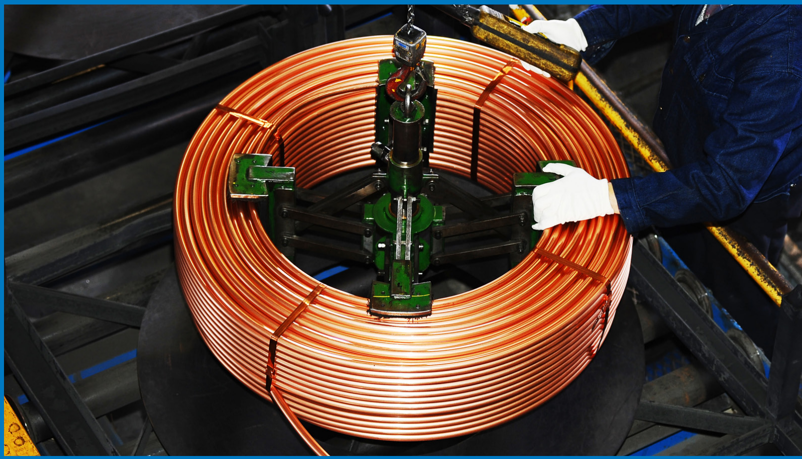
Renewable Energy:
A Green Light to Copper Demand



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Colin Hamilton
Global Commodities Analyst
BMO Capital Markets Limited
colin.hamilton@bmo.com
+44 (0)20 7664 8172

Kimberly Berman
Special Projects Analyst
BMO Nesbitt Burns Inc.
kimberly.berman@bmo.com
(416) 359-5611

Alex Terentiew
Metals & Mining Analyst
BMO Nesbitt Burns Inc.
alex.terentiew@bmo.com
(416) 359-6319

Ben Pham, CFA
Energy Infrastructure Analyst
BMO Nesbitt Burns Inc.
ben.pham@bmo.com
(416) 359-4061

Kash Kamal, CFA
Global Commodities Associate
BMO Capital Markets Limited
kash.kamal@bmo.com
+44 (0)20 7664 5352

Rory Blundell
Global Commodities Associate
BMO Capital Markets Limited
rory.blundell@bmo.com
+44 (0)20 7664 8119

Avi Benchetrit, CPA, CA
Metals & Mining Associate
BMO Nesbitt Burns Inc.
avi.benchetrit@bmo.com
(416) 359-4205

Jeff Zippel, CPA, CA
Energy Infrastructure Associate
BMO Nesbitt Burns Inc.
jeff.zippel@bmo.com
(416) 359-8110

BMO Capital Markets

BMO Capital Markets

Contributors

COLIN HAMILTON
Global Commodities Analyst
BMO Capital Markets Limited
colin.hamilton@bmo.com
+44 (0)20 7664 8172

KIMBERLY BERMAN
Special Projects Analyst
BMO Nesbitt Burns Inc.
kimberly.berman@bmo.com
(416) 359-5611

ALEX TERENTIEW
Metals & Mining Analyst
BMO Nesbitt Burns Inc.
alex.terentiew@bmo.com
(416) 359-6319

BEN PHAM, CFA
Energy Infrastructure Analyst
BMO Nesbitt Burns Inc.
ben.pham@bmo.com
(416) 359-4061

KASH KAMAL, CFA
Global Commodities Associate
BMO Capital Markets Limited
kash.kamal@bmo.com
+44 (0)20 7664 5352

RORY BLUNDELL
Global Commodities Associate
BMO Capital Markets Limited
rory.blundell@bmo.com
+44 (0)20 7664 8119

AVI BENCHETRIT, CPA, CA
Metals & Mining Associate
BMO Nesbitt Burns Inc.
avi.benchetrit@bmo.com
(416) 359-4205

JEFF ZIPPEL, CPA, CA
Energy Infrastructure Associate
BMO Nesbitt Burns Inc.
jeff.zippel@bmo.com
(416) 359-8110

Renewable Energy: A Green Light to Copper Demand

This report brings together two of BMO's core areas of expertise, the technical aspects of green technology impacts and commodity market analysis, to analyse the expected impact on global copper markets from two rapidly growing areas: electric vehicles (EVs)[1] and renewable energy. We have undertaken bottom-up research on copper use in both these sectors to quantify intensity of use, consumption trends and potential for substitution, in order to provide a better understanding of the longer-term thematics for copper over the decades to come.

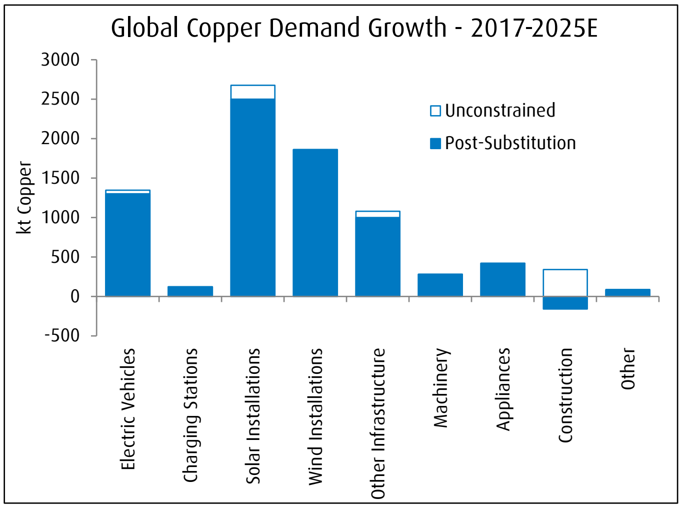
We have seen many research notes that consider long-term copper market fundamentals. However, these reports mainly focused on copper supply using basic industry consultant data. In contrast, we have started from first principles to derive expected demand, calculated a supply gap over the 2025-30 period, and incorporated our expectations of declines at existing mines, substitution, scrap recovery and supply elasticity. Furthermore, we have analysed over 100 potential copper projects using an incentive price methodology to determine the copper price needed to provide market equilibrium, on the basis that commodity markets simply don't see ever increasing deficits. While the longer-term story on copper is perhaps well-known, the purpose of our analysis is to make this better appreciated by highlighting the areas which drive the need for higher copper prices in future years.

Raising Our Copper Demand Forecast and Long-Term Price Expectation

Our research shows that renewable energy is the largest single driver of copper demand growth over the coming years, owing to the need to connect significant numbers of small-scale electricity generation units into the grid. Copper use to support both solar and wind installations are set to grow at a double-digit CAGR over the coming years, with the former set to add 2.5mtpa to global copper demand by 2025 and the latter 1.85mtpa. While this is our base case, we have also analysed a bull case where a renewed push for carbon reduction increases installation rates. Offshore wind installations are particularly copper intensive, averaging over 9t of copper per MW. Meanwhile, on our calculations, the automotive sector could add 1.5mtpa of copper demand growth by 2025, with this dominated by electric vehicle growth. Figures 1 and 2 below show the dominance of these areas in driving copper demand growth to 2025, and how this creates a gap to expected available supply.

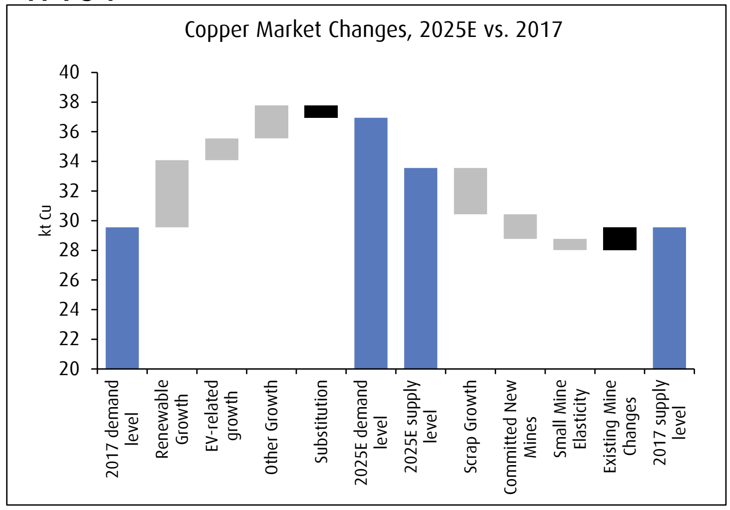
[1] Our definition of electric vehicles (EVs) includes battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs).

Figure 1: We see renewables as the largest driver of demand growth, even after allowing for substitution



Source: Copper Alliance, BMO Capital Markets

Figure 2: There are a number of factors in determining the copper supply gap in 2025 onwards



Source: Wood Mackenzie, Copper Alliance, BMO Capital Markets

~5mtpa of new projects from new primary mine supply is needed to solve the expected supply gap

As a result of this analysis, we have raised our estimated 2025 copper demand forecast by 1mtpa over our previous estimates. Putting this through our model, we see the need for ~5mtpa of new projects from new primary mine supply to solve the expected supply gap and bring the market into equilibrium over the 2025-2030 period.

After analyzing incentive prices for 109 copper projects, with combined capacity of just over 10mtpa of copper, we now estimate a required incentive price of $3.25/lb ($7,165/tonne) in 2018 dollar terms will be needed to provide market equilibrium. This is 7% higher than our previous $3.05/lb ($6,725/t) forecast. We have made no changes to our short- to medium-term forecasts.

We would also note that the copper market is moving into significant deficit over the next two years owing to a lack of supply growth. As a result, we expect copper pricing above our long-term equilibrium on a 12-24 month view. This gives copper appeal to both long-term and shorter-term investment strategies.

Figure 3: BMO's Copper Price Forecasts

	Unit	2017	Q1 2018	Q2 2018	Q3 2018	Q4 2018	2018	2019	2020	2021	LT
Copper											
New	**USD/lb**	**2.80**	**3.16**	**3.15**	**2.9**	**2.9**	**3.03**	**3.25**	**3.41**	**3.10**	**3.25**
Previous	USD/lb	2.80	3.16	3.15	2.9	2.9	3.03	3.25	3.41	3.10	3.05
Change	USD/lb			*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*7%*
New	**$/tonne**	**6173**	**6967**	**6944**	**6393**	**6393**	**6674**	**7165**	**7523**	**6834**	**7165**
Previous	$/tonne	6173	6967	6944	6393	6393	6674	7165	7523	6834	6724

Source: Wood Mackenzie, BMO Capital Markets. Note: 2017 and Q1 2018 are actuals.

Top 5 Proprietary Takeaways

1. **Our analysis gives us a greater degree of demand confidence** → We expect copper demand growth rates through 2030 at above a 3.0% CAGR, marking an acceleration on those seen over the past twenty years. Both EVs and renewable energy are global demand trends, but while China may be leading the way in both sectors, they are not solely a China story. Moreover, evidence is already available demonstrating that these secular themes are having an impact on both physical demand and financial market behaviour. **As a result, the demand growth story is de-risked somewhat from an investment perspective. In light of our demand analysis in** [section 2](#) **of this report, we have added 1mtpa of global copper consumption to 2025 vs. our previous estimates**. In our view, it is this increased confidence that justifies a higher long-run copper price.

2. **Renewable energy infrastructure is the biggest single driver of global demand growth over the coming years** → The need to connect significant numbers of small-scale electricity generation units into the grid provides a major boost to copper, with solar generation capacity set to triple and wind capacity set to double by 2025. Given this is a recent trend and that little scrap is generated from replacement, the shift to areas such as offshore wind only increase copper intensity further. Compared to this, growth from the electric vehicle segment (cars and charging infrastructure) is small, but not insignificant and certainly incremental to our expectations from two years ago.

3. **The copper project pipeline is historically thin** → The current and highly probable copper pipeline is at the lowest level we have seen this century, both in terms of the number of projects and capacity. Recent years have seen both cancellation and delivery of potential projects, which have served to reduce the list and shorten the x-axis on our incentive price curve.

4. **Raising our long-run copper price to $3.25/lb ($7,165/t)** → Changing long-run commodity prices should be a rare event, and should only take place where there is a marked shift in the future outlook. In our view, that event is the step-change we expect in demand expectations driven by renewables and electric vehicles. Through taking into account capital intensity, our estimation of operating cost and tax structures, we have built an incentive price curve incorporating 109 potential projects which could help solve the projected supply gap over 2025-30. Based on this analysis, we see $3.25/lb ($2018) as a reasonable long-term equilibrium price for copper, higher than the $2.75/lb average over the past five years, current pricing of ~$3/lb and consensus forecasts of 2018 long-term pricing at $2.95/lb. While there are upside risks to this forecast, we view this as a fair price given an extended period higher than this level would encourage more demand deferral and lower the supply gap.

5. **Different scenarios can drive a very different long-run price expectation** → We have also considered alternative scenarios, which result in a different average supply gap over 2025-30 and thus a different long-term price expectation to provide equilibrium. If we assume demand growth rates at half our base case, we end up with a long-run price of $2.75/lb ($6,060/t). Conversely, if we take the bull case for renewable installations, we would need a long-run price of $3.8/lb ($8,375/t).

Report Synopsis

Our discussion in this report addresses the looming copper supply gap in three major sections, which are briefly summarized below.

1. Quantifying the Supply Gap

Expected copper supply gap of > 5mtpa over the 2025-30 period. There are many moving parts to copper analysis, but taking into account our increased demand forecast and balancing this with expected trends in scrap recovery, existing mine output and substitution results in a copper market deficit averaging over 5mtpa during 2025-30. This is the gap that new supply will have to resolve, given growing deficit levels simply don't happen in commodity markets.

2. Copper Demand Fueled by EVs and Renewable Energy

BEVs require ~3.6x the amount of copper than ICE vehicles. Given that EV adoption is necessary to meet environmental regulatory targets, copper demand is likely to get a boost. We estimate that ICE fuel efficiency improvement rates would have to effectively double in order to meet environmental standards without help from much greater EV adoption. We do not see this as a possibility and see increasing EV penetration as inevitable. In our models, global EV penetration would need to reach ~12% in order to comply with environmental regulatory targets by 2025. That being said, we also believe that the current state of battery chemistry needs improvement and have conservatively forecast a 10% EV penetration rate by that time. BEVs require about 3.6x and PHEVs require 2.6x the amount of copper as ICEs. Thus, as EV sales start to ramp up to meet our 2025 target, an extra ~1.3mtpa of copper will be required.

Renewable energy is a big part of our forecasts. While electric vehicles dominate growth conversations in metals and mining, renewable energy is significantly more important for copper, and expectations of solar and wind installations are continuing to increase. Globally, the number of solar and wind facilities is expected to grow 10-14% through 2025 (and at ~5-7% CAGR through 2040 thereafter). We believe that this facilities growth will translate to equivalent growth in copper demand. The amount of copper used in solar assets ranges from 4-5kt/GW, while onshore wind has a similar midpoint of 4.5kt/GW but has a wider range of 2.3-6.8kt/GW. While the shift toward 'local utility structures' is likely to hurt transmission demand, this impacts aluminium rather than copper. The growth in domestic and industrial energy storage units increases the need for copper-intensive distribution capacity.

3. Incentive Price Analysis

Incentive price analysis points to higher copper prices being required. Through taking into account capital intensity, our estimation of operating cost, corporate tax rates and rates of return, we have built an incentive price curve incorporating these 109 projects which have combined capacity of just over 10mtpa of copper. This gives a reasonable guide to the copper price needed for long-term equilibrium, and the result is a base case of \$3.25/lb (\$7,165/t), representing a sustained leg higher than average pricing seen over the past five years.

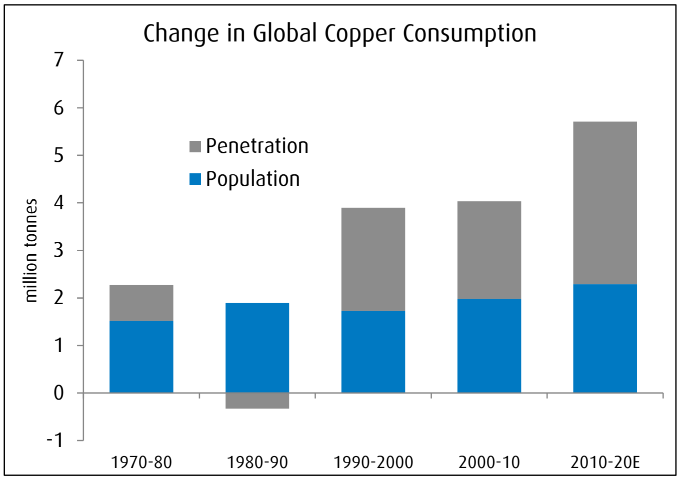
Impact on mining equities. The impact on the mining equities of incorporating our revised long-term copper price of \$3.25/lb (\$7,165/t) is summarized in *"Renewable Demand Gives Renewed Copper Confidence."* Net asset value estimates for the copper focused miners have risen on average by 17%, with some target prices revised slightly higher. Given our strengthened degree of demand confidence, we believe investors should accumulate shares in companies with growing copper production and improving balance sheets, with First Quantum Minerals, Ivanhoe Mines, Rio Tinto and Teck Resources our preferred names.[2]

[2] First Quantum and Teck Resources covered by Alex Terentiew, BMO Nesbitt-Burns, Inc. (not a FINRA registered analyst); Ivanhoe Mines covered by Andrew Mikitchook, BMO Nesbitt-Burns, Inc. (not a FINRA registered analyst); Rio Tinto covered jointly by Edward Sterck, BMO Capital Markets Limited (authorized and regulated by the Financial Services Authority in the UK and not a FINRA registered analyst) and David Gagliano, BMO Capital Markets Limited. For disclosure statements, including the analyst certification(s), please refer to pages 34 to 38.

