Why critical metals efficiency is essential for the clean energy transition

Summary

The energy transition from fossil-fuel-based systems to renewable sources will require intensive use of certain critical metals, notably copper, nickel, cobalt and lithium. Rising demand for these metals will be largely driven by batteries and other electrification of energy use – much less so by renewable power generation itself. And this demand is projected to rise very steeply under net-zero ambitions, making it increasingly apparent it will not be met in a timely, sustainable, or socially just way.

So how can the intensity of critical metals use in the energy transition be mitigated enough to put the Paris climate agreement within reach?

While *energy* efficiency is rightly driving uptake of batteries and direct electrification, we need to also consider *critical metals* efficiency. Optimising both of these factors together will address this question and deliver a successful and orderly energy transition. And this is impossible to achieve through electrification alone: complementary technologies that offer lower metals intensity and are enabled by different metals, such as the platinum group metals, must be used.

These metals aren't under the same pressure as other critical metals, with well-established sources of supply and established circularity. They enable existing technologies that can address hard-to-abate sectors, which will continue to account for a significant proportion of total energy consumption. These include hydrogen production, hydrogen-based fuels, fuel cell vehicles and bio-based fuels and chemicals. And in using these technologies, issues with intermittency and transportation of renewable energy supply can also be addressed, and infrastructure costs can be optimised.

This whitepaper elevates the discussion of metals efficiency so that it is fully understood and considered in the energy transition.

"It is apparent that steeply rising demand for certain critical metals will not be met in a timely, sustainable, or socially just way"

Introduction

Why does metals efficiency matter?

Increasing global energy efficiency is an important aspect of the energy transition. It reduces the scale of the decarbonisation challenge, while also decoupling economic growth from growth in energy demand to assist a socially just transition.

The need for energy efficiency is one of the factors driving uptake of technologies that enable electrification of energy demand, such as battery electric vehicles (BEVs). The reason for this is because, as we journey to net zero, energy sources are transitioning away from fossil fuels to incorporate more renewable energy, which is harvested as electricity.

Once an electron is generated, by far the most energy-efficient thing to do with it is to use it immediately, without any conversion, and as close to the point of generation as possible otherwise transmission losses can mount up. Hence, electrification of energy consumption not only makes it possible to use renewable power directly, but also greatly reduces energy losses.

But too often energy efficiency is presented as the sole or overriding consideration in all future energy use. This one-dimensional approach is highly problematic, for the following reasons:

- Firstly, it is now evident that increasing electrification of energy consumption will require intensive use of certain critical metals, and supply gaps are looming.
- Secondly, it is not logistically feasible to achieve a global energy economy that is 100% based on the direct use of renewable power: there won't be enough of it, the infrastructure that would be needed to carry electricity to every point of energy consumption is unfeasible, and direct use of electricity is impractical in many cases. Complementary technologies are needed, using hydrogen or advanced bioenergy in some form, that can work alongside direct electrification – but these will have to use much less of those critical metals already under supply stress due to electrification.

Taken together, these considerations show that any sensible and sustainable strategy for future technologies must factor in critical metals efficiency alongside energy efficiency.

The concept of metals efficiency

Energy efficiency is well understood, particularly in the context of fossil fuels: supply is finite and consumption impacts the environment; therefore, you should use energy efficiently. This efficiency is measured in units of energy needed to perform a particular task, for example litres of fuel (which correlates to kilojoules) used per kilometre travelled.

Metals efficiency is analogous: supply is finite and extraction impacts the environment; therefore, you should use metals efficiently. The applicable unit of measurement is quantity of metal required to perform a particular duty (such as kilograms per vehicle), as shown in the examples discussed later in this paper.

Arguably, for renewable energy, critical metals efficiency is *more* important than energy efficiency. After all, the sun and wind are essentially infinite and non-polluting – but the metals we use to harness them are not and are facing a supply gap.

> "Too often energy efficiency is presented as the sole or overriding consideration in all future energy use"

What are critical metals?

