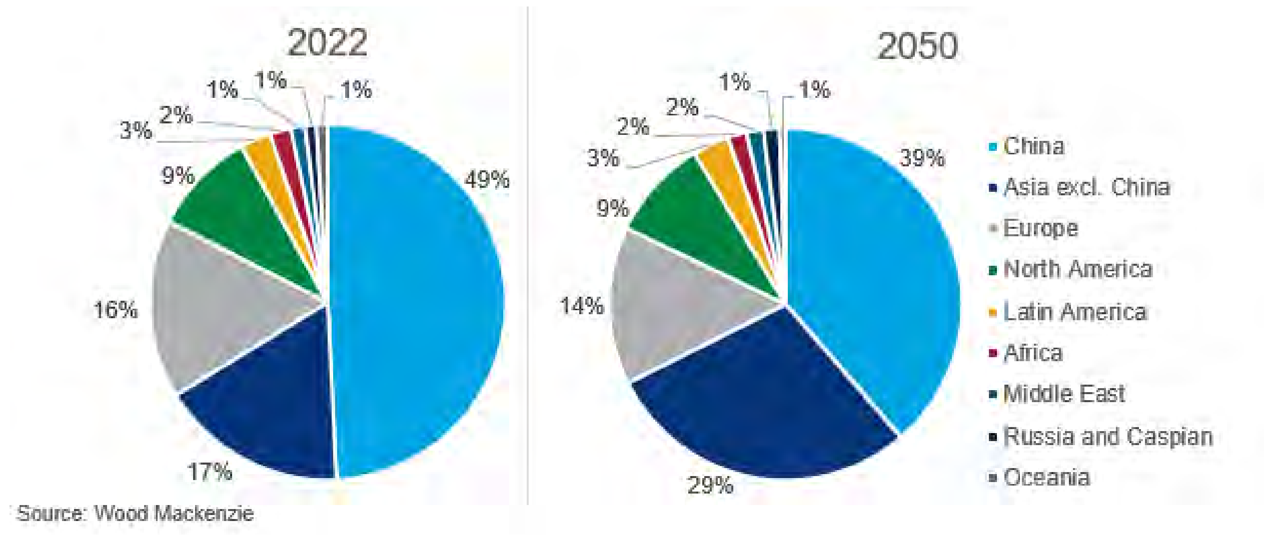


Figure 2: *Changes in global zinc consumption 2022 vs 2050.*

galvanising are starting to be taken up, especially in construction materials. ZAM coatings reduce zinc usage by over a third and offer superior corrosive protection properties.

Supply

With global zinc consumption at 13.6Mt in 2022 and forecast to grow to 19.8Mt by 2050, additional smelting capacity will be required to meet demand. In the short to medium term, refined production can come from expansions at existing smelters and additional production from planned smelter construction. Average refined production growth of 2.8% p.a. until 2027 is forecast. The bulk of the addition and cheapest and quickest method is to increase utilization rates. Outside of China, the average global utilization rate of around 90% should rise to the 95% level. In China, which accounts for 45% of global refined production, an average utilization rate of 75% will have to rise to 90% by the end of the decade. However,