1. Quantifying the Supply Gap

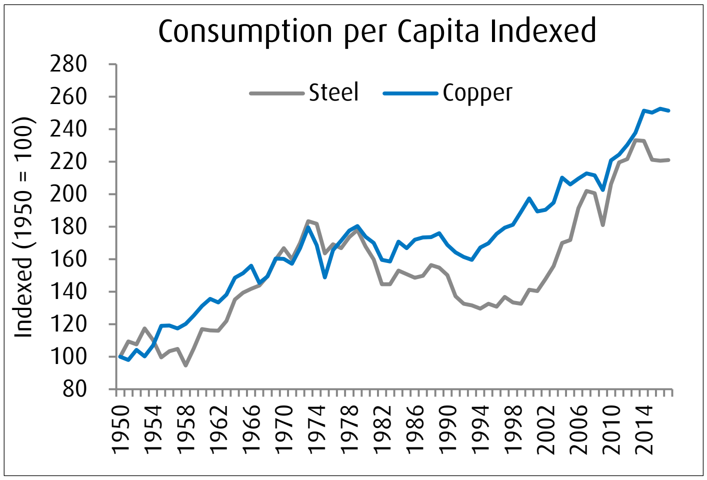
On a longer-term view, copper demand has seen consistent growth, if at a rate lower than many industrial metal peers. Partly this is down to the annuity of global population growth which has benefitted all commodities; however, copper has also seen increasing penetration in use on a per capita basis. This is down to the 'wealth effect' on copper, with economics growth and urbanization seeing increased demand for copper-containing wires and consumer products. On a longer-term basis, while it is naturally exposed to industrial cycles, copper's consumption growth has thus been more consistent than for other early stage metals such as steel, where we have seen sustained periods of falling demand on a global basis historically.

Figure 4: Intensity of copper consumption has been rising on a global basis…



Source: ICSG, worldsteel, BMO Capital Markets

Figure 5: …and has been much more consistent than for peer commodities such as steel.



Source: ICSG, worldsteel, BMO Capital Markets

Currently, global copper demand is ~30mtpa, which includes that produced from direct use of scrap. This can be split into various core end-uses.

We see the renewable grid infrastructure accounting for 74% of all copper demand growth to 2025 – at 5.5mtpa

Infrastructure/Electrical Network accounts for ~35% of current demand. Grid infrastructure is heavily reliant on copper for wiring, transformers and motors with only overhead transmission lines dominated by lighter-weight aluminum owing to the need to minimize pylon supports. Of course, this segment includes the largest copper consumer in the world, China's State Grid, which we estimate consumes up to 10% of global copper in any given year. As discussed in detail in section 2 of this report, given the push towards dispersed generation sources for renewable energy, and the need to support grid upgrades for electric vehicle charging, we see this sector accounting for 74% of all copper demand growth to 2025, equivalent to 5.5mtpa. This is far and away the largest area for copper growth in our model, with the work detailed in section 2 of our report adding ~1mtpa of copper demand over previous estimates.

We see 24% of demand construction that will decline through 2025 due to low voltage wiring substitution

There is always some element of crossover between infrastructure and **construction** in terms of copper use, as one effectively runs straight into the other in terms of electrical wiring. In addition to this, copper tubes and pipes are an industry standard for water and heating systems in developed economies. A key benefit copper has over other metals is its bacteriostatic properties and soldering ability, while it still has demand in architectural/aesthetic areas. Currently, we see 24% of demand in construction, but we see this declining through 2025 owing to potential substitution; mainly in low voltage wiring. We discuss this more in coming paragraphs.

A combination of **white goods** and **general consumer** use also accounts for 24% of copper demand, with the main applications again involving electrical or heat transfer. The widespread growth in computing and portable devices has seen copper's use in connectors, circuit boards, microchips and semiconductors increase substantially in recent years. As global incomes grow, so copper demand in this area is likely to grow in line with this, as every incremental household desires slightly more air conditioners or appliances. We see this area accounting for 6% of copper demand growth through 2025, equivalent to 470ktpa.

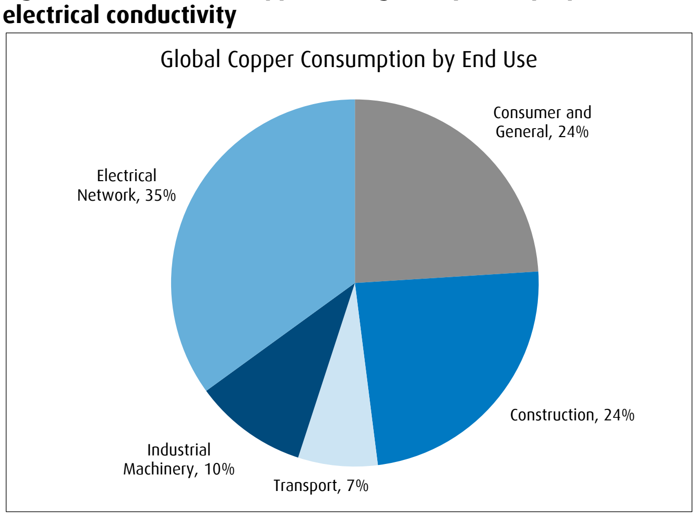
Machinery makes up around 10% of copper demand currently, also for electrical conductivity in the main. With a trend towards robotics and automation, we see this accounting for 4% of copper demand growth through 2025, or 280ktpa.

Lastly, **transportation** makes up around 7% of current copper demand (though this doesn't include infrastructure for transportation). Copper forms key components for automotive, aerospace and rail applications. The thermal properties make it an ideal metal to dissipate heat while its conductivity aids increased sophistication in navigation and automated systems. With increased demand in electric vehicles, as discussed in section 2, we see transportation driving 18% of copper demand growth through 2025, or 1,330ktpa.

Given the growth in renewable energy and EV sector, we see total copper unit demand growing ~3% over the next decade

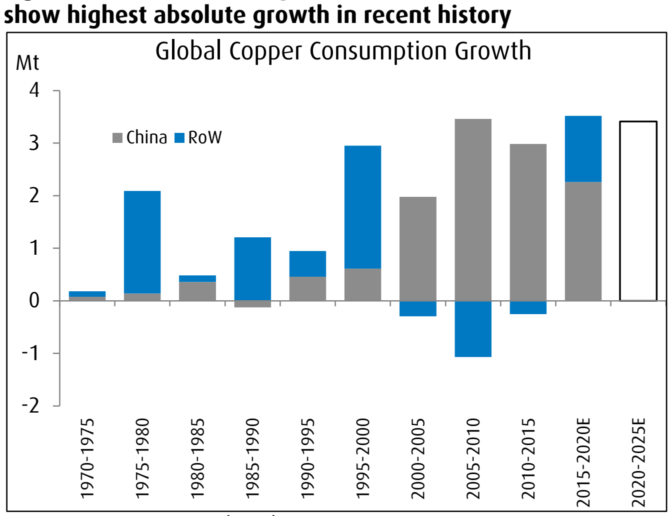
With the growth in renewable energy and electric vehicles, both global trends, we see total copper unit demand growing at a +3.1% CAGR through 2025, and 3% through 2030. This is above the trend seen over the past twenty years, a period which included China's urbanisation and industrialization push. This results in refined copper consumption growing by over 3mt for both the 2015-2020 and 2020-2025 periods. Given the global nature of copper demand growth, we have not explicitly broken out where the first use copper consumption takes place, particularly as the growing influence of trade restrictions potentially reshapes global manufacturing.

Figure 6: Over 60% of copper used globally is for purposes of electrical conductivity



Source: Copper Alliance, BMO Capital Markets

Figure 7: The current five years, and that to follow, are set to show highest absolute growth in recent history



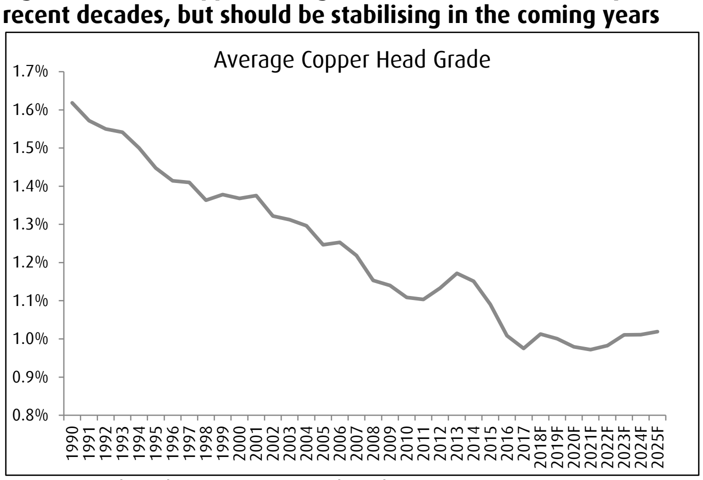
Source: ICSG, BMO Capital Markets

In terms of long-term copper forecasts, given this robust outlook without doubt there is likely to be a supply gap in copper. There is, however, a number of moving supply parts where assumptions are needed to quantify such a gap, namely:

- **Declining grades at existing assets**. Twenty years ago, the average grade of a working copper mine was 1.6%. Now, it is 1.0%. Not only are new assets dilutive, but the nature of any existing asset is that the good stuff gets mined first to give the best upfront payback. However, available data suggests a stabilisation in copper grades over the coming years, breaking the decline trend. While this is clearly a potential source of disruption in future supply forecasts, we build in no impact from this.

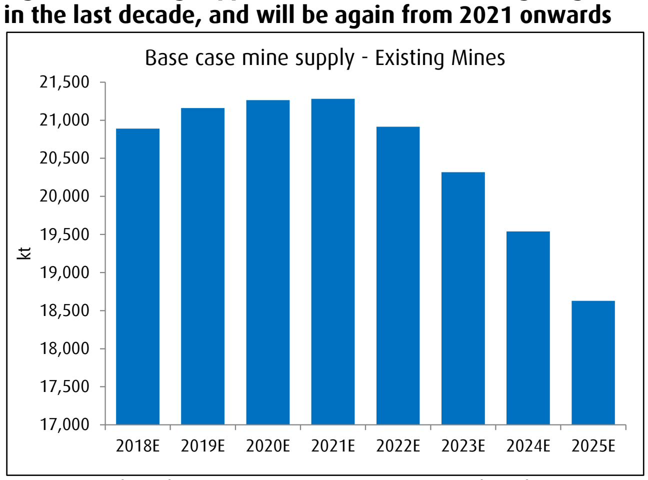
- **Underperformance of existing operations**. For all of the concerns over copper supply that have persisted for much of this century, new projects have consistently come through the pipeline and deliver new copper units to market, even if delayed and over budget. Rather, the perennial struggles of existing copper assets, particularly the large operations, have posed the biggest hurdle to overall supply growth. To put this in context, the largest 10 copper mines in the world in 2007 produced ~4.8mt of copper (in 2005 this number was in excess of 5mt). Those same operations in 2017 produced ~4.3mt. We have slight growth (pre-disruption) from existing assets through 2021, but after this point with many SXEW operations hitting end of life, the decline accelerates. By 2025, we see a drop of 1.53mtpa from existing operations.

Figure 8: Global copper head grades have fallen markedly over recent decades, but should be stabilising in the coming years



Source: Wood Mackenzie, BMO Capital Markets

Figure 9: Existing copper mines have been a drag on growth in the last decade, and will be again from 2021 onwards



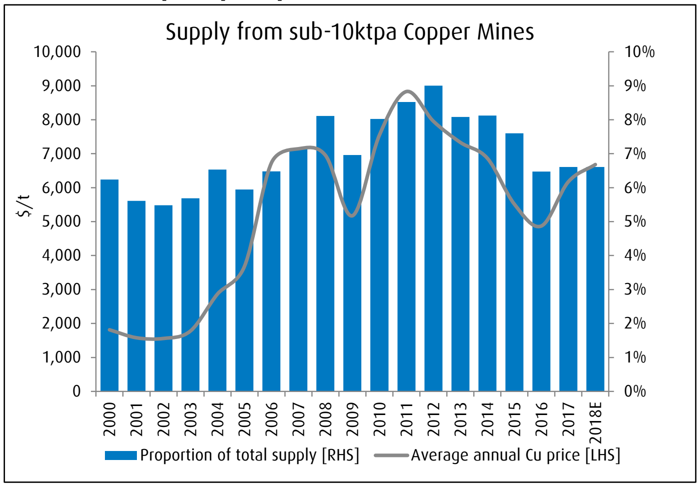
Source: Wood Mackenzie, Company Data, BMO Capital Markets

Elasticity of smaller mines. When and commodity price rises, it is normal to see a supply reaction from smaller operations (typically private sector-owned). As figure 10 highlights, in copper the proportion of supply coming from sub-10ktpa operations typically gains (or falls) one year after copper price moves. Even with the Chinese clampdown on domestic mine supply, which impacts one key area of elasticity, we assume there will be some reaction from smaller mines (notably small-scale SXEW in Chile and the DRC) which could add ~750ktpa of material by 2025.

Growth in scrap availability. In the short term, scrap is the most elastic part of the copper supply chain to price. Longer term, it has to be modelled as inelastic. Even though consumption has been on a downward trend in recent times, accentuated this year by Chinese restrictions, we assume a steady rise in recovery rates over the coming years – both in smelter/refinery and direct scrap use.

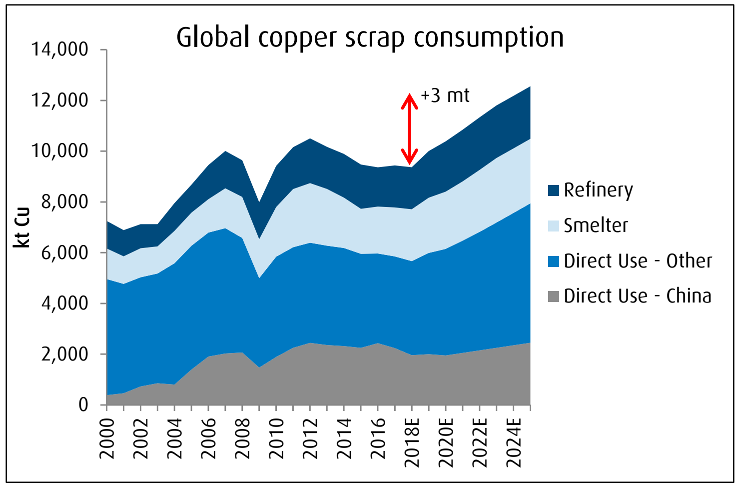
On the latter, however, we do assume most of the growth comes from ex-China as the industry shifts to other South East Asian countries where environmental restrictions are not as stringent. Overall, we see 3.1mtpa additional scrap consumed in 2025 versus current levels.

Figure 10: Copper does have some supply elasticity – smaller mines react to price prompts



Source: ICSG, Wood Mackenzie, BMO Capital Markets

Figure 11: We expect ~3mt of copper scrap availability by 2025



Source: Wood Mackenzie, BMO Capital Markets

One final area to be considered is thrifting or demand destruction of copper. Of course, such demand destruction is not a new thing in copper. The Copper Alliance estimates that losses of 250-400ktpa have been taking place over much of the past decade, either through substitution or miniaturization. However, with a large deficit emerging in 2019-20 on our numbers, solving this will involve a more significant shift, with substitution for aluminium the most likely candidate. This has to be incentivized through price, and there is much debate over at what level this happens, which of course depends on the individual application.

In our view, electrical cabling offers the most likely solution for the level of substitution needed as there is a viable (if inferior) alternative in aluminium. Even then, there are barriers to change, given higher value apartments and the push towards connected homes naturally requires more cabling. For medium voltage under street cabling in cities, the lack of space means aluminium replacement simply isn't an option. Therefore, we see the path of least resistance seeing substitution in lower value Chinese housing development, particularly under the government sponsored social-rental housing push. Since the last copper price spike in 2011, China has changed standards to permit the use of aluminium alloy cabling in residential developments, so this price-sensitive pressure release valve is now there.