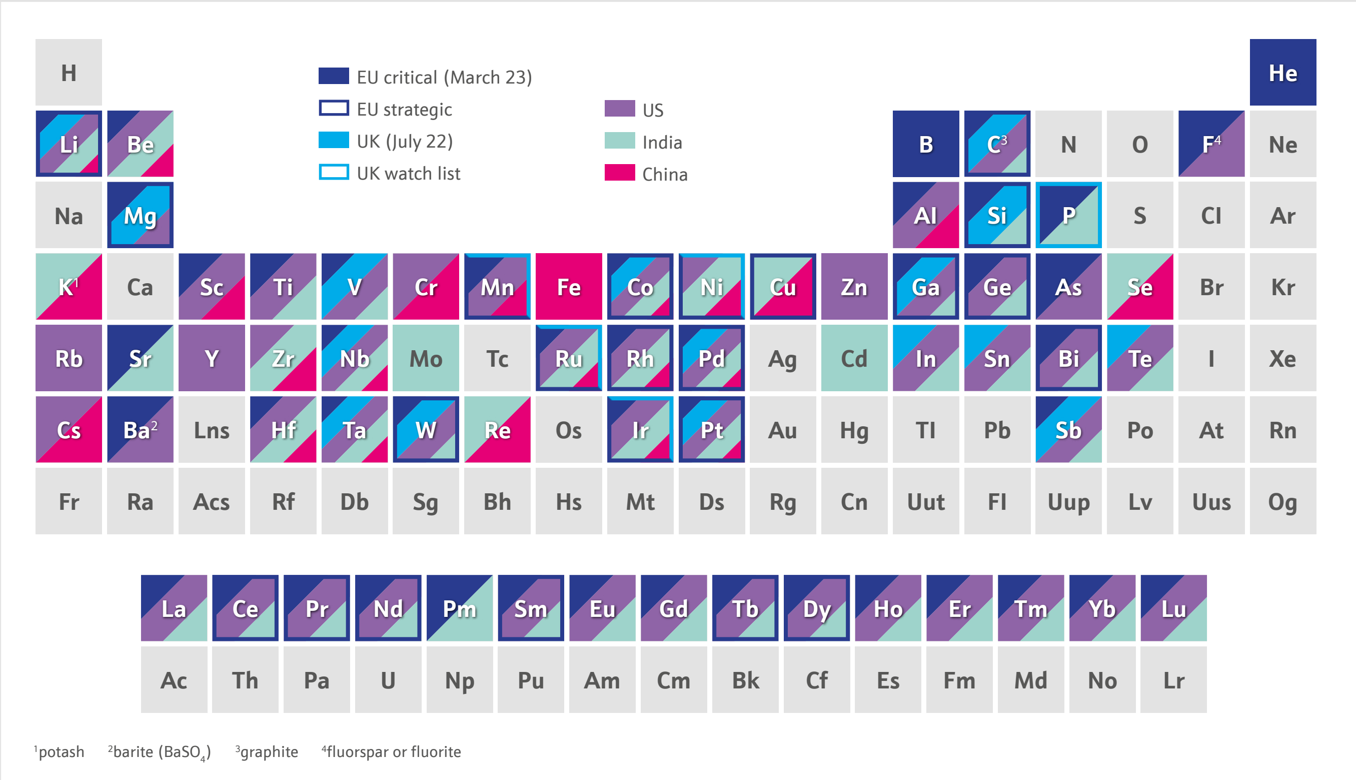

Figure 1 Elements currently listed as 'critical' in various jurisdictions

'Critical raw materials' are attracting increasing regulatory attention. Generally, this term refers to any material that is of economic or technological importance but is at risk of short supply or supply disruption. In some cases, the term 'strategic materials' is also used for materials that are needed for energy transition, defence, or other key technologies.

In this paper, we will use the term 'critical metals' to refer specifically to the metals needed for energy transition technologies, focusing on copper, lithium, cobalt, nickel, and the platinum group metals (PGMs).