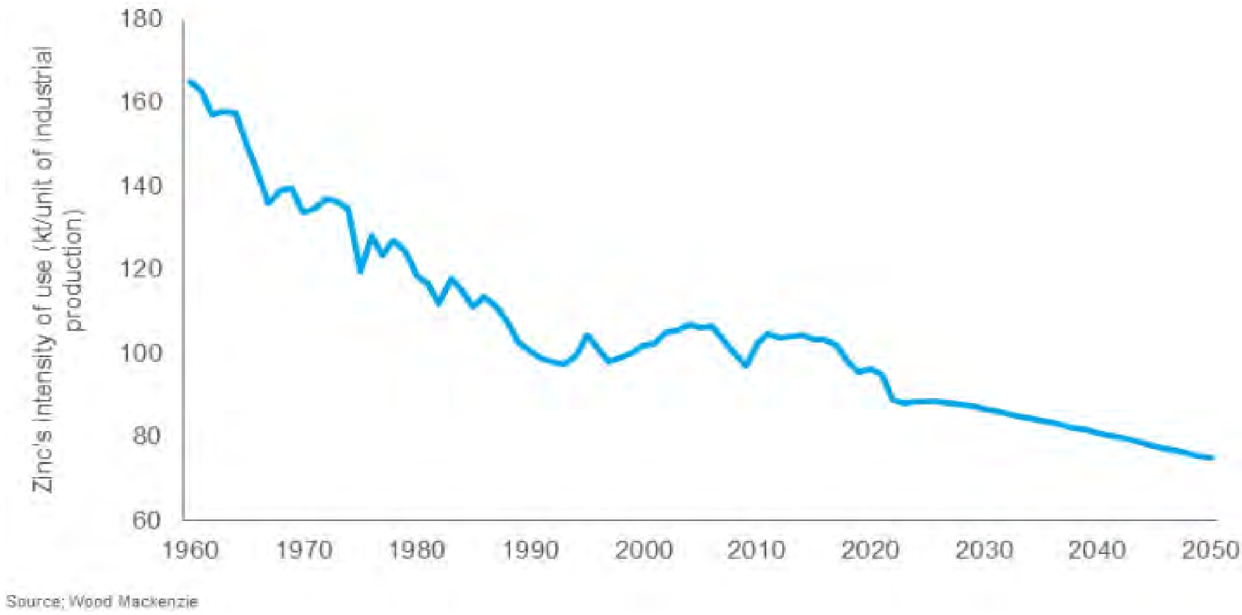


***Figure 3:** Structural shifts in zinc's first uses have resulted in a sharp decline in intensity of use.*

sustaining high rates or greatly raising them in short spaces of is burdened with risk. In addition, tough environmental regulations in China which came into force around the turn of the millennium would have to be overcome to reach the desired rate. By the end of the decade additional smelting capacity will be needed to keep up with projected refined zinc demand and the closure of older and more polluting smelters.

Mine supply production forecast comprises a mine capability forecast, a disruption allowance for unforeseen events, and an allowance for expected mine life extensions and new projects. With zinc mining, the size and nature of the orebody and value of the metal tends to mean that mining occurs mostly using underground methods. Whilst proven and probable ore reserves which have been determined to be economically mineable are locally delineated, they do not usually reflect the entire orebody and associated mineral resources. As a result, zinc mines have a long history of mine life extensions. Where mining conditions or metallurgy exceed expectations, or where external factors such as metal prices improve the profitability of