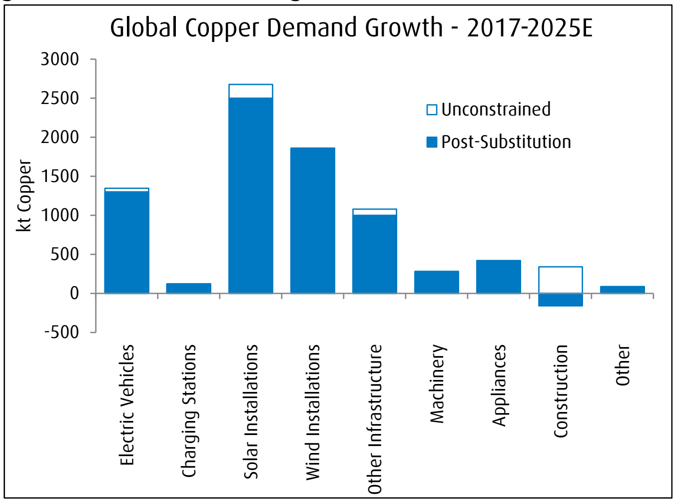
Demand destruction is only on a needs must basis

To be clear, demand destruction is only on a needs must basis, and in our view wouldn't be considered until the copper/aluminium price ratio is significantly higher than currently seen. However, once this demand is 'lost' it is unlikely to recover quickly. We model ~800ktpa of incremental substitution by 2025 over and above usual trends.

In our view it wouldn't be considered until the copper/aluminium price ratio is significantly higher than currently seen

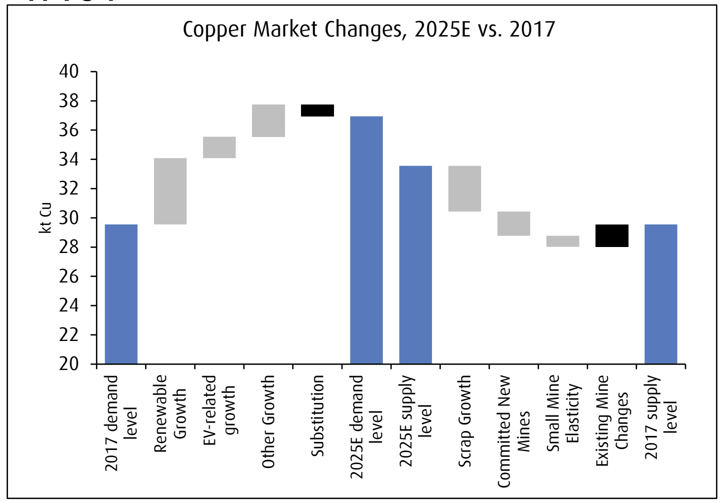
Figure 12 shows the impact of the different demand areas on absolute growth between 2017 and 2025, both in an unconstrained environment and taking into account our expectations of substitution. Infrastructure to support solar energy installations is the largest single driver, followed by needs for wind energy. Electric vehicles are also significant, while construction is the only drag owing to our assumption of substitution.

Figure 12: We see renewables as the largest driver of demand growth, even after allowing for substitution



Source: Copper Alliance, BMO Capital Markets

Figure 13: There are a number of factors in determining the copper supply gap in 2025 onwards



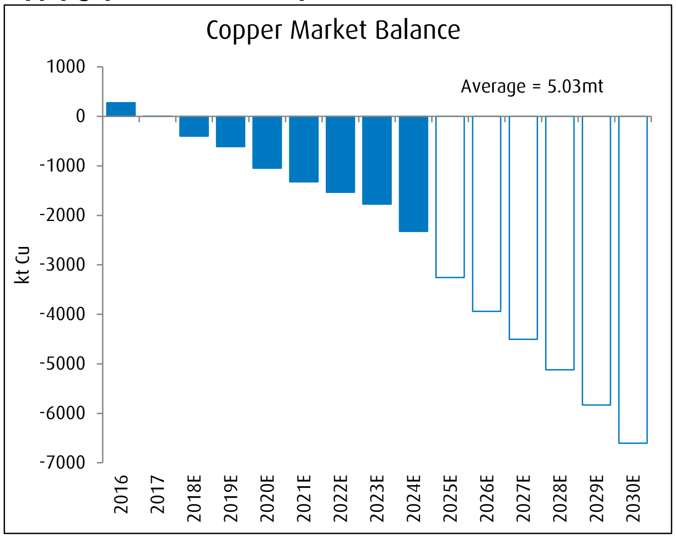
Source: Wood Mackenzie, Copper Alliance, BMO Capital Markets

Putting all these elements together, the waterfall chart in figure 13 shows the changes we expect in the copper market through 2025 versus 2017's levels. The end result is a relatively substantial supply gap.

Of course, this supply gap naturally rises over time. For purposes of incentive pricing, we are interested in the 2025-30 period, as this is the one where new projects can realistically provide equilibrium. Over this period we see an average annual supply gap of just over 5mt. Given deficits of such a level simply don't (and cannot) occur in commodity markets, we need to incentivise sufficient projects to fill this gap.

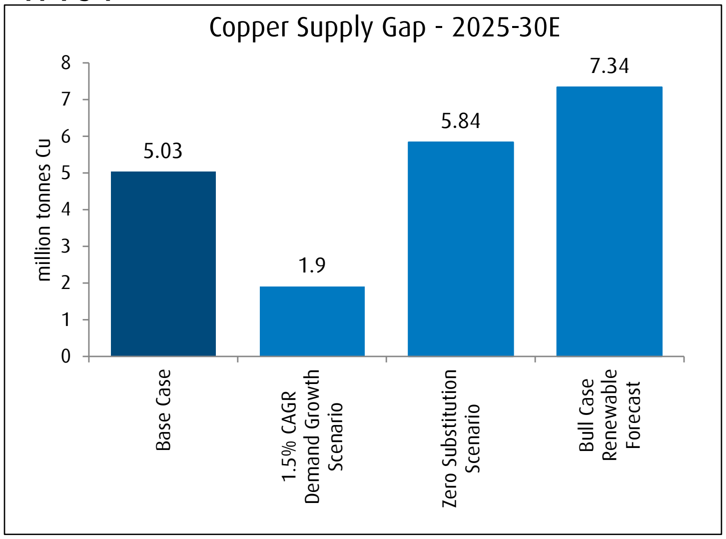
Though this is our base case supply gap, we have also considered alternative scenarios. Should overall demand come in lower than our forecast and grow at just a 1.5% CAGR, all other things being equal, the average 2025-30 gap reduces to 1.9mt. If we assume demand substitution doesn't take place the gap would rise to 5.84mt, while if we factor in the bull case on renewable installations discussed in section 2 we would see an average gap of 7.3mt.

Figure 14: Everything else being even, we see an average supply gap in excess of 5mtpa over 2025-30



Source: ICSG, BMO Capital Markets

Figure 15: Different scenarios naturally drive different levels of supply gap



Source: Wood Mackenzie, Copper Alliance, BMO Capital Markets

2. Copper Demand Fueled by EVs and Renewable Energy

Growth in the solar and wind energy sector will mean an additional ~4,360ktpa of copper

Copper is an essential element for the future of clean technology. In conjunction with being an excellent thermal and electrical conductor that is second only to silver by a negligible amount among major metals, copper is durable, reliable, malleable and safe with properties that allow it to be used in a wide range of applications in many different environments. It also exhibits sustainable characteristics as it is 100% recyclable and maintains its original electrochemical properties at the end of the recycling process. According to a cradle to grave analysis from Siemens AG and The International Copper Association, production of copper represents ~2% of CO_2 emissions in the production process of wind energy, which would be offset in 3-5 days once operational. As such, copper windings are often considered the most valuable part of scrap motors.

We believe that the expected couple digit percentage growth of solar and wind energy sector will mean an additional ~4,360ktpa of copper needed in 2025 over current levels. Meanwhile, given our forecasts of a 10% EV penetration by 2025, we estimate that copper demand in the automotive sector will grow significantly as the electric vehicle (EV) market continues to grow.

Our EV sector discussion focuses on the following broad themes: (1) the expanded use of copper in the automotive industry, our EV penetration forecasts, increasing vehicle demand for all vehicle types, and the effects of these factors on copper demand; and (2) a technical analysis of copper usage, function, longevity and construction related to electric motors, lithium-ion batteries, and EV charging infrastructure.

Our renewable energy discussion focuses on the effect of infrastructure growth on copper demand which includes: (1) a technical discussion of copper vs. aluminium use for wind and solar and the superiority of copper over aluminium for wind turbines; and (2) an analysis of global demand growth for renewable energy.

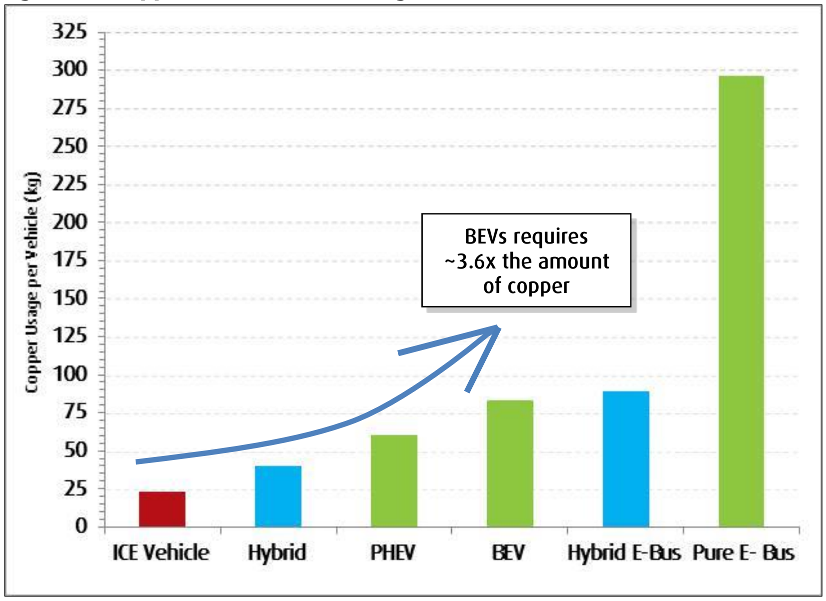
Electric Vehicle Market and Copper Demand

a. Expanded Use of Copper in the Automotive Industry

As the automotive industry continues to electrify its fleets, this adds another incremental source of copper demand. Our definition of electric vehicles (EVs) includes battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs). BEVs are fully electric and powered by a rechargeable lithium-ion battery pack that is charged by plugging into the grid while plug-in hybrids (PHEVs) run on electricity first, then once that capacity is used; the gas engine kicks in. There are also hybrid-electric (HEVs) that use a gasoline engine as the main source of power for acceleration, but draws power from its small electric motor when operating at lower speeds to reduce overall fuel consumption.

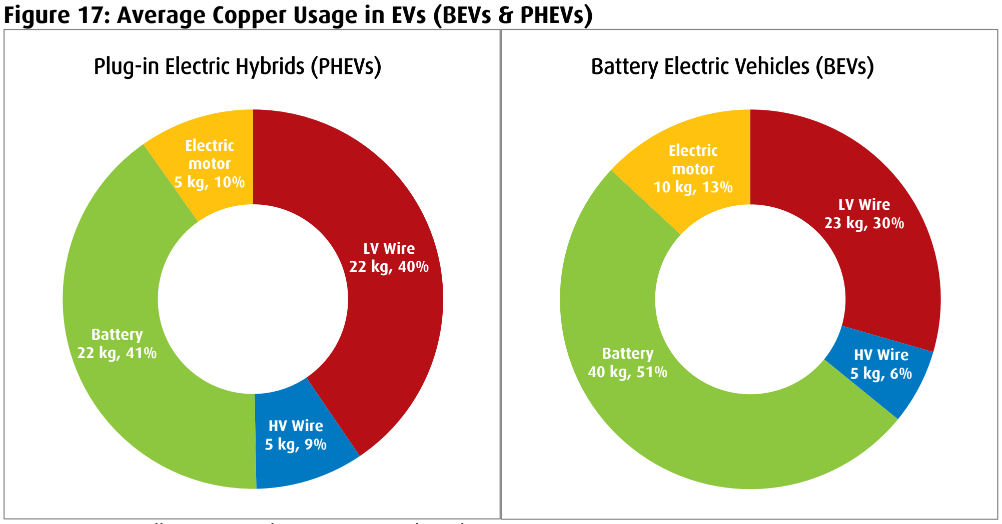
On our estimation traditional internal combustion engine (ICE) vehicles contain ~23kg of copper, mainly for low voltage (LV) wiring. However, EVs contain more copper through use in high voltage wiring as well as for windings and rotors in the electric motor, busbars in the battery packs and (currently) collectors in lithium-ion battery cells. We estimate PHEVs and BEVs contain ~60kg and ~83kg of copper depending on the size of the battery pack, the type of electric motor used and the overall design. For example, while BYD uses ~64kg of copper in its Tang PHEV model, their e6 BEV contains 110kg of copper due to the increased amount used in the battery (66.6kg versus 40kg).

Figure 16: Copper Content Is Much Higher in the Electric Powertrain



Source: International Copper Association, BMO Capital Markets

Figure 17: Average Copper Usage in EVs (BEVs & PHEVs)

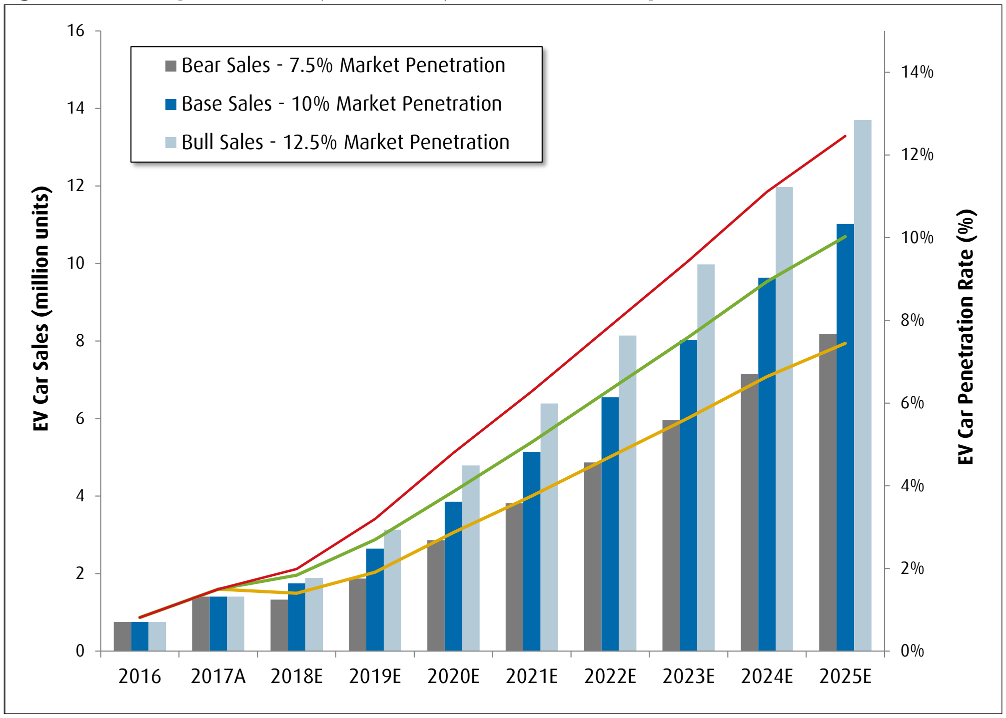


Source: Copper Alliance, IDTechEx, BMO Capital Markets

BMO Is Forecasting a 10% EV Penetration (6% BEVs, 4% PHEVs) by 2025

As we have stated in earlier publications, it is difficult to accurately predict the pace of transition from fossil fuel-powered ICEs (internal combustion engines) to EVs (BEVs and PHEVs) as there are a number of factors that include government regulations, charging infrastructure and consumer acceptance. That being said, **we believe that our base case estimate of a 10% penetration rate by 2025 (a ~30% CAGR) is very reasonable**.

Figure 18: We Expect 10% EV (BEV + PHEV) Car Penetration by 2025



Source: Industry Reports, Company Reports, BMO Capital Markets

Upside From Regulatory Pressure – EV Penetration Increases to ~12%

It makes socio-economic sense for governments to support the EV industry as increasing market uptake reduces emissions at the local level

Pollution from the transport sector is responsible for about 25-30% of global greenhouse gas emissions (GHG) that are leading contributors to global climate change. As such, there has been a large international push to ratify agreements such as the Paris Agreement in an effort to curb global emissions. Since the transportation sector is a significant contributor, part of the overall strategy has been the introduction of ICE phase-out plans. This makes sense to us given that the technology is already on the roads and that *16% of emissions come from light duty vehicle use*. This in turn has also put pressure on automobile supply chains as OEMs increase fuel efficiency. As a result, our models show that there needs to be ~12% EV penetration by 2025 to meet stated emissions targets.

Policy instruments have already been successful in setting fuel efficiency standards and increasing public outcry by creating awareness about road pollution issues (such as the detrimental effects on health). **The strategy here is clear — increasing the number of EVs on the road has been deemed necessary for environmental compliance.** For this to take place there needs to be investment in copper-intensive public infrastructure. Therefore, we are confident that the current electric vehicle wave is here to stay especially given the ability of EVs to reduce emissions at the local level, which at the very least, will curb the debilitating pollution levels rising in urban centres.