"Arguably, for renewable energy, critical metals efficiency is even more important than energy efficiency"

The net zero future

Changes in energy supply

The net zero emissions (NZE) scenario from the International Energy Agency (IEA) entails a rapid shift in primary energy supply away from fossil fuels. It projects a considerable expansion in both modern bioenergy (at the expense of traditional biomass) and in nuclear power. But the most dramatic change is an eight-fold increase in renewable power generation by 2050 versus 2022, comprising mainly solar, wind and hydropower (Figure 2).

Net-zero forecasts from a range of other reputable bodies project similar amounts of renewable sources being necessary by 2050. Recognising this, at the recent COP28 climate summit over 100 countries agreed to triple renewable energy capacity by 2030.

With this transformation in energy supply comes a substantial change in how energy is carried to the consumer. In essence, this can be described as a significant increase in 'energy-by-wire' at the expense of 'energy-by-pipe', since more energy will be carried as electrons instead of in some form of gas or liquid, as has largely been the case in the fossil fuel economy (Figure 3).

"For net zero, an eight-fold increase in renewable power generation is needed by 2050"

Source: IEA World Energy Outlook 2023 – Free dataset

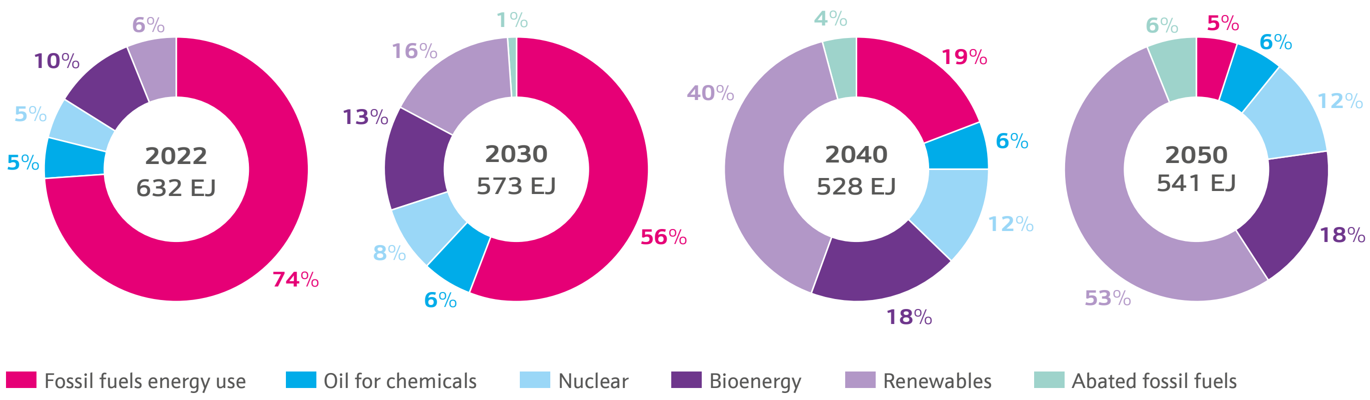

Figure 2 Changes in global primary energy supply in the IEA's NZE scenario

Source: IEA World Energy Outlook 2023 – Free dataset

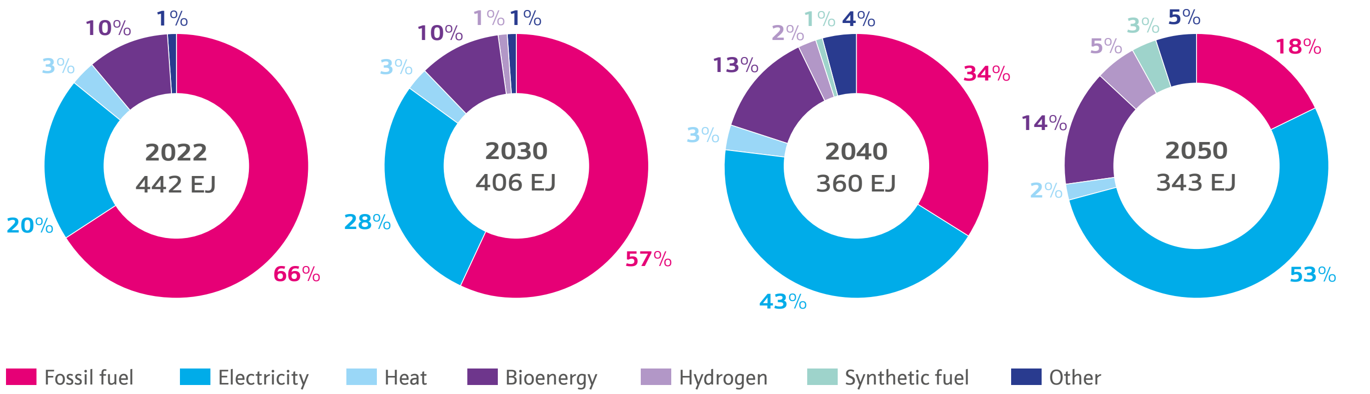