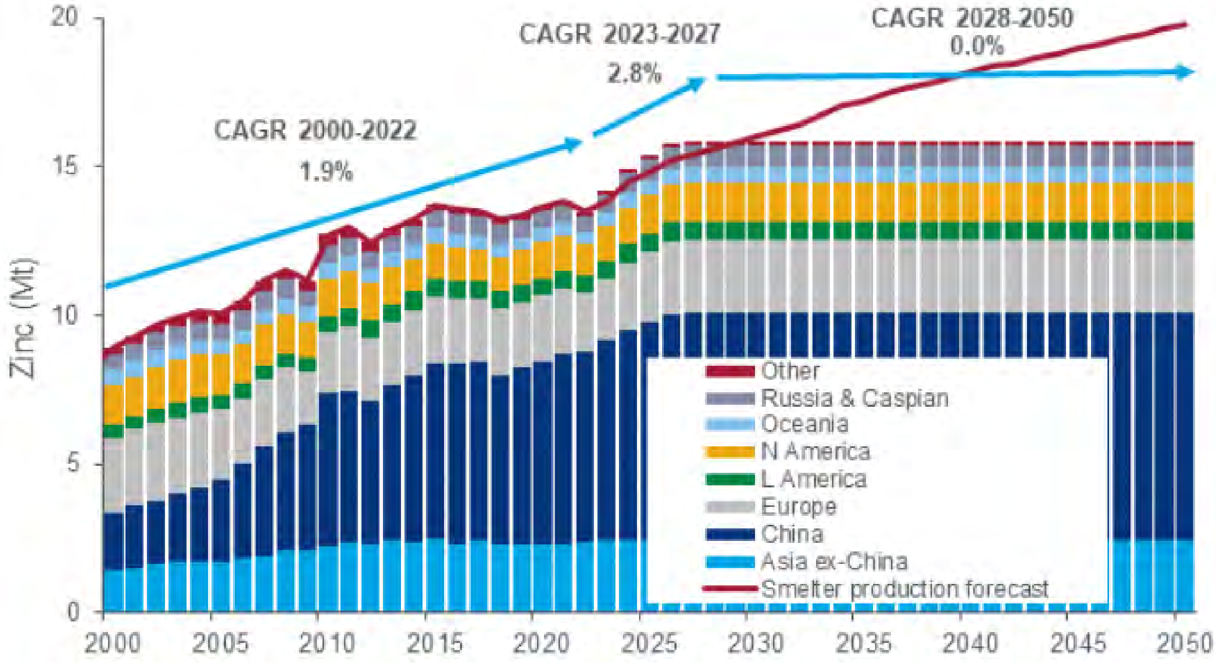


***Figure 4:** Increased smelter production capability needed from 2030.*

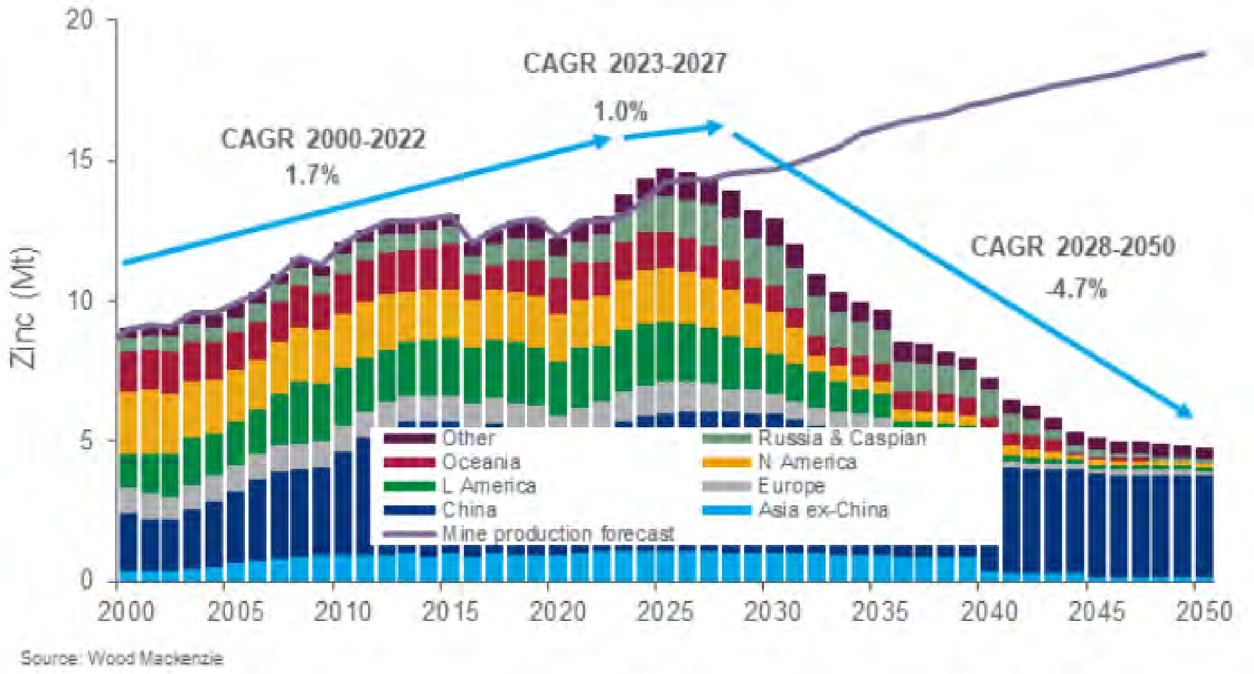


***Figure 5**: Identified mine production capability expected to peak by 2025/2026.*

once uneconomic ore, mine expansions may be justified.

These are some examples that are factored into the capability forecast.

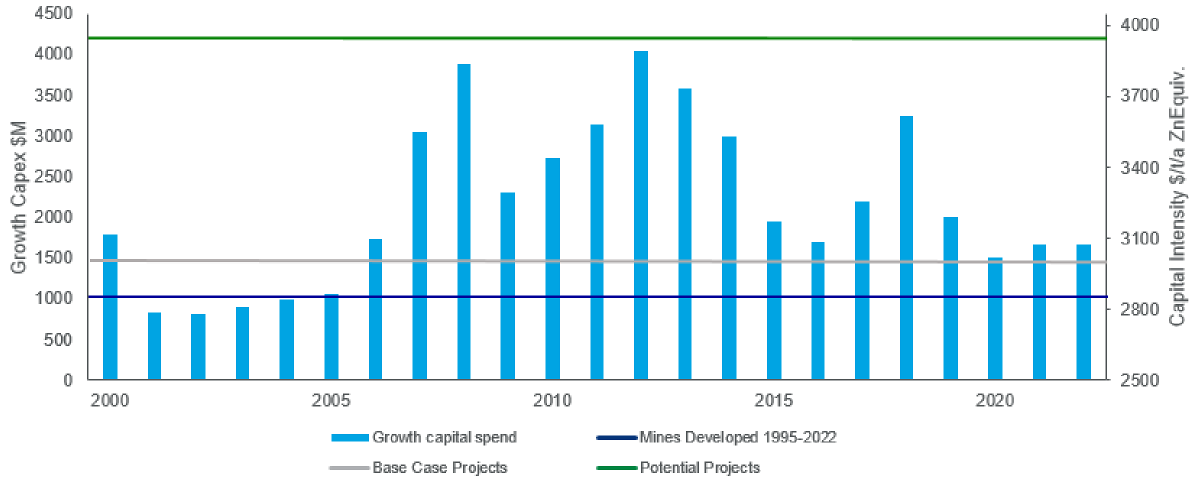
Over the last five years until 2022, global zinc mine production has averaged about 12.8Mt, with growth dipping by 5% in 2020 due to the Covid pandemic. Global zinc mine production is forecast to increase over the next three years from new mine projects that have been incentivized by medium-term expectations for a relatively high zinc price. By 2026, thirty-two projects will enter production adding roughly 1.5Mtpa contained zinc to the market. Some of the larger, +100kt/a contained zinc mine projects include Asmara, Buenavista, Kipushi, Korbalikhinsky, and Ozernoye. In addition, expansions at existing mines will add almost 2Mt contained zinc, notable examples are Century, Gamsberg, Neves Corvo and Zhairem. These additions to mine capability will compound on to large concentrate surpluses that began in 2022 following on from the Covid related disruptions. A large concentrate surplus is forecast to continue until 2026 and will likely maintain elevated TCs. These factors will delay development of some projects in the medium term.