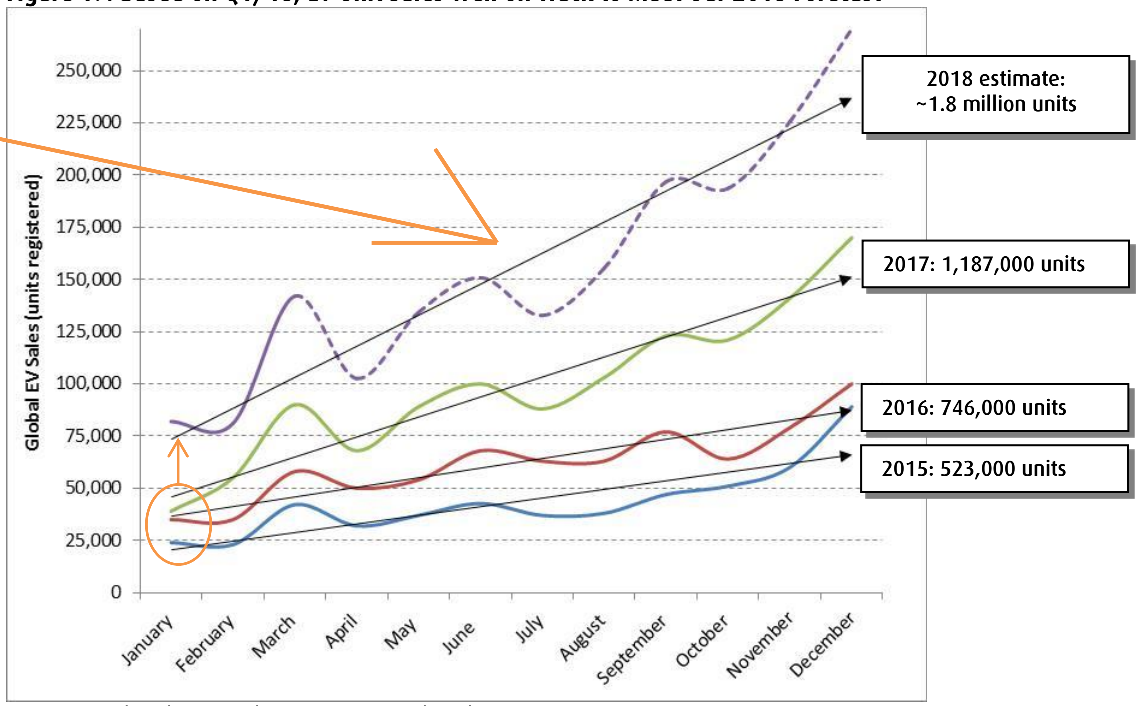
Q1 2018 Review: Regulatory Constraints and Increasing Vehicle Range Paying Off

In the first quarter of 2018, EV unit sales in the top three markets were 66% higher than the same period last year. The cyclical nature of the EV sector is apparent as growth ebbs and flows throughout the year with December typically being the strongest month. With this strong start to the year, we believe that our year-end target of ~1.8 million EV units is a reasonable estimate. Furthermore, we are seeing a steepening of the sales curve throughout the year.

Figure 19: Based on Q1/18, EV Unit Sales Well on Track to Meet Our 2018 Forecast

Signs that EV sales are at the beginning of the S-curve

Strong start: Q1/18 unit sales are 66% higher than Q1/17



Source: EV-sales Blog, EV Volumes, BMO Capital Markets

China's big push in the EV space led to record 136% growth in Q1. This sales growth occurred despite the usual slowdown in January and February after the big year-end sales push that normally reduces supply and the number of national and local holidays during Chinese New Year. The Chinese EV market is changing quickly as new regulations favor vehicles with better battery systems that produce higher range. The rule that exempts EVs from purchase taxes has been extended to 2020 and a dual-credit policy was introduced in April that imposes a minimum EV credit amount on OEMs – or they risk being fined. In addition, the changes to the new incentive program that increased the minimum credit qualification on BEVs from 80km to 100km came into effect.

The European EV market grew 38% in Q1 due to the new Nissan Leaf and increasing production. The Nissan Leaf 2.0 only made its debut in February and the 8,171 units sold (6,053 in March alone) so far in this market is impressive, in our view. However, BEV growth has been hampered by lithium-ion battery supply constraints. OEMs have expanded production and five new gigafactories are expected to be operational by 2020 as battery makers position themselves to meet growing demand. While LG Chem is planning to expand production, the $360 million battery factory being built in Poland is only expected to be operational 8-10 months from now. TerraE Holding and Tesla are also expected to release details of gigafactory plans in Europe shortly.

Figure 20: Five European Gigafactories Expected to be Operational by 2020

Company	Location	Site size	Estimated Cost	Output	Expected Production Launch
Northvolt AB	Skellefteå, Sweden	tbd	$4.7 billion	8GWh/year	2020
SK Innovation Co.	Komárom, Hungary	430,000 m^2	$777 million	7.5GWh/year	early 2020
Daimler AG	Kamenz, Germany	80,000 m^2	$560 million	tbd	fall 2018
LG Chem Ltd.	Wroclaw Poland	41,300 m^2	$360 million	4GWh/year	2018/2019
Samsung SDI Co.	Göd, Hungary	330,000 m^2	$358 million	2.5GWh/year	late 2018

Source: Media Reports, BMO Capital Markets

Tesla's Model 3 and the Chevy Bolt boost U.S. EV sales 34.8% y/y. In the first four months of 2018, Tesla represented 32.2% of this market compared to 22.1% for the same period last year. Tesla has increased deliveries of the Model 3 – 8,180 units have been sold so far, representing 50.2% of all Tesla's vehicle sales. We expect this vehicle to continue to do well throughout 2018 barring any more serious production delays or financial hiccups. Furthermore, sales of the Chevy Bolt grew 28.8% year to date with 5,650 units sold compared to the same period last year. We expect this growth to continue, and perhaps even increase, as GM announced plans to increase production of the Bolt later this year as demand is currently outstripping supply.

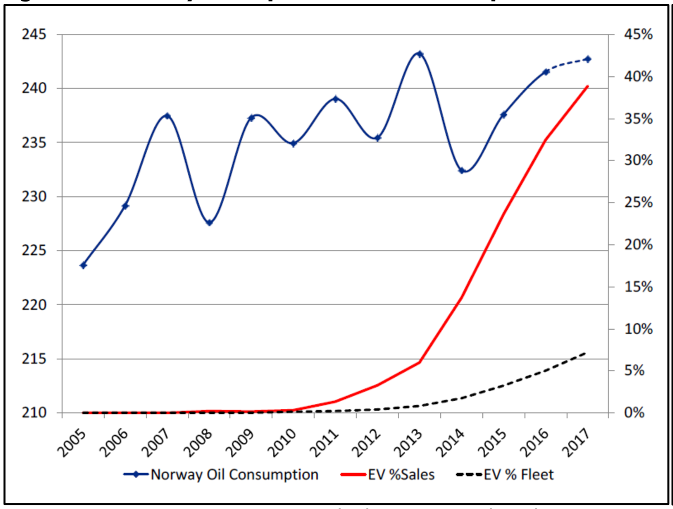
ICE Vehicles and EVs Are Not Mutually Exclusive

In our recent report titled *"Of EVs and Oil Demand,"* we concluded that sales of EVs and traditional ICE vehicles are not mutually exclusive. This view is primarily based on the time it will take for battery technology and charging infrastructure to evolve to a level where 'range anxiety' is no longer an issue. Range anxiety, or the fear of being stranded, is one of the key hurdles for wide-scale EV adoption. Therefore, our models are based on the trend toward multiple vehicle ownership and a 'fit for purpose' use of both electric and ICE vehicles. A recent study concluded that 85% of EV owners in Norway (the country leading EV adoption) have two or more vehicles in their household and at least one is an ICE vehicle. In fact, Norway's oil consumption has generally increased over the 2014-2016 timeframe when EV sales were also increasing rapidly.

We are modeling multiple vehicle ownership that will include ICE vehicles over the next decade

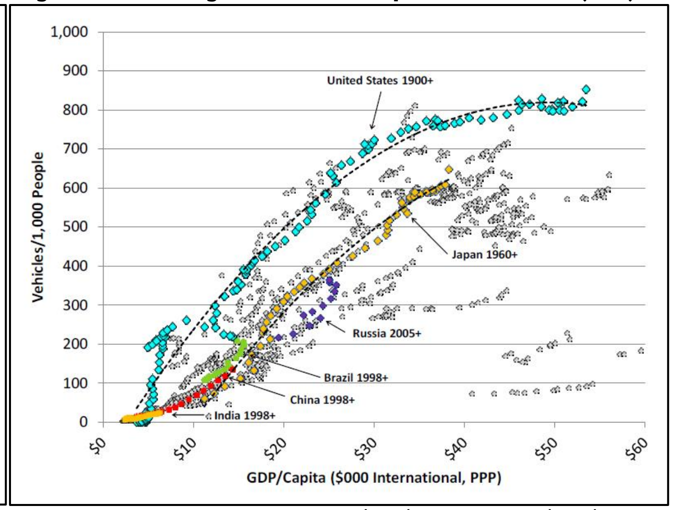
We believe that overall demand for vehicles, regardless of the powertrain, is expected to increase dramatically as global GDP per capita increases. According to projections by a number of institutions including the International Monetary Fund (IMF), global economic activity is expected to roughly double over the next two decades, with annual growth rates averaging 3.2-3.5%. This means that demand for vehicles alone, regardless of the engine type, is expected to increase 17% by 2025 compared to the ~94 million vehicles sold in 2017. As can be surmised, ICE vehicles will still make up the bulk of that demand.

Figure 21: Norway's EV Uptake vs. Oil Consumption



Source: IMF, OECD Long-term GDP Outlook, BMO Capital Markets

Figure 22: Passenger Vehicle Sales per $Million GDP (PPP)



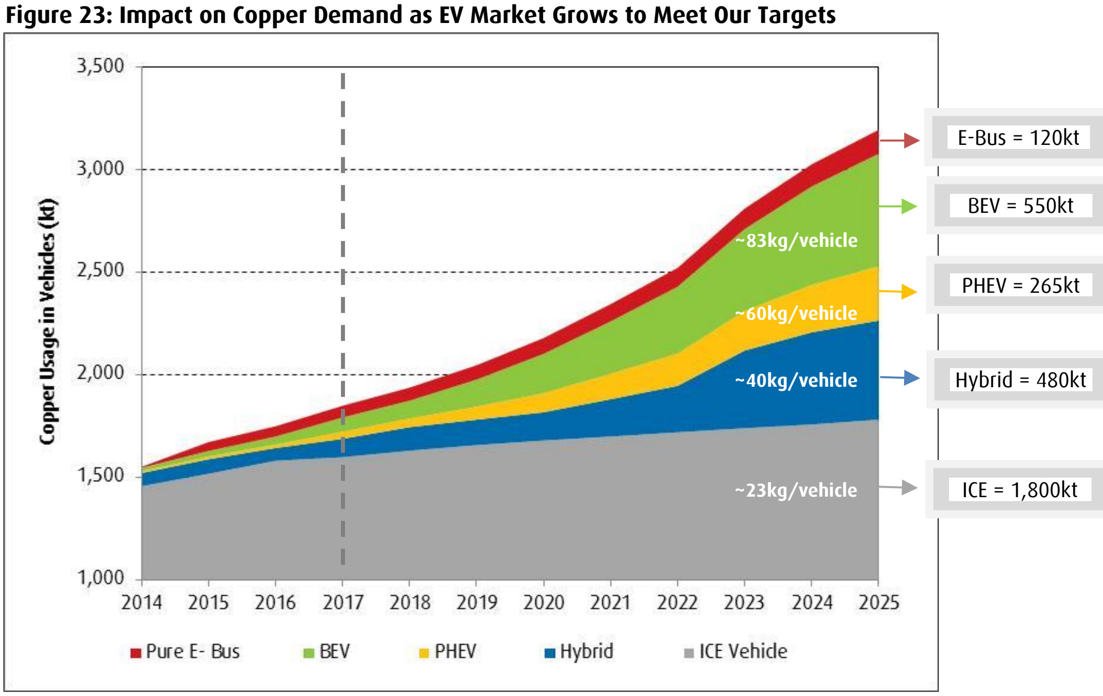
Source: BP Energy Statistics, IEA, EV Sales Blog, BMO Capital Markets

Increasing Vehicle Demand = 1.7x Increase in Copper Demand by 2025

While they only represent a small proportion (~7%) of current copper demand, ICE vehicles will still be a positive demand driver over the next seven years as our models still show a 10.3% increase in ICE vehicle sales in 2025 versus 2017 despite growing EV sales. This means that despite only containing ~23kg of copper each on average, OEMs will require ~1,800kt in 2025 to meet expected ICE vehicle demand. However, it is the additional copper required (~1,300kt by 2025) from the electrification of vehicles (BEVs, PHEVs and Hybrids) that will catapult copper demand from the auto sector over the 3,000kt level.

BEV, PHEV and hybrid sales start to significantly contribute to copper demand from 2019 onward

Figure 23: Impact on Copper Demand as EV Market Grows to Meet Our Targets



Source: International Copper Association, BMO Capital Markets

a. Technical Analysis – Copper Usage and Function in EV Market

A Detailed Breakdown of Copper Usage in Electric Motors

Source: GM

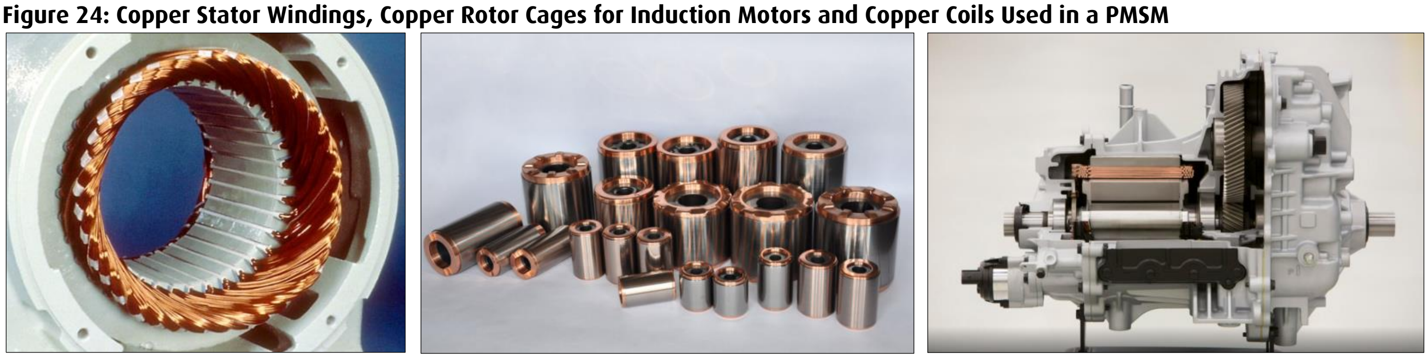
A PMSM motor uses half the amount of copper, but it uses rare earths metals that can increase costs by about 20-70%

Electric motors (e-motors) are much simpler than traditional engines as they have fewer critical components. The design has not changed much over the last century and e-motors are typically composed of two elements, a stator that stays put and a rotor that spins in its open centre. The two types of e-motors used are induction motors, which are used in ~23% of EVs, while permanent magnet synchronous motors are used in about ~77% of EVs. The main difference between them is how the magnetic fields are generated, which in turn affects the amount of copper used.

1. The induction motor (IM) is used in a wide variety of applications including some EVs such as Tesla's Model S and X. Sometimes referred to as AC asynchronous motor, IMs use electric currents that enter the copper windings inside the stator to create the magnetic field required to spin the rotor. **The copper stator windings can contain over 5,200 feet (1,575 metres) of copper wiring in the windings**. OEMs will often choose a copper squirrel cage rotor instead of aluminum because the electrical efficiency is improved by more than 5% thereby reducing the weight and size per unit of horsepower. Furthermore, internal resistance is reduced by half. In addition, it produces lower torque values at high speeds more efficiently and generates less heat, reducing the need for fans to cool the system and increasing the lifespan of the motor.

2. The permanent magnet synchronous motor (PMSM) is used in most other EV models including the Chevrolet Bolt, BMW i3 and Tesla's Model 3. **The steel rotor uses embedded magnets in lieu of copper bars to create a permanent magnetic field.** The same amount of copper windings is used in the stator and when the current flows through them, another magnetic field is created that interacts with the permanent one, causing the rotor to spin. The PMSM motor typically uses about half the amount of copper (~4.5kg vs. ~9.1kg for an induction motor).