Figure 3 Changes in global energy carriers in the IEA's NZE scenario (Final consumption of energy by form)

Changes in energy consumption

The technologies used to consume energy will change too. Because of the importance of energy efficiency, our future energy economy will see more direct use of electricity, displacing the use of fossil fuels. For example, passenger car technology will shift from reliance on the internal combustion engine towards electric vehicles, and gas-fired heating in many people's homes will be replaced by heat pumps.

As these examples show, there are several use-cases that are well addressed by direct electrification, particularly in light duty transport, much of our buildings energy use, and some light industry. But this is far from all energy consumption (Figure 4).

The remainder, comprising most industry usage and all forms of energy-intensive transportation, is collectively referred to as the 'hard-to-abate' sectors. Because most of these use cases are impractical – if not impossible – to decarbonise via electrification, they will instead turn to clean hydrogen or sustainable fuels, either based on hydrogen or advanced biofuels (Figure 5). In other words, they need some form of gas or liquid rather than electrons.

"Most industry and all forms of energy-intensive transportation are extremely difficult to decarbonise via electrification"

Source: IEA World Energy Outlook 2023 – Free dataset

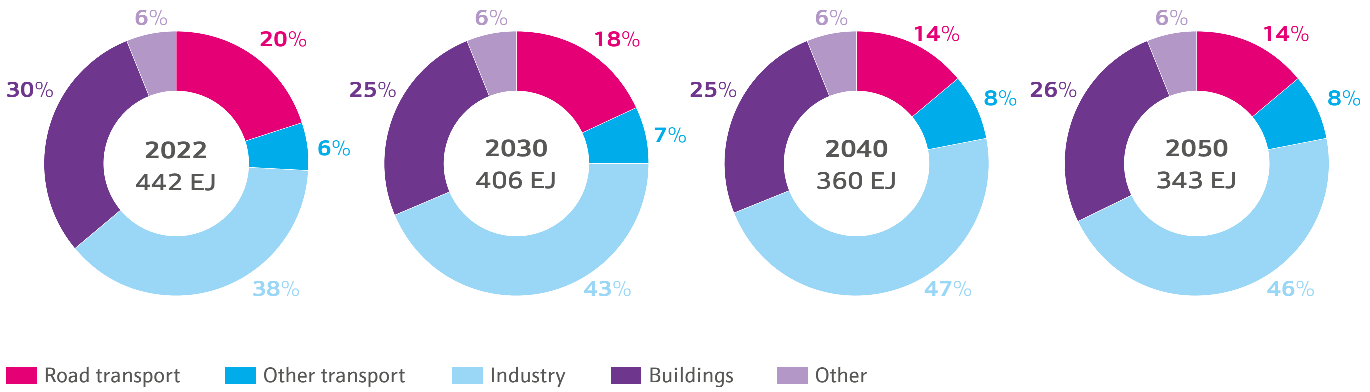

Figure 4 Changes in global energy consumption in the IEA's NZE scenario (Final consumption of energy by sector)