However, with the requirement for new mine supply to be 5.6Mt by 2032, rising to 14.5Mt by 2050, the medium to long term outlook remains positive for new projects. Projects now coming online and the ramp-up at recently commissioned mines will result in an annual increase in mine production capability of 2.8% until 2028 but this will slow to 1.7% by 2032, with additional new projects required to contribute 4.6Mtpa to global mine. This supply requirement translates to an average 240ktpa of new production by 2040. For zinc mines, this is equivalent to the construction of three medium sized mines every year.

Growth in capital expenditure and intensities increasing for zinc projects

To meet the additional mine supply requirement of 5.6Mt by 2032, or about 240ktpa until 2040, will require significant investments to move projects forward into production. Growth capex, the total capex for expansion projects at existing mines, and initial capex, project capex required to exploit their ores, in the five years up to 2022 averaged US$2 billion a year and remain below the average spend since 2000. Additional capital expenditure in the region of US$4 billion a year will be required to bring future projects to production. The average capital intensity of a group of 73 zinc mine projects sits around US$3950/tpa zinc equivalent, with capital intensity being the unit dollar capital cost per annual tonne of paid zinc or equivalent value of zinc plus by-product metals. This is almost US$1100/tpa zinc equivalent higher than the capital intensity for mines developed between 1995-2022. To meet a yearly supply requirement of 240ktpa up to 2040 will translate to spending roughly US$1.8 billion on initial capex per year alone.

In recent decades it has typically taken around 14 years for zinc projects to progress from initial feasibility studies through bankable feasibility studies, permitting, financing and construction, so there is a significant lead time for new projects to contribute to global production. Whilst operating cost competitiveness is key, many other factors have also been determined when a project entered production. Most recently, Aripuana encountered commissioning delays because of late design changes implemented to the mine plan. Construction at Aripuana and Juanicipio were also delayed due to worker shortages because of Covid related mobility restrictions. Looking earlier into the project timeline, the necessity for increased technical



Source: Wood Mackenzie

Figure 6: *Project growth capital expenditure spend and capital intensity of current project pipeline.*