Figure 24: Copper Stator Windings, Copper Rotor Cages for Induction Motors and Copper Coils Used in a PMSM



Source: Cleantechnica, Copper Alliance, GM

There are pros and cons to each type of e-motor and OEMs have to balance cost, efficiency and performance. For example, an induction motor may produce the power required for high performance vehicles that have more range (e.g., Model S), but it is much heavier and less efficient, incurring 2-3 times the energy loss as a PMSM. IMs also have to create two magnetic fields, whereas PMSMs only have to create one and the use of magnets eliminates the internal resistance caused by the copper in the rotor. However, while the PMSM e-motor may not incur the same energy loss and is smaller than an induction motor, the magnets contain scarce rare elements, such as neodymium and dysprosium, which can increase costs by about 20-70%

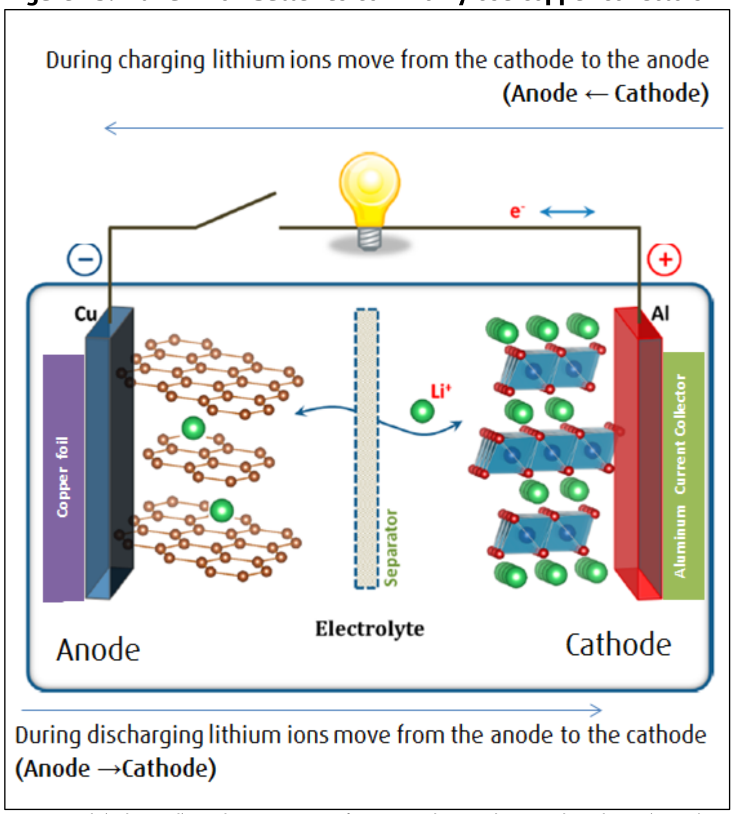
depending on the availability. Both motors experience *'copper losses'* or energy losses through resistance in the copper windings. However, changing the composition of the windings is not easy as the malleability of copper makes it hard to replace.

The Use of Copper Foil Collectors in Lithium-Ion Battery Cells

The term "lithium ion battery" encompasses a number of chemistries where lithium ions move back and forth between the electrodes (cathode ↔ anode). The different lithium-ion battery chemistries currently on the market are typically named after the elements used in the cathode, such as the NMC (nickel, manganese, cobalt) battery used in the Chevrolet Bolt and the NCA (nickel, cobalt, aluminum) battery used by Tesla.

There is about 1.1-to-1.2 kg of copper per kWh in lithium ion battery packs, which includes the copper foil current collectors

Figure 25: Lithium-Ion Batteries Commonly Use Copper Collectors



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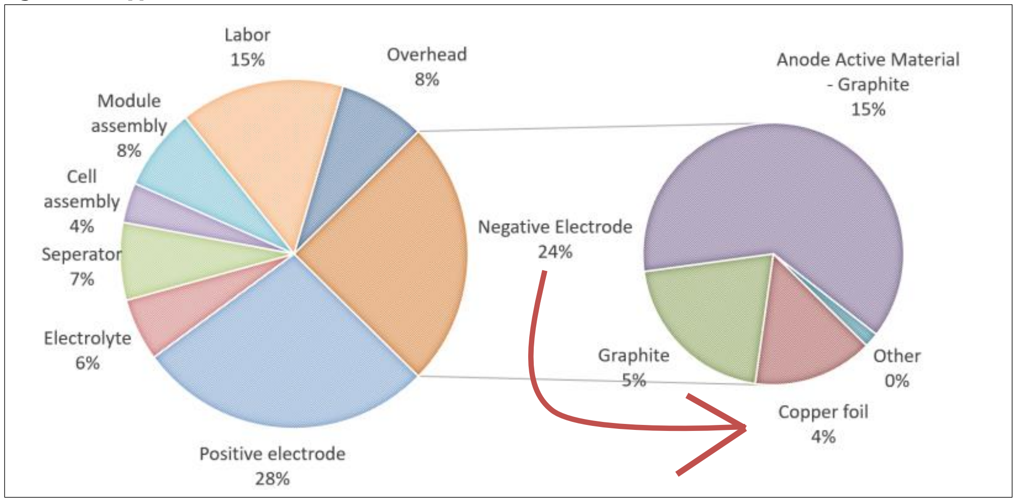
In our report *"The Lithium Ion Battery and the EV Market: The Science Behind What you Can't See,"* we discussed the challenges battery scientists face when attempting to reduce or remove expensive commodities, such as cobalt, from the chemistry. The main focus of the battery industry has been to improve electrode function in a way that increases capacity while reducing overall cell costs. We don't see that changing anytime soon as the stability of active materials is vital to the performance, safety and longevity of the battery. However, other battery system components such as separators, liquid electrolytes and current collectors, are still very important to the overall cost structure. Improvements in the composition and production processes of these parts can also help in increasing the efficiency and capacity of the battery while reducing costs.

Copper foil represents ~4% of the cost of the anode and ~1% of the entire battery

Figure 26: Typical Cost Breakdown of Lithium Ion Batteries



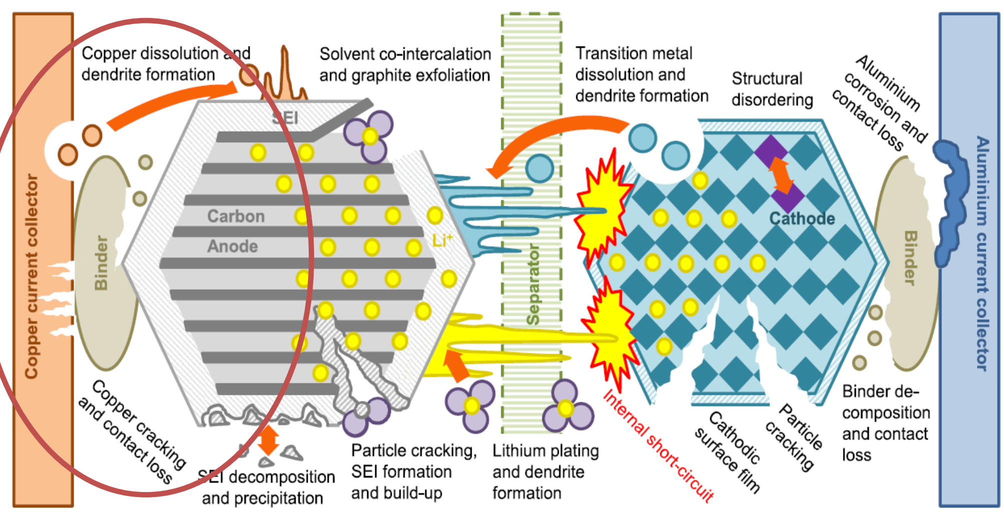
Source: Berckmans *et al.* (2017). *Cost Projection of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030.* 10(9):1314 © Creative Commons Attribution License

The Current Collectors Are Important for Battery Function and Longevity

Current collectors are critical to the function of the lithium ion battery as they collect the current, minimize the internal resistance, and help stabilize the system during charging and discharging. The choice of materials for this role depends on the electronic conductivity (the ability to manage the electron transfer into the electrodes during cycling) as well as the relative electric potentials compared to the electrodes. Typically the current collector has a higher potential than the electrode. An aluminum current collector is commonly used for the cathode while copper is used for the anode as its electric potentials have the stabilizing qualities needed for the respective electrode materials. But as can be seen below, both metals have their issues within the system.

Copper is used as a collector for the anode as its electric potentials have the stabilizing qualities needed for graphite

Figure 27: Copper Dissolution Contributes to Overall Ageing of the Battery or Failure



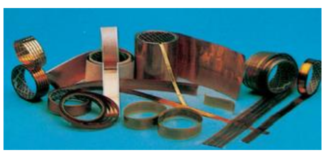
Source: Birkl *et al.* (2017). *Degradation diagnostics for lithium ion cells.* Journal of Power Sources; 341:373-386. © Creative Commons Attribution License

We believe copper will continue to be used as a current collector as it is very difficult to change any component of the battery without consequence

Focusing on the copper current collector side of the battery, there are a number of degradation factors that occur including copper dissolution, cracking and contact loss. Of these, the most pressing issue is cracking as the adhesion force between the binder and the oxide layer on the copper surface is much weaker than that of the aluminum current collector. The cracking issue is also exacerbated by the tendency of the graphite materials in the anode to swell during cycling. Another key issue is that the typical electrolyte used ($LiPF_6$) is highly reactive and eventually, pits tend to form. The electrolyte also encourages the degradation of the binding between the collector surface and the anode. Eventually, the ability to charge and discharge the battery diminishes. In other words, the degradation of the copper collector reduces the longevity of the battery.

In the end, we believe that the use of copper foil will remain the choice material for the anode current collector, especially since any changes to the make-up of the components within a lithium-ion battery cell can cause other problems to arise as there are a myriad of unintentional chemical processes and side reactions that can occur within cell. Therefore, researchers are looking to prevent dissolution and corrosion through slight modifications such as using a protective graphene layer or creating films for stronger adhesion to the anode.

Reducing Copper Foil Thickness as a Cost Savings Strategy?



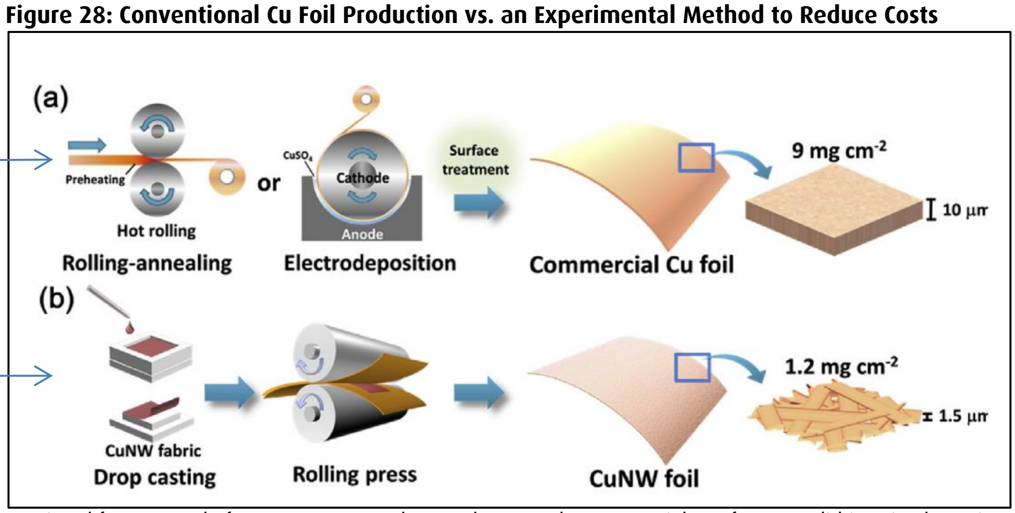
Source: Total Materia

Copper foil accounts for ~10% of the weight of the individual cells in the battery pack based on the typical foils used with an areal density of ~9mg/cm^2 and a thickness of ~10µm. The conventional methods of copper foil production include a rolling-annealing process or an electrodeposition process. Both methods produce sheets in the 6µm to 10µm range. However, thicknesses that are less than 6µm cannot be obtained. At an average cost of ~$7.5/lb, reducing thickness could provide a cost advantage while increasing battery performance. For example, researchers from the National Tsing Hua University in Taiwan were able to reduce the thickness of copper foil to 1.5µm by using a rolling press drop casting method. The product, CuNW foil, also had higher energy density and had a different surface texture that enabled better adhesion to the graphite anode. However, while this is certainly very promising, the costs involved with changing the status quo could be economically unfeasible. Therefore, we believe that the copper foil used in the current collectors will likely remain ~10µm for the time being. Furthermore, there is also a trend to actually increase the thickness of the foil in order to meet increased energy density demands needed for cathode chemistries such as NMC and NCA.

The traditional production process constrains the thickness of the copper foil to 6µm to 10µm

Experimental processes such as this will take time and may be too costly to implement

Figure 28: Conventional Cu Foil Production vs. an Experimental Method to Reduce Costs



Reprinted from Journal of Power Sources, vol. 346, Chu, H. and Tuan, H., High-performance lithium-ion batteries with 1.5µm thin copper nanowire foil as a current collector, 40-48, ©2017, with permission from Elsevier.

Copper Busbars Are Used in Battery Pack Construction

The 60kWh battery pack in the Chevy Bolt contains about 288 lithium ion cells in five sections, 10 modules and 96 cell groups. In constructing these packs, the collector tabs of each cell passes through the walls of a sealed pouch and are connected to bar-shaped conductors called bus bars. These bus bars are typically made from copper or aluminum, but copper has increased electrical conductivity, reduced resistance and increased stability and is therefore a likely material going forward as the industry moves to improve the energy density of the battery packs. In simple practical terms, copper conductors take up less space. However, as the cell density increases, the number of cells needed and therefore the number of bus bars decreases. Yet despite the intention of OEMs to increase vehicle range, the average battery pack size in a BEV is still ~50kWh and we will adjust our models accordingly when that increases.

Expanding Charging Infrastructure Also Means More Copper

We believe public infrastructure is likely going to be a mix of level 2 charging ports and fast chargers

PHEV can easily plug into traditional electric outlets and if in a bind, drivers can fill up the gas tank. Increasing BEV uptake is necessary for countries to meet emission targets and the low number of charging infrastructure available is an important impediment to wide-scale adoption. Our 10% EV market penetration by 2025 assumes that public infrastructure will also increase.

There are currently three main EV charge types characterized by the power (kW) produced, equating to speed of charge. As the power increases, so does copper content.

- **Level 1C (Slow chargers: 120V/15-20 Amps) → 0.7-1.5 kg of copper:** The most common form of charging is typically overnight at home as a full charge takes many hours with power delivery of up to 3kW.
- **Level 2C (Typical household chargers: 240V/80 Amps) → 8 kg of copper:** Can fully recharge EVs in ~1-4 hours with power delivery of 7-22kW (speeds will depend on the model's on-board charger). These chargers are typically found near shopping centres or supermarkets.
- **Level 3C (Fast Chargers: 480V/300 Amps) → 8-16kg of copper:** Fast chargers can provide ~80% charge in ~30 minutes with varying power delivery (40- 120kW). They are typically found in locations close to highways and are the preferred charging stations for Tesla's vehicles.

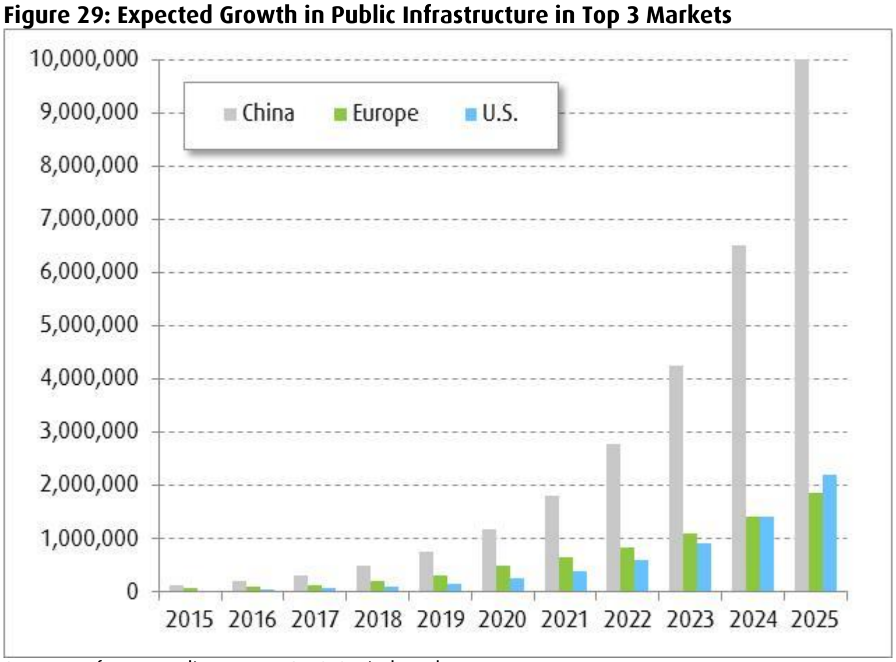
Source: Battery University

There are also different types of fast chargers (level 3C), which include CHAdeMO (left), SAE CCS and Tesla's supercharger. There is a battle over what type will dominate globally as Japanese OEMs favor CHAdeMO, European and North American OEMs favour SAE CCS while Tesla has its own proprietary format. However, using a supercharger all the time degrades the battery and Tesla's onboard computer will slow the fast charging process if it is used too often. In addition, some OEMs install fast charging capability, but advise not to use it very often. Therefore, we believe that public infrastructure is likely going to be a mix of mostly level 2 charging stations at grocery stores, malls, offices and apartment buildings with fast chargers more likely at pit stops along major highways.