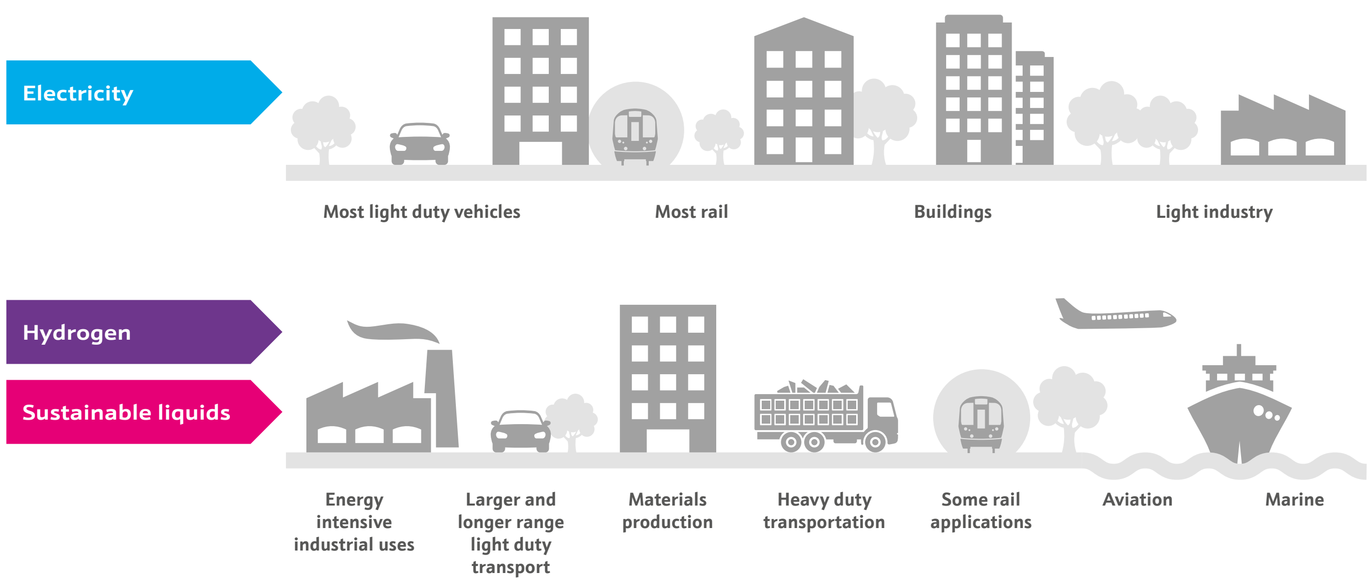

Figure 5 A mixture of use cases needs different forms of clean energy

The critical metals gap

Unprecedented growth in demand

The technologies that enable these changes in energy supply and consumption rely on the intensive use of critical metals[1]. The IEA projects demand growth for certain metals under the NZE Scenario, with the most substantial rate of increase expected to occur between today and 2040[2]. By 2040 demand for copper rises by 60% relative to 2022, while cobalt and nickel demand more than double and demand for lithium increases ten-fold (Figure 6a).

This is almost entirely driven by growth in clean energy technology requirements for these metals (Figure 6b). A closer look at the data in Figure 6c reveals that it is not the expansion in renewable power generation that is driving the bulk of this growth in metal demand. Most of the increase comes from the growth in battery electric vehicles (BEVs) and expansion of electric infrastructure.