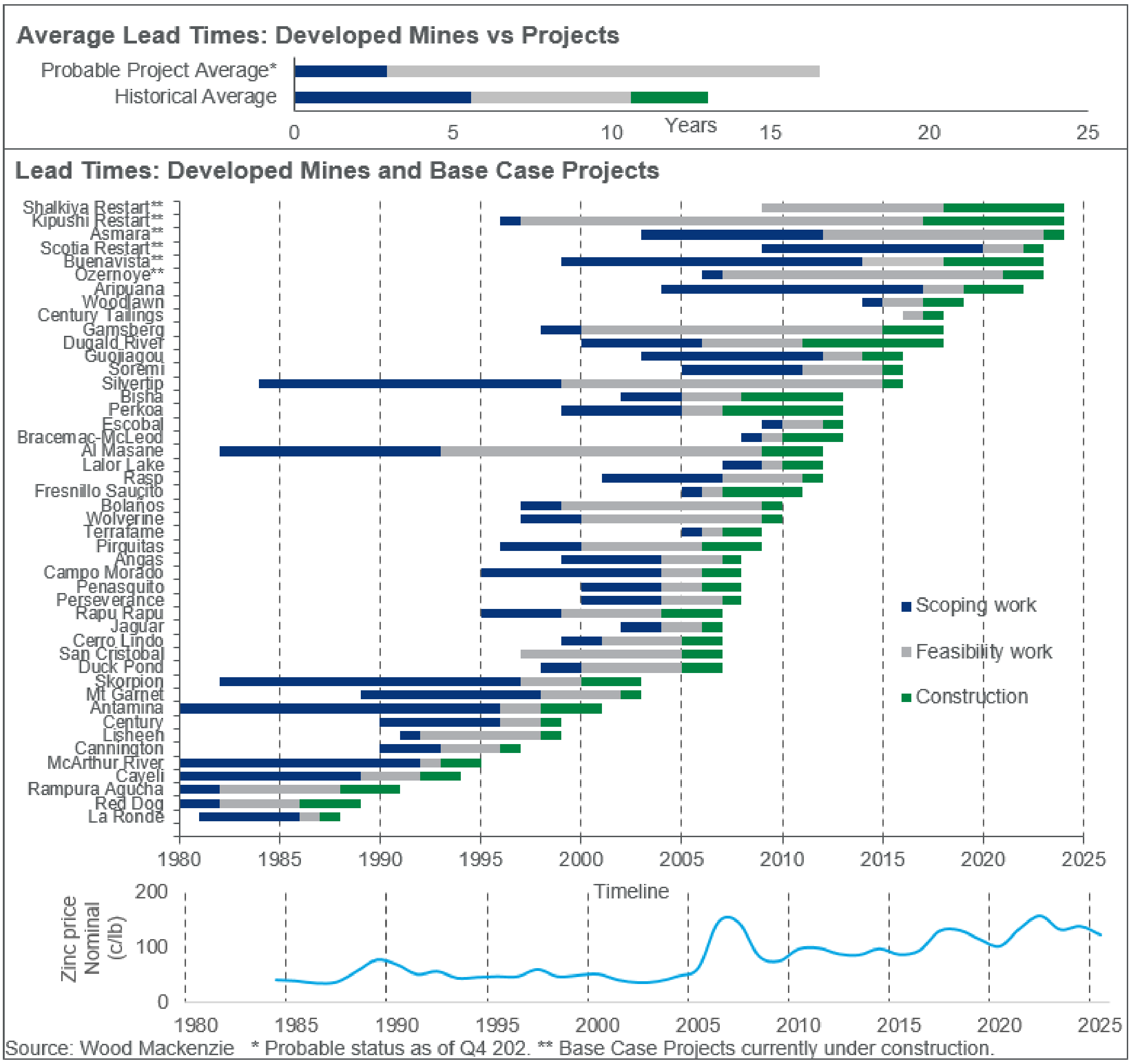


Figure 7: *Average project lead time from scoping to production.*

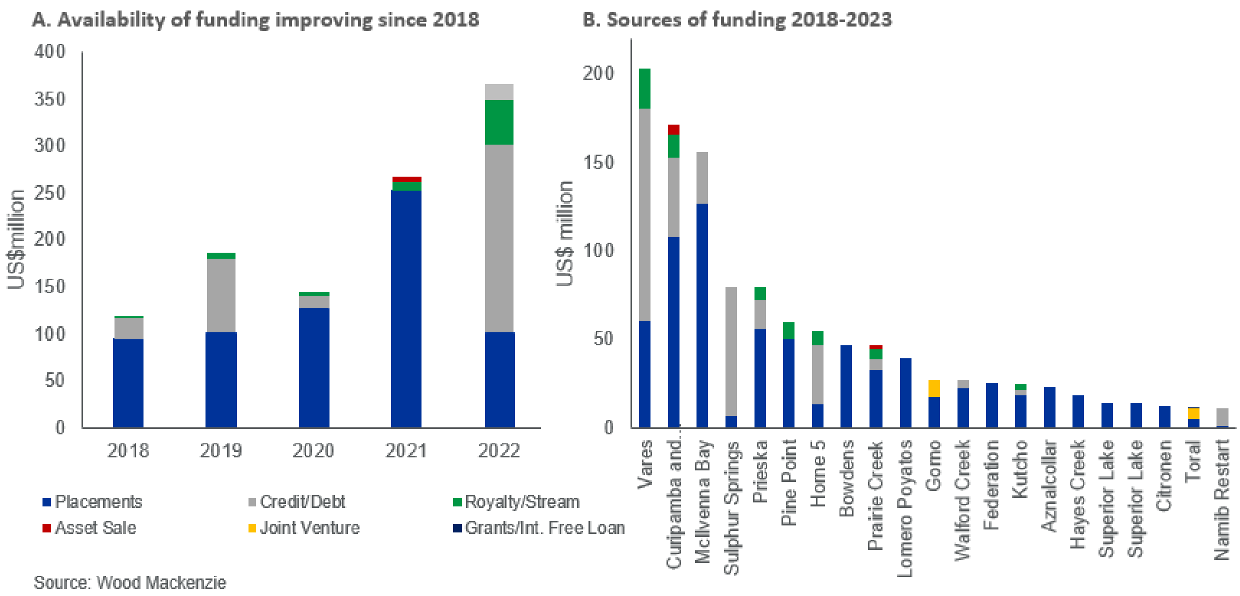


Figure 8: *Availability of funding improving over the last 5 years.*

studies meant that Kipushi, Gamsberg and Ozernoe took an additional 10 to 15 years to move from feasibility work to construction and to secure finance.

Availability of project financing has become more widely available to junior explorers and development companies in recent years, providing valuable funds for these companies to push forward their project through to the next stages of appraisals. Over the last five years, funding received by publicly traded explorers with zinc projects has come in several different forms but was dominated by private placements. Other forms include debt and public offerings, and less conventional forms such as royalty or stream agreements have also taken place as well as government initiatives through the form of merit-based grants. Individual funding events have also varied in total size which suggests that in addition to the range of funding options available, there is also a broad range of pocket sizes out there to dig into. Capital raises have been as large, one-off agreements in the US$10's million, or as smaller, more frequent raises from less than US$1 million to US$10 million. Whilst more advanced projects have sometimes attracted larger amounts of financing, this correlation is not as strong as one may have expected.