There are currently between 50,000 and 70,000 level 2 charging stations at public locations in the U.S. and the industry is forecasting over 2.2 million by 2025. China, the world's largest market for EVs, is planning to install 10 million public charging stations within that same timeframe. Europe's EV strategy is dependent on the country with Norway leading the charge. However, we expect the charging infrastructure to grow from 131,300 stations now to 1.86 million over the next seven years. Copper is typically used in the charging unit, the electrical panel, and at least 25ft of charging cable. With this growth in mind, as well as the need for about 0.7-1.5kg of copper per home charging station and 8-10 kg for the stations used in public locations, this equates to about an additional 100kt in copper usage in 2025. **This does not include the infrastructure supplying the additional chargers, which is likely to be multiples of this number.**

China is leading the way with charging infrastructure that will contain ~5-8kg of copper per unit

Figure 29: Expected Growth in Public Infrastructure in Top 3 Markets



Source: eafo.eu, media reports, BMO Capital Markets

Renewable Energy Infrastructure Growth and Copper Demand

Renewable energy needs copper to build infrastructure and wind energy uses 2.3-6.8kt/GW of copper, which is 4-6x the amount of traditional energy sources

Renewable energy infrastructure growth a significant copper demand driver. Copper usage in the energy sector is typically measured as the amount of copper (kg or lbs) needed to install a kW of renewable energy, which is about 4-6 times the amount needed for fossil fuel or nuclear energy sources. This is down to having a larger number of disperse, smaller generation units connected into the power grid. And this is certainly a growth area. According to the International Energy Association (IEA), cumulative grid-connected wind capacity reached 529GW in 2017, accounting for ~4% of the world's electricity production, and is expected to grow to over 830GW over the next five years.

There has also been a renewed interest in solar power systems in the last couple of years. New cumulative solar power systems reached a capacity of ~340GW in 2017, which is expected to double to over 685GW over the next five years. While at first glance this forecast appears optimistic, China's aggressive push to mitigate its complicated pollution problem is a key assumption and solar is seen as a principal solution as the country is also home to 60% of global solar manufacturing capacity.

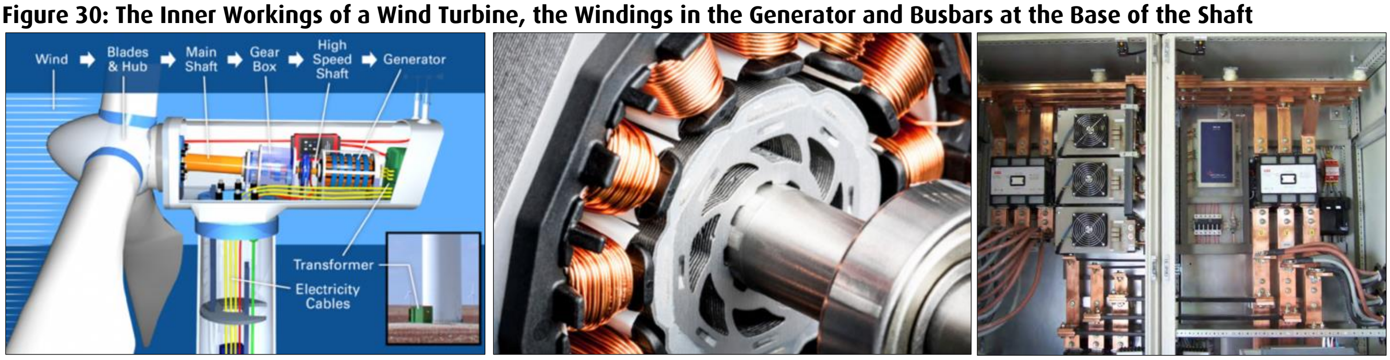
a. Technical Issues in Renewable Energy

Wind Energy Turbines Use Copper in the Same Way as an E-Motor

While wind turbines use PSMS motors, they use an extraordinary amount of copper wiring

The primary use of copper in wind energy technologies is in the coil windings in the stator and rotor portions of the generator that turns wind energy into electricity for consumption. While wind turbines are typically synchronous (use permanent magnet rotors in lieu of copper ones), there is an extraordinary amount of copper wiring needed to transmit the electricity generated down the base of the turbine and into the grid. Copper cables tend to be more efficient, waste less energy and are also recommended to ground the turbine in case of a lightning strike. A study from the U.S. Geological Survey (USGS) noted that a 91.5 MW wind power plant uses about 56 km of low voltage wire and grounding cable and more than 108 km of high voltage copper cabling. There is also a substantial amount of copper in the transformer coils.

Figure 30: The Inner Workings of a Wind Turbine, the Windings in the Generator and Busbars at the Base of the Shaft



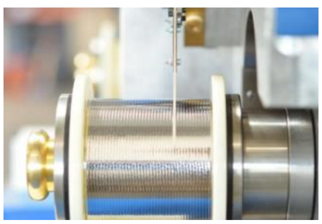
Source: Xcel Energy, Enercon GmbH, CDA

Aluminum Can Be Used, But at the Expense of Size and Connectivity

1.6x times the amount of aluminum wiring is needed to carry the copper equivalent amount of electrical current

While aluminum is also a strong conductor of electricity and significantly cheaper than copper, aluminum coils tend to be on the larger size, meaning that more space is required to contain aluminum windings. It is estimated that 1.6x times the amount of aluminum wiring is needed to carry the copper equivalent amount of electrical current. Furthermore, the wiring in the upper part of the turbine (called the nacelle) needs to be much more flexible that other more stationary applications due to the twisting and rotating of the blade and hub. Aluminum is prone to metal fatigue and can break and crack during the winding process. A coating forms on the surface of the aluminum wiring (a hard layer of insulating oxide) when exposed to air during use, which reduces the conductivity to the point that eventually erodes the contacts and exhibits a 5-10% increase in resistance. As such, scientists tend to coat the wiring with materials, such as tin, to prevent/reduce this increase in resistance. While copper also oxidizes, the changes in conductivity and the increase in resistance are nominal by comparison.

Usage of Copper in Solar Power Generation



Source: Plasmait GmbH

The amount of copper used in solar power generation varies as there are different technologies available. Traditional crystalline silicon (c-Si) panels represent 85-90% of the market. Solar power generators based on this technology use copper cabling and grounding wires as well as copper wiring in the inverters and transformers. While again, aluminum can be used, the wiring is thicker and must be carefully installed to screw connections as they can loosen, causing an electrical arc that elevates the risk of fire. Bare copper wire is also the ultimate choice to ground household electrical systems. Rooftop solar panels need to be connected into this household system using the same material.

Photovoltaic cells have interconnected ribbon, essentially comprised of hot dipped tinned copper conductors (left), which carries the current generated in the cells to copper busbars, which in turn carry the electric current to a junction box. Aluminum conductors and busbars can also be used to lower overall costs. However, conductors will have to be larger, meaning that additional costs will be incurred because the installation would have to be larger relative to one that uses copper conductors. Furthermore, aluminum oxidizes when exposed to moisture and increases internal resistance, causing heat that deteriorates the insulation.

Thin film panels, such as copper-indium-gallium diselenide (CIGS) panels, have received a lot of attention recently because they are less expensive than traditional silicon-based panels and not as susceptible to damage. However, despite the fact that copper is a key component, the efficiency gains of ~20% or more have not been proven on a large scale and therefore, the market is very small.

b. Renewable Energy – Global Demand Growth

Forecasting 10% Growth in Copper Demand From Renewable Energy

With the global outlook for solar and wind facilities expected to grow 8-15% through 2025 (and at a ~5-7% CAGR through 2040 thereafter), BMO estimates equivalent growth in copper demand in this sector. The International Energy Agency notes two scenarios, in what we call the Base Case. This involves incorporating existing energy policies, as well as their expectation of changes that are likely to occur based on implementing announced policy intentions. However, our Bull Case is based on an approach to achieve internationally agreed objectives on climate change, air quality and global access to modern energy. In both cases, renewables are expected to become an increasing contributor to the global energy capacity that will push copper demand in order to build assets.

The amount of copper used in solar assets ranges from 4-5kt/GW, while onshore wind has a similar midpoint of 4.5kt/GW but has a wider range of 2.3-6.8kt/GW. As the size of these renewable energy farms continues to grow, so will demand for copper.

Figure 31: BMO Base Case Scenario for Renewable Growth

Renewables - Base Scenario		2016A	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
Global Installed Renewable Capacity											
Solar [1]	GW	299	344	361	415	477	549	631	707	813	939
Wind[1]	GW	466	522	574	632	682	723	766	820	877	932
Total	**GW**	**765**	**866**	**935**	**1,047**	**1,160**	**1,272**	**1,398**	**1,527**	**1,691**	**1,871**
Year-on-year chg	%	19.7%	13.2%	8.0%	11.9%	10.8%	9.7%	9.9%	9.3%	10.7%	10.7%
Expected Copper Required											
Solar	kt	1,346	1,547	1,625	1,868	2,149	2,471	2,842	3,183	3,660	4,226
Year-on-year chg	kt	333	202	77	244	280	322	371	341	477	566
Year-on-year chg	%	32.9%	15.0%	5.0%	15.0%	15.0%	15.0%	15.0%	12.0%	15.0%	15.5%
Wind	kt	2,114	2,367	2,604	2,865	3,094	3,279	3,476	3,719	3,980	4,227
Year-on-year chg	kt	236	254	237	260	229	186	197	243	260	248
Year-on-year chg	%	12.6%	12.0%	10.0%	10.0%	8.0%	6.0%	6.0%	7.0%	7.0%	6.2%
Total	**kt**	**3,459**	**3,915**	**4,229**	**4,733**	**5,242**	**5,750**	**6,318**	**6,902**	**7,640**	**8,453**
Year-on-year chg	kt	569	455	314	504	509	508	567	584	738	813
Year-on-year chg	%	19.7%	13.2%	8.0%	11.9%	10.8%	9.7%	9.9%	9.2%	10.7%	10.6%

1. 2017E-2024E have been derived from the International Energy Agency's 2017 World Energy Outlook
Source: IEA, FEECO International, BMO Capital Markets

Figure 32: BMO Bull Case Scenario for Renewable Growth

Renewables - Bullish Scenario		2016A	2017E	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
Global Installed Renewable Capacity											
Solar [1]	GW	299	353	381	450	531	626	739	850	1,003	1,188
Wind[1]	GW	466	535	605	682	757	824	898	986	1,084	1,184
Total	**GW**	**765**	**888**	**986**	**1,132**	**1,287**	**1,450**	**1,636**	**1,836**	**2,087**	**2,372**
Year-on-year chg	%	19.7%	16.1%	11.0%	14.9%	13.7%	12.7%	12.8%	12.2%	13.6%	13.7%
Expected Copper Required											
Solar	kt	1,346	1,588	1,715	2,023	2,388	2,817	3,324	3,823	4,511	5,346
Year-on-year chg	kt	333	242	127	309	364	430	507	499	688	835
Year-on-year chg	%	32.9%	18.0%	8.0%	18.0%	18.0%	18.0%	18.0%	15.0%	18.0%	18.5%
Wind	kt	2,114	2,429	2,742	3,096	3,433	3,739	4,071	4,475	4,917	5,371
Year-on-year chg	kt	236	315	313	354	337	306	333	403	443	453
Year-on-year chg	%	12.6%	14.9%	12.9%	12.9%	10.9%	8.9%	8.9%	9.9%	9.9%	9.2%
Total	**kt**	**3,459**	**4,016**	**4,457**	**5,119**	**5,821**	**6,556**	**7,396**	**8,298**	**9,429**	**10,717**
Year-on-year chg	kt	569	557	440	662	702	735	840	902	1,131	1,288
Year-on-year chg	%	19.7%	16.1%	11.0%	14.9%	13.7%	12.6%	12.8%	12.2%	13.6%	13.7%

1. 2017E-2024E have been derived from the International Energy Agency's 2017 World Energy Outlook
Source: IEA, FEECO International, BMO Capital Markets

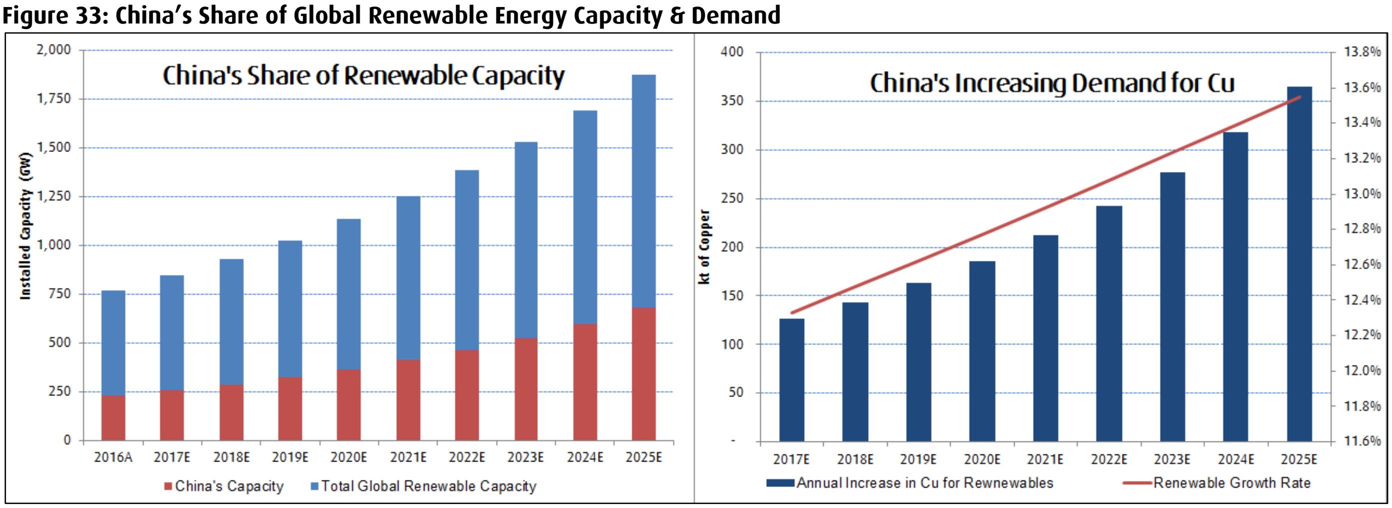
China Leads With ~30% of Global Renewable Capacity

Source: Smithsonian

China may be the world's largest emitter of greenhouse gases, remains heavily dependent on coal, and continues to battle debilitating pollution, but the country has implemented aggressive emission reduction targets that include forcing industries to clean up or face severe financial consequences. Moreover, China is increasingly looking to play the good guy in terms of improving environmental conditions, particularly since the US pulled out of the Paris agreement. Last year, China was the driving force behind the global growth in solar energy, investing $86.5 billion in the sector (56% of the total solar energy investment globally) and Chinese factories account for 60% of global photovoltaic cell production. In the summer of last year, China 'turned on' the largest floating solar farm (left). Furthermore, the country is planning to invest $100 million in wind power facilities by 2020, establishing 210GW of infrastructure.

We believe that China's energy demand shift will continue to be the most significant contributor to the growth of renewables, with its share of global energy capacity estimated to grow from 30% to ~35% by 2025. Solar and wind facilities are expected drive this growth, increasing from ~15% of China's overall energy capacity to ~30% by 2025 and 40% by 2040.

Figure 33: China's Share of Global Renewable Energy Capacity & Demand



Source: Company Reports, BMO Capital Markets

Offshore Wind Energy Appears to Be Gaining Momentum

Innovation has allowed wind farms to be built farther offshore, minimizing visual pollution

In the late 1990s, densely populated countries in Europe looked at alternatives to onshore wind farms as the amount of suitable sites for wind farms dwindled. According to WindEurope, the 17 wind farms in the North Sea provided 3,148MW in additional capacity in 2017 and currently have a total of 15,780 MW of wind energy (4,149 grid connected turbines) available to 10 countries. Another 82 turbines (1,930MW) are expected to be connected in the first half of this year. However, other countries that also have wind energy potential have not followed suit.