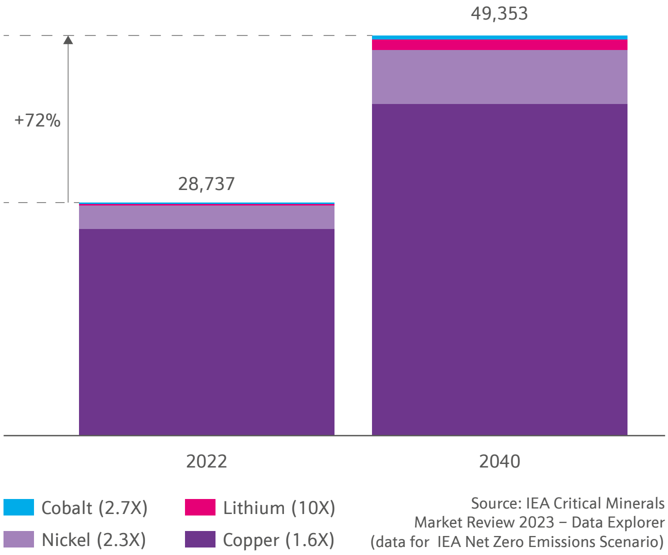

Figure 6a Projected growth in total demand to 2040 (kilotonnes, kt)

The supply gap

For some critical metals, it will be extremely challenging to scale up supply fast enough to keep pace with rapidly increasing demand. Most notably, sizeable market deficits are forecast for lithium[3], nickel[4], cobalt[5], and copper. These are projected to begin toward the end of this decade and escalate to supply gaps of over 20% of forecast demand by 2035.

Recycling of these critical metals, although forecast to considerably expand, will not close the emerging supply-demand gaps. Secondary supply of lithium, cobalt and nickel is only forecast to meet between 5% and 15% of battery metal demand by 2033, putting almost all the dependence on primary (mined) base metals for at least the next decade.

Addressing the gap will require unprecedented levels of investment to expand primary supply, which is unlikely given the cyclical nature of mining and the tight timeframe in which this new supply is needed. A typical discovery-to-production lead time for a new mine can be ten years, often much longer.

Also of growing concern are the severe environmental and social consequences that could result from attempts to close the gap. Discussions of sea-floor mining, for example, raise questions about a transition that prioritises personal mobility above biodiversity and environmental sustainability.

This is currently exemplified by Indonesian nickel. Indonesia is set to be the world's foremost producer of nickel, but production is heavily reliant on energy derived from coal, with carbon emissions two to six times greater than nickel production from sulphide deposits[7]. In addition, the harmful impacts of nickel mining in Indonesia on local people and the environment are already evident and have no place in a truly 'just' transition[8].

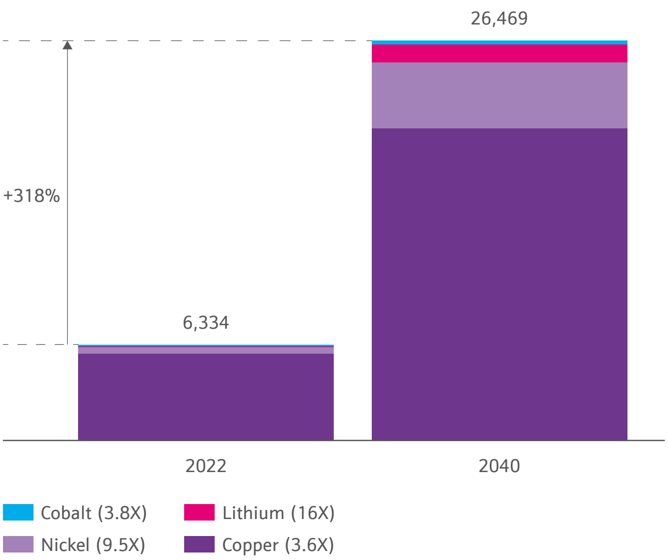

Figure 6b Projected clean technology demand growth by metal (kt)