Geology of Zinc Mines

Zinc is found in various geological settings accumulated in ore bodies often in association with other metals, most commonly

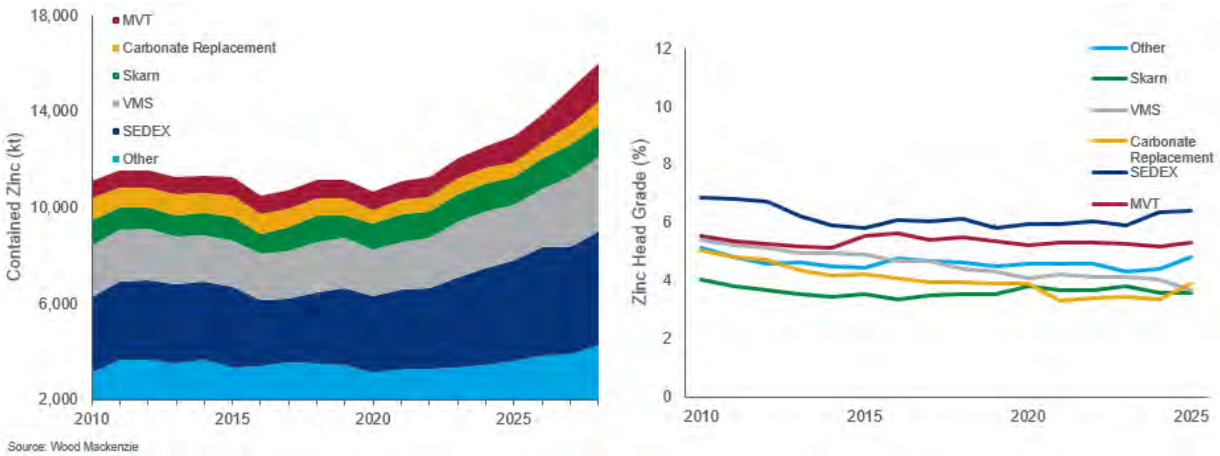


Figure 9: *Contained zinc production and zinc head grade by deposit type.*

A

Deposit Type	Zinc Grade %	Lead Grade %	Copper Grade %	Silver Grade g/t	Gold Grade g/t
Irish-Type	**7.8**	**1.8**	**0.1**	**14.1**	**0.0**
SedEx	5.0	1.5	0.0	31.9	0.0
VHMS	3.3	0.8	0.9	43.5	0.7
MVT	3.2	1.3	0.0	14.9	0.0
Carbonate Replacement	2.9	0.9	0.4	49.7	0.1
Other	2.8	1.0	0.0	50.1	0.3
Skarn	1.6	0.3	0.7	23.1	0.1

B.

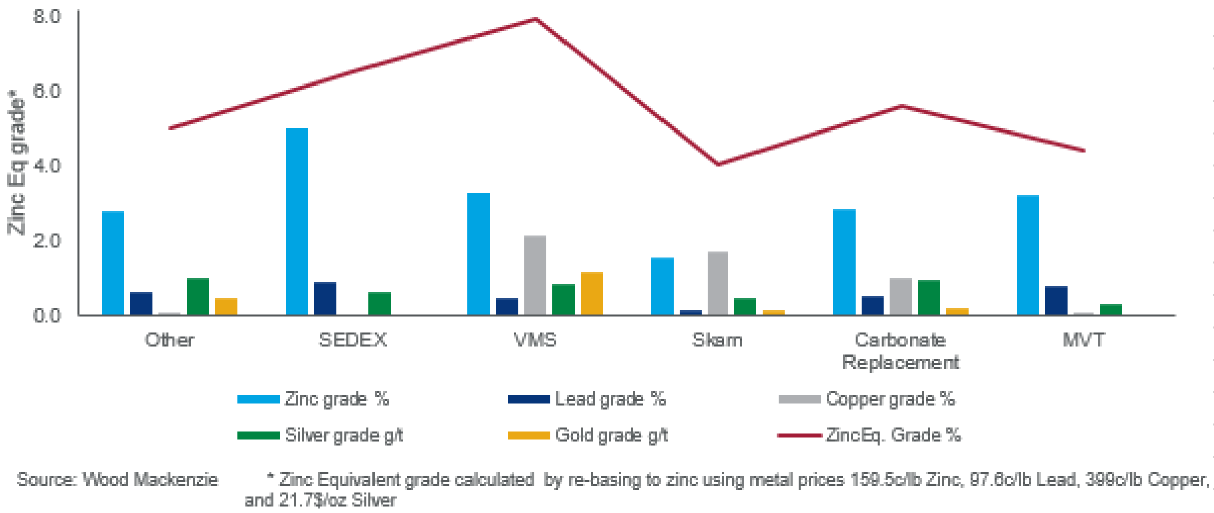


Figure 10: *Average polymetallic grades in 2022 by deposit type (A). Having other valuable metals in your deposit can make up for tonnage (B). Irish-type data from Ashton et al (this Volume).*