Planning process for any wind farm is fraught with uncertainties, especially those offshore

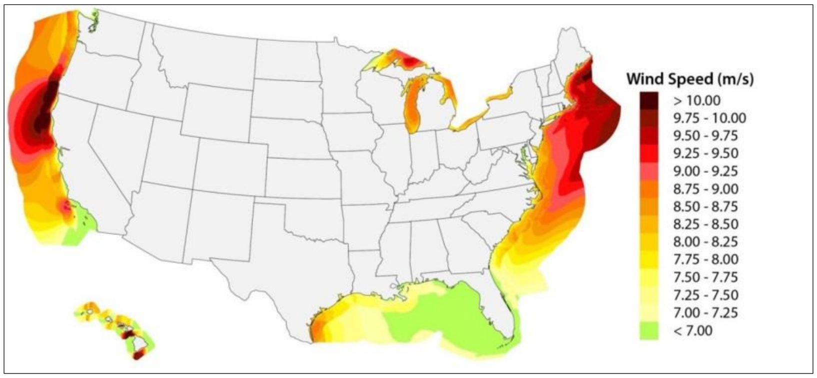
The location and establishment of wind farms, particularly offshore, is an arduous process that is filled with red tape (land agreements, leases, etc.), proximity to electricity infrastructure and lack of local suppliers have impeded adoption. These projects also tend to be logistical nightmares as coordination of the assembly of various portions of the installation is difficult as parts often come from different suppliers and assembly often requires specialized technicians. Offshore turbines are also more costly than those on land because of the engineering involved and the complicated foundations required. Furthermore, there have been public concerns about visual pollution along the coastline.

Typical proposed sites on-and-off shore have steady wind speeds of at least 6-7 m/s throughout the year with periodic highs of 12-14 m/s. The U.S. has been known for some time as the perfect spot for offshore wind energy and as can be seen below, the Northeast and Northern California coasts are particularly attractive. As such, Avangrid Renewables LLC is in the planning process of establishing a 122,000 acre wind farm in federal waters off the coast of North Carolina and New York State has mandated that the share of renewable energy mix includes 2.4GWs of offshore wind energy. However, we are still cautiously optimistic at this juncture. Even though tax credits for solar and wind energy were maintained in the recently passed tax bill, this momentum could be curbed if the legislators make the industry economically unfeasible in other respects, such as the need for foreign parts and specific expertise.

Offshore wind turbines use 41% more copper than those built on land

Despite our skepticism, offshore wind farms tend to use much more copper as aluminum corrodes more rapidly in salt water applications, with estimates around 9.6kt/GW (approximately 41% higher than the high end of our onshore estimate). With offshore facilities estimated to make up ~7% of global wind capacity by 2025 (~3% currently), we see this as additional upside to copper demand, which could lead to an additional 2-7% increase annually as onshore wind continues to get rolled out.

Figure 34: Offshore Wind Energy Potential in the U.S.



Source: NREL

3. Incentive Price Analysis

To solve the supply gap calculated in section 1, we have conducted a conventional incentive price analysis on projects which have potential to come to market by 2030 at the latest. We have excluded highly speculative projects or those with little hope of accessing necessary funding. Through taking into account capital intensity, our estimation of operating cost, corporate tax rates, and rates of return, we have built an incentive price curve incorporating these 109 projects, which have combined capacity of just over 10mtpa of copper.

In doing this, it should be noted that the current probable and highly probable copper pipeline is currently the lowest we have seen this century, both in terms of the number of projects and capacity. Recent years have seen both cancellation and delivery of potential projects, both of which have served to reduce the list.

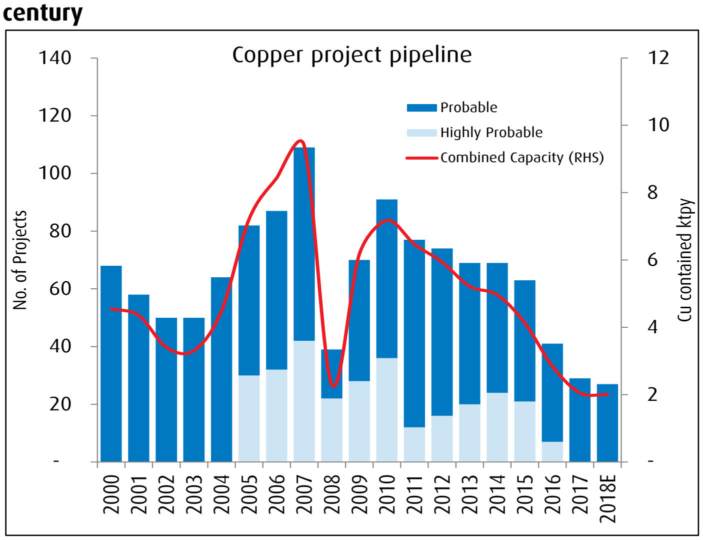
The current copper pipeline is the lowest we have seen this century

To put this in context, figure 35 shows the number of copper projects classified as probable and highly probable in Wood Mackenzie's outlook at the start of any given year. At the start of 2018 there were no highly probable projects and only ~20 probable projects, which combined make up just 2mt of supply. Even in the depths of the financial crisis, more projects were coming through the pipeline while 2010 had around 4x the current number.

In addition, the long lead time, high upfront capex market-moving megaprojects seen in the last cycle are simply not palatable to boards and investors at the present time. Hence, the potential delivery of megaprojects (which in copper we would consider those accounting for >1% of global supply) has been hard hit. After delivery of Cobre Panama (with the main ramp early next year), we are left with a gap until we see the next batch of 200ktpa-plus projects in 2022-23. This is when the likes of Kamoa, Oyu Tolgoi Phase 2 and QB2 are likely to offer meaningful supply growth.

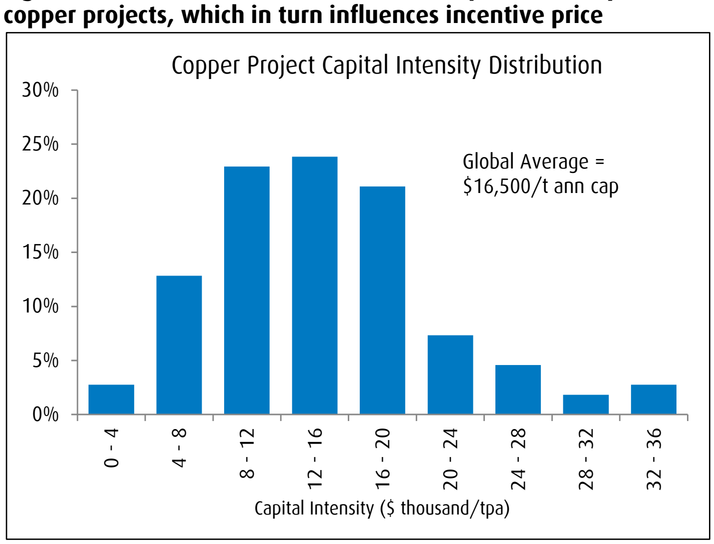
Figure 36 looks at the capital intensity distribution of projects we have considered, given the important influence this has on incentive price. Around 70% of projects have a capital intensity of between $8,000 and $20,000 per tonne of annualized capacity, with the global average now roughly $16,500/t. This compares to a simple average of projects delivered over the past 10 years of $13,350/t.

Figure 35: The copper project pipeline is now the leanest this century



Source: Wood Mackenzie, BMO Capital Markets

Figure 36: There is a wide distribution of capital intensity for copper projects, which in turn influences incentive price



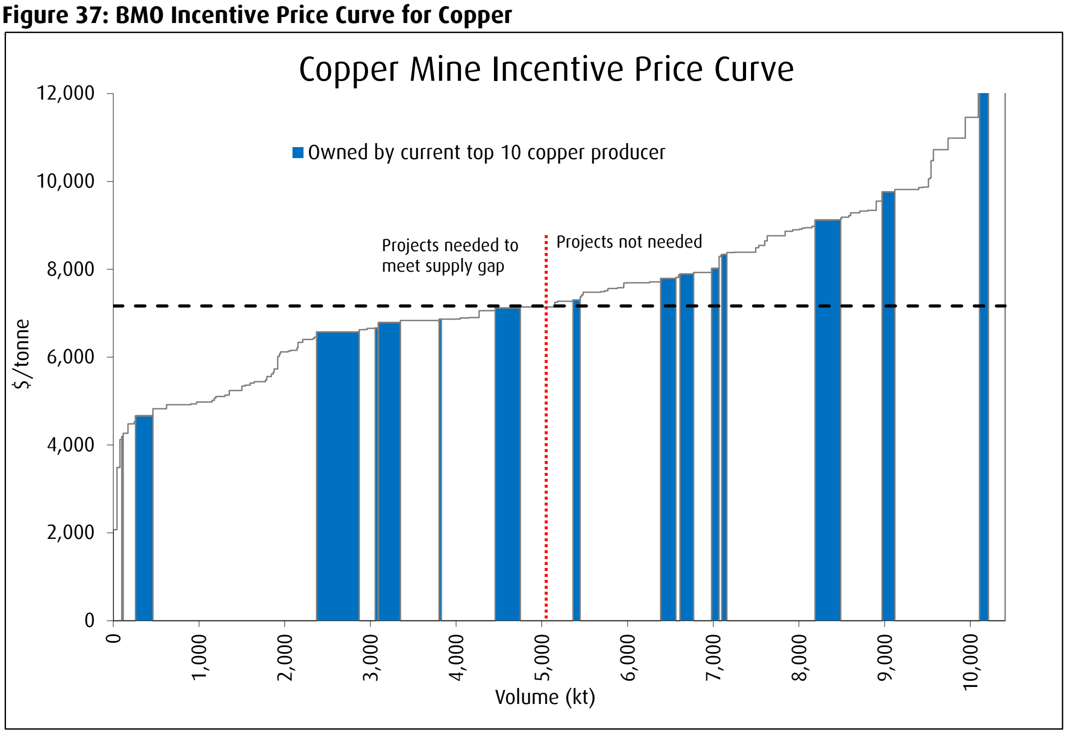
Source: Wood Mackenzie, Company Data, BMO Capital Markets

Figure 37 shows our incentive price curve for the projects analysed. There is a wide range of incentive prices, from $1.5/lb ($3,300/t) at the low end to $4.5/lb ($10,000/t) at the higher end, with a steady trend in between. Notably, just 2mt (~20%) of analysed projects would be justified by the average copper price over the past five years. Of course, incentive curves will always be open to interpretation as every producer will have different acceptable rates of return and different long-run price expectations. However, through applying a consistent calculation methodology, we believe our analysis gives a reasonable guide to what is fair in terms of long-run market equilibrium. It should also be noted that we do not factor in discrete political, environmental or geopolitical risk over and above the effect on cost of capital.

Given this, it is interesting to look at this curve in terms of what is owned by major copper producers, as highlighted by the blue bars on the curve. Firstly, their collective ownership of projects is relatively small compared to the total number. Secondly, their projects are evenly distributed through the curve. From this, it is fair to say that different strategies will likely be employed over the coming years. Those with good projects will likely progress them (provided boards become more comfortable with longer-term fundamentals) while others may be forced to buy (or partner for) growth should they want to maintain market share.

We would be delighted to discuss the position of any individual copper project on this curve—please reach out to us directly.

Figure 37: BMO Incentive Price Curve for Copper



Source: Wood Mackenzie, BMO Capital Markets

Given our expectation of a 5mtpa supply gap over 2025-30, after taking into account demand and scrap recovery expectations, this leads us to a required incentive price of $3.25/lb ($7,165/tonne) in 2018 dollar terms. Given likely inflation, this would mean nominal pricing of ~$3.65/lb (~$8,000/tonne) over this period. This is 7% higher than our previous $3.05/lb ($6,725/t) forecast.

After taking into account demand and scrap recovery expectations, our models show an incentive price of $3.25/lb ($7,165/tonne) in 2018 dollar terms

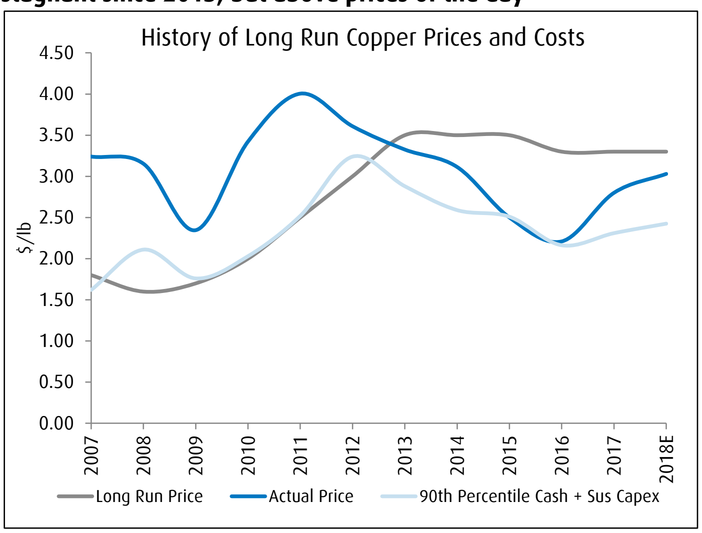
Of course, long-run incentive prices are not a specific forecast for a given year. Rather, they are an equilibrium price around which a commodity (in this case copper) will naturally fluctuate based on demand cycles. However, in our view this points to a scenario where copper prices will take a sustained leg higher from the ~$2.75/lb ($6,100/t) level they have averaged over the past five years.

Just 10 years ago, consensus long-run copper prices were just $1.50/lb ($3,300/t). Having moved in line with the 90th percentile during the post-GFC commodity upcycle, expectations have remained stagnant since 2013. This has resulted in a situation where long-term price expectations are above both prices of the day and the cost curve, which makes project financing more difficult but also is a fair reflection of some of the structural supply challenges in the copper market. **However, given our increased demand forecasts and confidence in the secular nature of the factors which drive them (being renewable energy and electric vehicles), we feel a higher long-term price is fundamentally justified.**

While $3.25/lb is our new base case, we have also looked at what the implied incentive price would be under the different supply gap scenarios considered in section 1. Under the 1.5% CAGR demand growth scenario, $2.70/lb ($5,950/t) would be sufficient. In a zero substitution scenario, $3.44/lb ($7,585/t) would be required. Meanwhile, were we to use the bull case for renewables identified in section 2 then $3.80/lb ($8,375/t) would be the outcome.

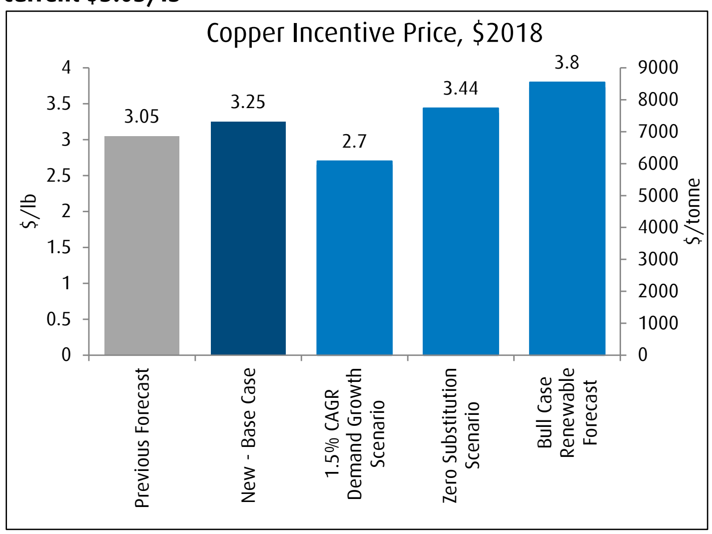
Given that we have perhaps erred on the cautious side in supply assumptions, there is an argument that a sustained period above $3.25/lb could be required for market equilibrium. We do not necessarily disagree with this, but feel that $3.25/lb is fair given an extended period higher than this level would encourage more demand deferral and ultimately lower the supply gap.