lead, copper, silver and gold. For zinc market studies, Wood Mackenzie considers eight types of zinc deposits from which SedEx-type and MVT deposits make up roughly half of global zinc ore reserves and contribute approximately 45% of global mined zinc production. Their large tonnages are exploited using both underground and open pit mining methods. Six of the top ten producing zinc mines are SedEx-type deposits and accounted for 1.9Mt of contained zinc production in 2022, or 15% of global production. Examples include Red Dog in USA, Rampura-Agucha in India and McArthur River in Australia. Future production from SedEx, Irish-type and MVT deposits is forecast to increase in the coming years as the Ozernoye project in Russia (345-400ktpa), Shalkiya project in Kazakhstan (125ktpa) and Danaopo project in China (45ktpa) enter production. SedEx and Irish-type deposits have one of the highest average zinc grades although there is a large range from around 2% Zn at a number of mines mostly in China to around 15% Zn at some of the larger SedEx and Irish-type deposits, again Red Dog being a notable example.

Zinc mines have been increasingly polymetallic in nature since the turn of the millennium. Larger mines that came into production include Antamina and Penasquito, and smaller more recent examples include Aripuana, Juanicipio, and Woodlawn starting in 2019. Being polymetallic means more financial and risk diversification through the exposure to more than one metal price and the ability to selectively increase production from areas that will benefit from high prices of a particular metal. Whilst large tonnages make SedEx-type deposits attractive operation, mines exploiting other deposit types can prove to be more attractive from a financial and risk perspective due to their polymetallic nature, such as VMS-type deposits. Analyzing 2022 head grades from a range of zinc producing mines shows that VHMS-type deposits had an 8% zinc equivalent grade in comparison to 6.6% for SedEx-type deposits. Irish-carbonate hosted-type deposits in Ireland average the highest zinc equivalent grade at 9.6%.

A look into Concentrates and the Influence of Geology

Zinc deposits are processed via the differential floatation route to form a saleable concentrate. Final zinc concentrate quality is crucial as it directly affects the efficiency of downstream refining processes at individual smelters. The concentrate quality will shape a project's marketing strategy and screen the

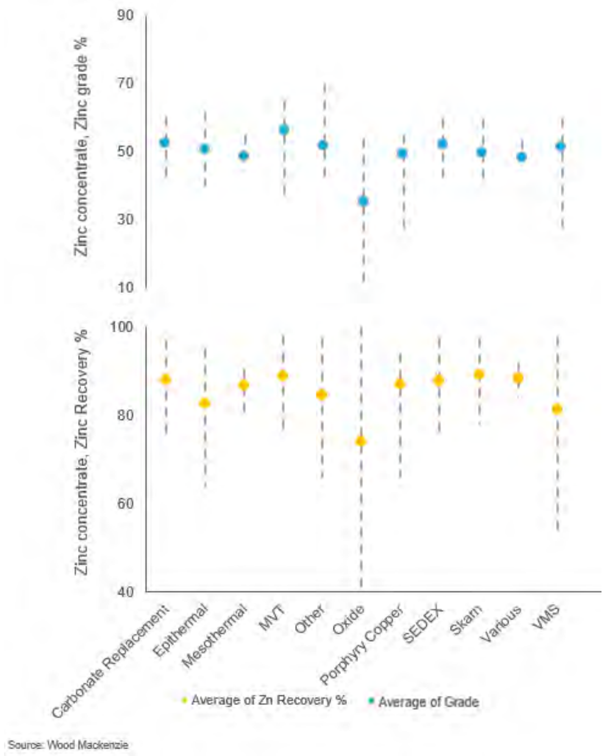


Figure 11: *Average zinc grade and recovery to zinc concentrates.*

suitability of a particular smelter. Mis-allocating concentrate risks either costing more or reducing income for the seller by not enabling them to fully benefit from metal credits or reductions in concentrate treatment penalties. Therefore, it is necessary to evaluate a smelter's technology, its local proximity relative to more downstream industries as well as its distance to the project. Whilst a particular concentrate quality may not be suited to a particular smelter, they may prove useful for blending purposes for smelters to meet their capacity requirements and impurity thresholds.

Metal recovery will control the final characteristics of a concentrate and to an extent the abundance of credit and penalty elements, affecting the final value of the product. Zinc recovery rates tend to be determined by the mineralogy of the deposit, how fine the minerals are and the extent of interstitial mineral matrices. SedEx-type deposits tend to have a fine mineralogy which can mean standard milling is insufficient to expose enough zinc bearing minerals to flotation reagents. This can result in substantial amounts of zinc bearing minerals reporting to tailings. One method employed to reduce this loss is fine grinding of ore which can further liberate mineral constituents from gangue minerals. Ore sorting on ROM material prior to grinding can also assist in reducing the amount of waste material moving through to flotation and would precede grinding. In the presence of other metals in ore, other methods of partial segregation include magnetic and gravity separation. Failure to rectify a low metal recovery or the inability to split and concentrate multiple metals individually can lead to a mine to take the decision to convert some of its production into a bulk concentrate containing a combination of different metals, typically zinc and lead and occasionally also copper. Whilst demand does exist for bulk concentrates, sellers are limited to only a handful of smelters able to process them. Similarly, impurities can have large implications on recovery and grade and can also interfere with the flotation process by decreasing the floatable zinc. This will lead to dilution of the concentrate and loss of the valuable metal, resulting in a less sustainable operation because of this operational deficiency.

At smelters, finer concentrate particle sizes can lead to loss of material and higher energy inputs during the roasting process, resulting in a lower smelter recovery. Impurities can also have an impact on the smelting of the concentrate. Impurities such as silica and iron cause higher energy consumption and make handing and separation of waste slag more difficult. They can also increase wear of the furnace linings over time which will require more smelter maintenance time. In the roast-leach-electrowinning process ("RLE"), too much iron may also cause more zinc reporting to ferrite rather than oxide during roasting. This will result in a more complex and costly recovery of the zinc from the ferrite residue or loss if the iron residue

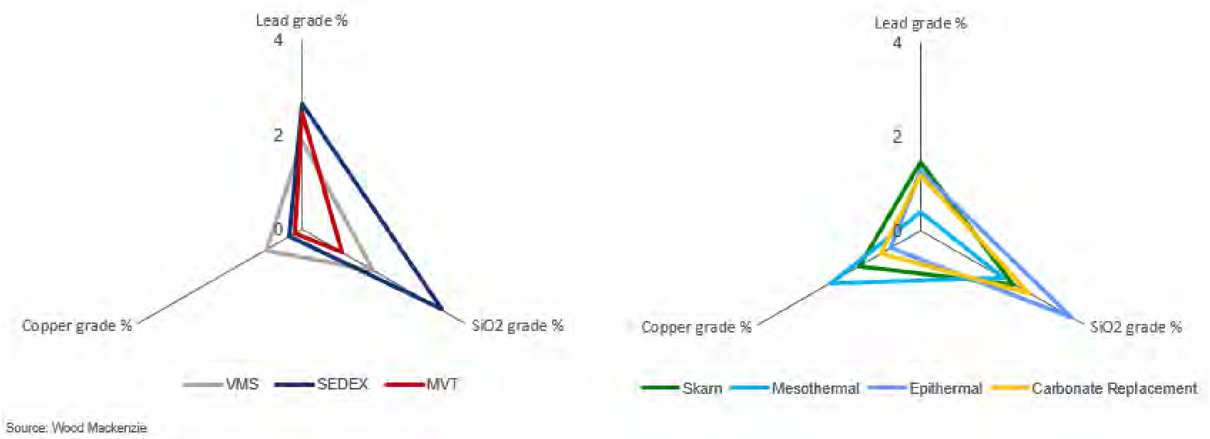


Figure 12: *Lead-Copper-SiO_2 content in zinc concentrates by deposit type.*

is dumped. Other impurities such as fluorine and chlorine can corrode the acid plant if their levels are too high. Mercury and selenium which report to the roaster gas stream as do fluorine and chlorine, can damage the quality of sulphuric acid produced and potentially make them unsellable. Cadmium, copper, cobalt and nickel affect the final quality of the zinc product and are usually removed with zinc dust during the leaching stage. Removal takes time and more processing and therefore will add to the total smelting cost.

Whilst concentrates with high levels of impurities are less easily marketable, they are treatable either with the addition of a higher penalty fee or through blending with cleaner concentrates. Being able to correctly allocate concentrates to individual smelters based on their capacity, capability and strategy is important.

SedEx-type and MVT deposits produce moderately clean zinc concentrates with zinc grades averaging between 50-52%. Whilst generally low in silver or gold, their concentrates can contain other bonus elements that are recoverable and in payable amounts. An example is germanium which requires an additional treatment route but nevertheless is currently sourced from zinc concentrates. However, low concentrations of other valuable metals means that the concentrates are amenable to smelters that use a week acid leach only for zinc recovery. These concentrates tend to contain iron, silica and lead close to penalty thresholds and do often attract additional smelting charges.

Comparing concentrates relative to their combined copper + lead + silica grade and whether the grade sits below 5% can be an effective first pass method to examine cleanliness of a concentrate due to the difficulty in treating these three components by smelters. Due to geology, SedEx-type clastic-hosted deposits have relatively high SiO_2 and lead grades which can push the concentrates into penalty territory. However, together with MVT deposits they have the lowest copper grades and often sit below the combined 5% copper + lead + silica grade.