Figure 38: Long-run price expectations have been relatively stagnant since 2013, but above prices of the day



Source: LME, Wood Mackenzie, BMO Capital Markets

Figure 39: We view $3.25/lb as a fair incentive price, up from the current $3.05/lb



Source: BMO Capital Markets

Figure 40: BMO's Copper Supply-Demand Balance

Copper		2017	2018E	2019E	2020E	2021E	2022E	2023E	2024E	2025E
SUPPLY										
Mine Supply										
Chile	kt	5,537	5,732	5,691	5,615	5,530	5,441	5,528	5,579	5,277
Peru	kt	2,435	2,347	2,320	2,297	2,270	2,259	2,225	2,145	2,124
U.S.	kt	1,377	1,301	1,329	1,318	1,420	1,468	1,523	1,447	1,381
China	kt	1,531	1,580	1,654	1,752	1,884	1,960	2,001	2,001	2,001
Australia	kt	874	914	958	962	902	959	942	897	762
Indonesia	kt	640	668	348	569	957	970	734	709	655
DRC	kt	1,161	1,223	1,354	1,483	1,492	1,604	1,703	1,626	1,532
Zambia	kt	792	865	984	1,069	1,109	1,094	1,075	1,064	905
Rest of World	kt	5,861	5,845	6,023	6,103	5,966	5,813	5,864	5,707	5,737
Mine Supply	**kt**	**20,208**	**20,475**	**20,661**	**21,169**	**21,531**	**21,567**	**21,594**	**21,176**	**20,375**
Year-on-year chg	%	-0.1%	1.3%	0.9%	2.5%	1.7%	0.2%	0.1%	-1.9%	-3.8%
Smelter Supply	**kt**	**18,468**	**19,175**	**19,628**	**19,584**	**19,939**	**20,306**	**20,710**	**20,959**	**21,212**
Year-on-year chg	%	-0.4%	3.8%	2.4%	-0.2%	1.8%	1.8%	2.0%	1.2%	1.2%
Refined Supply	**kt**	**20,111**	**20,611**	**21,068**	**21,167**	**21,588**	**22,000**	**22,413**	**22,868**	**23,129**
Year-on-year chg	%	2.3%	2.5%	2.2%	0.5%	2.0%	1.9%	1.9%	2.0%	1.1%
TOTAL REFINED SUPPLY	kt	**23,213**	**23,784**	**24,249**	**24,320**	**24,552**	**24,884**	**25,309**	**25,588**	**25,511**
Year-on-year chg	%	1.9%	2.5%	2.0%	0.3%	1.0%	1.3%	1.7%	1.1%	-0.3%
Total scrap used	kt	3,574	3,479	3,777	3,997	4,109	4,199	4,259	4,498	4,538
CONSUMPTION										
China	kt	11,063	11,695	12,058	12,371	12,699	12,993	13,284	13,737	14,211
Japan	kt	1,041	1,057	1,072	1,070	1,072	1,076	1,080	1,081	1,083
India	kt	536	560	596	630	666	705	750	797	844
Other Asia	kt	2,421	2,496	2,581	2,669	2,745	2,825	2,909	2,993	3,073
United States	kt	1,947	1,985	2,022	2,044	2,068	2,095	2,132	2,164	2,200
Europe	kt	3,789	3,861	3,928	3,995	4,064	4,141	4,223	4,303	4,386
Rest of World	kt	2,411	2,529	2,602	2,587	2,561	2,583	2,705	2,838	2,967
REFINED CONSUMPTION	kt	**23,208**	**24,183**	**24,859**	**25,366**	**25,875**	**26,417**	**27,082**	**27,913**	**28,764**
Year-on-year chg	%	3.1%	4.2%	2.8%	2.0%	2.0%	2.1%	2.5%	3.1%	3.0%
Surplus (Deficit)	kt	5	-399	-610	-1,046	-1,323	-1,534	-1,772	-2,324	-3,253

Source: ICSG, Wood Mackenzie, BMO Capital Markets

Companies mentioned (priced as of the close on May 22, 2018):

First Quantum Minerals (FM-TSX; C$21.90; Outperform by Alex Terentiew, BMO Nesbitt-Burns, Inc.)
Ivanhoe Mines (IVN-TSX;C$3.50; Outperform by Andrew Mikitchook, BMO Nesbitt-Burns, Inc.)
Rio Tinto (RIO-LSE; £44.15; Outperform by Edward Sterck, BMO Capital Markets Limited, and David Gagliano, BMO Capital Markets Corp.)
Teck Resources (TECK.B-TSX; C$36.59; Outperform by Alex Terentiew, BMO Nesbitt-Burns, Inc.)

Bibliography

Arantegui, R. (2015). *Material use in electricity generators in wind turbines – state-of-the-art and future specifications.* Journal of Cleaner Production; 87:275-283.

Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L. and Van Mierlo, J. (2017). *Cost Projections of State of the Art Lithium-Ion Batteries for Electric Vehicles Up to 2030.* Energies; 10:1314; doi:10.3390/en10091314.

Birkl, C. *et al.* (2017). *Degradation diagnostics for lithium ion cells*. Journal of Power Sources; 341:373-386.

Chen, K., Xue, D. and Komarneni, S. (2015). *Beyond theoretical capacity in Cu-based integrated anode: Insight into the structural evolution of CuO.* Journal of Power Sources; 275:136-143.

Chu, H. and Tuan, H. (2017). *High-performance lithium-ion batteries with 1.5µm thin copper nanowire foil as a current collector.* Journal of Power Sources; 346:40-48.

Dai, S., Chen, J., Ren, Y., Liu, Z., Chen, J., Li, C., Zhang, X., Zhang, X. and Zeng, T. (2017). *Electrochemical Corosion Behavior of the Copper Current Collector in the Electrolyte of Lithium-ion Batteries.* Int. J. Electrochem. Sci., 12: 10589-10598.

Frank, R. and Morton, C. (2007). *Comparative Corrosion and Current Burst Testing of Copper and Aluminum Electrical Power Connectors.* IEEE Transactions on Industry Applications; 43(2): 462-468.

Goodenough, J. and Park, K. (2013). *The Li-Ion Rechargeable Battery: A Perspective.* J. Am. Chem. Soc.; 135:1167-1176.

Goss, J., Popescu, M. and Staton, D. (2013). *A comparison of an interior permanent magnet and copper rotor induction motor in a hybrid electric vehicle application.* Electric Machines & Drives Conference (IEMDC), 2013 IEEE International.

IEA (2017). *Market Report: Renewables 2017: Analysis and Forecasts to 2022.* iea.org.

Jackson, P., Hariskos, D., Lotter, E., Paetel, S., Wuertz, R., Menner, R., Wischmann, W. and Powalla, M. (2011). *New world record efficiency for Cu(In, Ga) Se_2 thin-film solar cells beyond 20%.* Progress in Photovoltaics; 19(7):894-897.

Kim, H. and Choi, W. (2018). *Graphene modified copper current collector for enhanced electrochemical performance of Li-ion battery.* Scripta Materialia; 146:100-104.

Larminie, J. and Lowry, J. (2012). *Electric Vehicle Technology Explained, 2nd Edition.* John Wiley & Sons Ltd. West Sussex, UK.

Liu, X., Wang, D., Zhang, B., Luan, C., Qin, T., Zhang, W., Wang, D., Shi, X., Deng, T., Zheng, W. (2018). *Vertical graphene nanowalls coating of copper current collector for enhancing rate performance of graphite anode of Li ion battery: The merit of optimized interface architecture.* Electrochimica Acta; 268:234-240.

Shukang, C., Cuiping, L., Feng, C. and Hailong, G. (2012). *Research on Induction Motor for Mini Electric Vehicles.* Energy Procedia; 17:249-257.

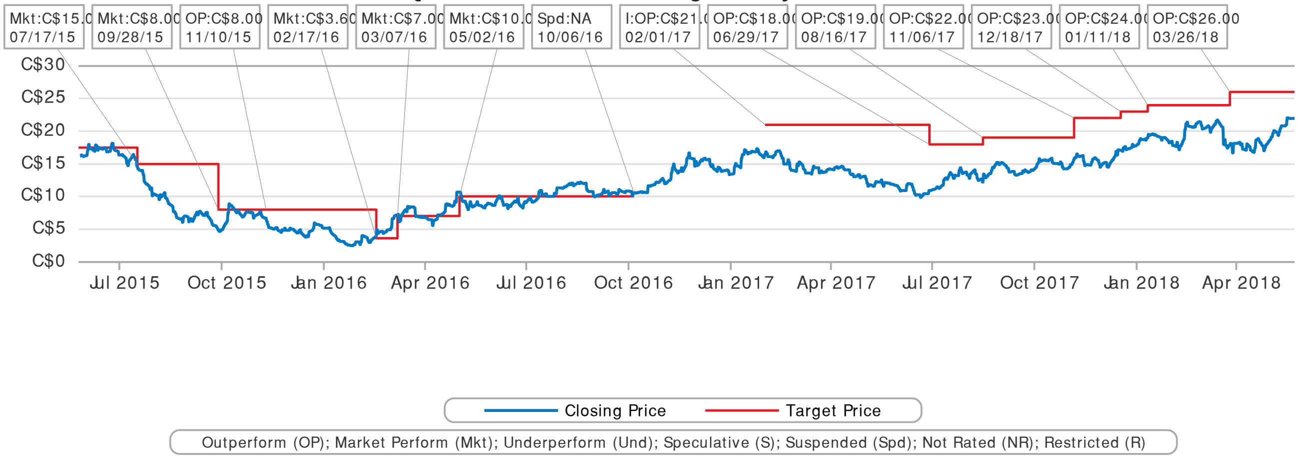
Widmer, J., Martin, R. and Kimiabeigi, M. (2015). *Electric vehicle traction motors without rare earth magnets.* Sustainable Materials and Technologies; 3:7-13.

Wilmer, D. (2011). *Wind Energy in the United States and Materials Required for the Land-Based Wind Turbine Industry from 2010-2030.* USGS.gov.

Zu, C., Renault, S., Ebadi, M., Wang, Z., Bjorklund, E., Guyomard, D., Brandell, D., Edstrom, K. and Gustafsson, T. (2017). Chemistry of Materials; 29:2254-2263.

Zheng, Z., Wang, Z., Song, X., Xun, S., Battaglia, V. and Liu, G. (2014). *Biomimetic Nanostructuring of Copper Thin Films Enhances Adhesion to the Negative Electrode Laminate in Lithium-Ion Batteries.* ChemSusChem; 7: 2853-2858.

First Quantum Minerals Rating History as of 05/22/2018



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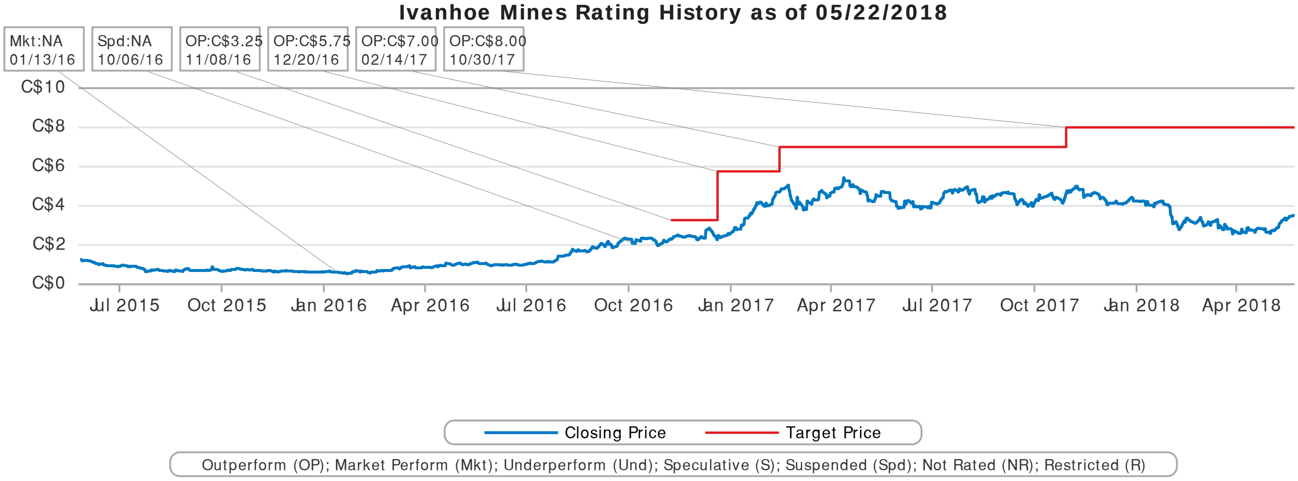

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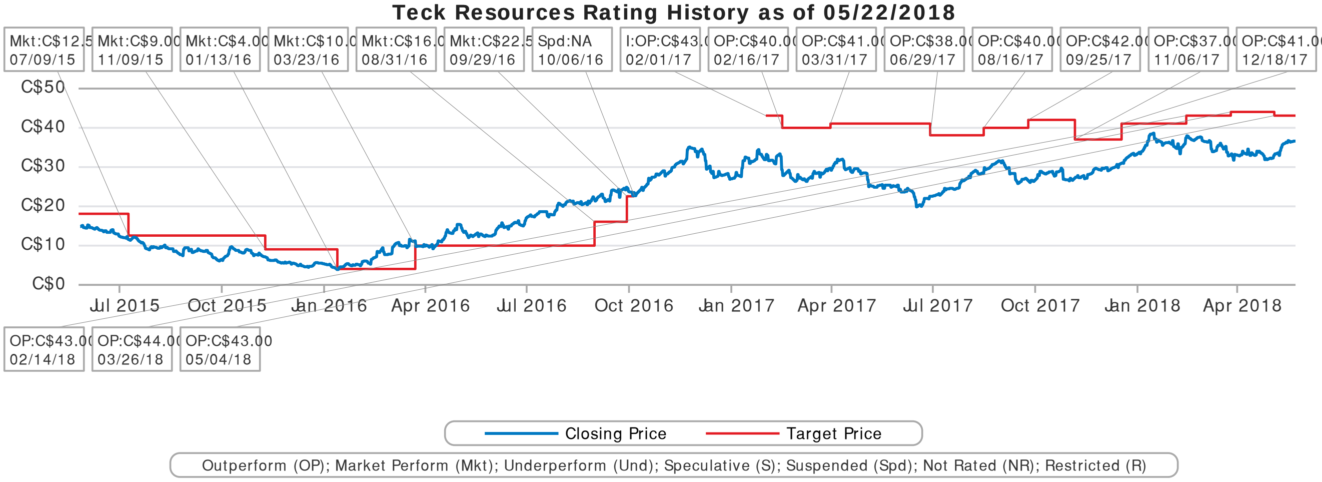

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Methodology: The target price is derived using a blend of NAV and EV/EBITDA multiples.

Risks: Risks to our target price include a material difference of actual commodity prices compared to our price assumptions, the outcome of Zambian tax negotiations, and any potential significant delays ramping up the Cobre Panama mine.

Methodology and Risks to Target Price/Valuation for Ivanhoe Mines (IVN-TSX)

Methodology: In line with the rest of the sector coverage universe, we use NAV to value development-stage assets. IVN's world-class assets in our view justify a $NPV_{10\%}$ setting multiple of 1.05x P/NAV. Our valuation does not include any assumptions of financing dilution/costs, but we use a P/NAV target-setting multiple below that of financed peers but above other developers due to the exceptional grades and scale of Ivanhoe's assets.

Risks: The lead Kakula/Kamoa assets are in the Congolese copper belt—a more stable portion of the Congo—and are near several operating mines, including those owned by seniors. The Platreef deposit in South Africa is exposed to jurisdictional risk, but South Africa is a known investment destination. Construction and financing risk are due to project scale and capex. Ivanhoe's projects are not technically challenging. Ivanhoe has secured partners to reduce financial risk.

Methodology and Risks to Target Price/Valuation for Rio Tinto (RIO-LSE)

Methodology: The target price is derived using a weighted blend of NPV, EBITDA multiples, growth factors and mine life.

Risks: Rio Tinto's price performance is subject to global demand for its key commodities (iron ore, aluminium, copper, met coal) and foreign exchange rates (mainly AUD and CAD).

Methodology and Risks to Target Price/Valuation for Teck Resources (TECK.B-TSX)

Methodology: The target price is derived using a blend of NAV and EV/EBITDA multiples.

Risks: Risks to our target price include a material difference of actual commodity prices compared with our price assumptions.

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Hold	Market Perform	48.9%	16.1%	45.4%	47.5%	44.4%	39.7%
Sell	Underperform	2.3%	15.4%	2.1%	2.4%	1.3%	5.0%

* Reflects rating distribution of all companies covered by BMO Capital Markets Corp. equity research analysts.

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BMO Capital Markets

Equity Research Analysts

Director of Canadian Equity Research
Bert Powell, CFA 416-359-5301

Associate Director – Canada
Hari Sambasivam 416-359-8357

Director of US Equity Research
Carl Kirst, CFA 212-885-4113

Associate Director – US
Todd J. Jonasz 212-885-4051

ENERGY

Oil & Gas – Integrateds
Randy Ollenberger 403-515-1502

Oil & Gas – E&P
Jared Dziuba, CFA 403-515-3672
Phillip Jungwirth, CFA 303-436-1127
Ray Kwan, P.Eng. 403-515-1501
Dan McSpirit 303-436-1117
Mike Murphy, P.Geol. 403-515-1540
David Round +44 (0)20 7664 8052

Oil & Gas – Oilfield Services
Daniel Boyd, CFA 713-547-0812
Mike Mazar, CPA, CA, CFA 403-515-1538

MATERIALS

Commodity Strategy
Colin Hamilton +44 (0)20 7664 8172

Base Metals & Mining
David Gagliano, CFA 212-885-4013
Alexander Pearce +44 (0)20 7246 5435
Edward Sterck +44 (0)20 7246 5421
Alex Terentiew 416-359-6319

Precious Metals & Minerals
Andrew Breichmanas, P.Eng. +44 (0)20 7246 5430
Andrew Kaip, P. Geo. 416-359-7224
Andrew Mikitchook, P.Eng., CFA 416-359-5782
Sanam Nourbakhsh +44 (0)20 7664 8091
Brian Quast, P. Eng., JD 416-359-6824
Ryan Thompson, CFA 416-359-6814

Fertilizers & Chemicals
Joel Jackson, P.Eng., CFA 416-359-4250

US Chemicals
John McNulty, CFA 212-885-4031

Packaging & Forest Products
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Brian G. Belski 212-885-4151
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Economics
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