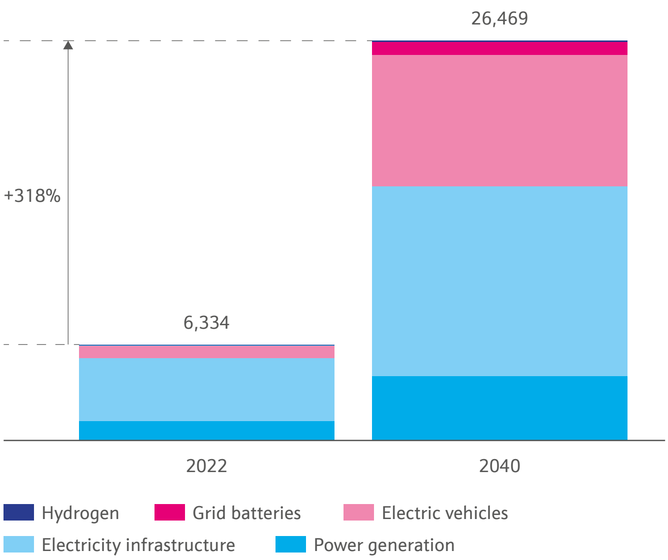

Figure 6c Projected clean technology demand growth by application (kt)

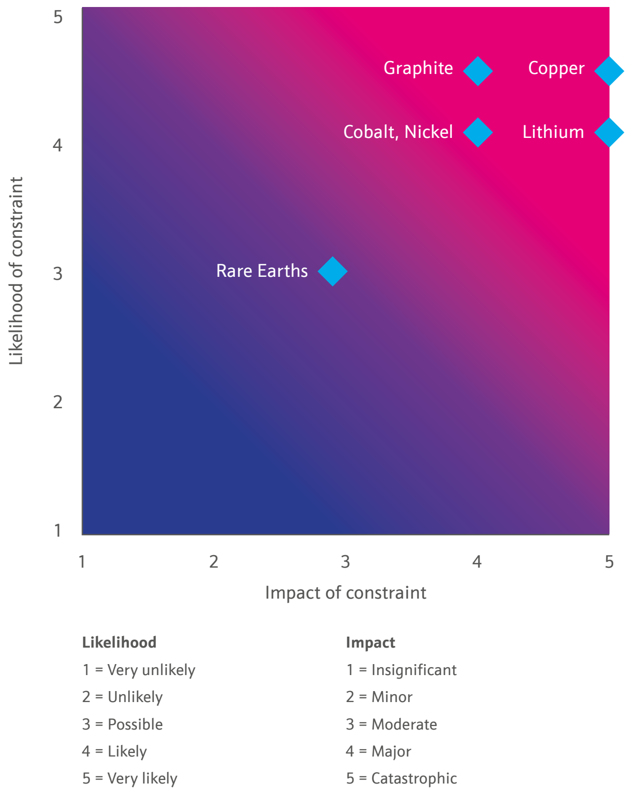

Figure 7 Assessed material supply risks to BEV forecasts, 2023–2035

Implications of the supply-demand gap

Johnson Matthey has used a range of external forecasts to assess the likelihood and impact of insufficient critical metals supply constraining growth in BEV deployments to 2035. The supply of copper, nickel, cobalt, lithium (and other materials such as graphite) are all individually judged to be likely or very likely to constrain BEV forecasts. And the constraints would have a major or even catastrophic impact on realising expected BEV volumes (Figure 7).

While individual risks may be mitigated, in our view it is virtually certain that at least one of these constraints will materialise. BEV forecasts, as they stand, are probably unachievable.

This shows the disastrous impact of an over-reliance on a single technology and the resulting critical metals supply gap: a delayed or derailed transition to a net-zero future. That eventuality must be anticipated and addressed by using complementary technologies to lower the overall critical metals intensity of the energy transition.

> "The disastrous consequence of an over-reliance on a single technology is a delayed or derailed energy transition"

Sustainable technologies to improve critical metals efficiency

In this section we discuss two key examples of how an analysis of metals efficiency informs technology choices.

Metals efficient road vehicles

Figure 8 shows an estimate of typical critical metals loadings in the powertrain of a medium passenger car (in kilograms per vehicle), depending on whether it is a conventional gasoline vehicle, a fuel cell electric vehicle (FCEV), or a pure BEV.

The zero emissions vehicle with the lowest critical metals intensity (i.e., the highest metal efficiency) is the FCEV, even though it contains a small hybrid battery pack as well as a fuel cell stack.

This is enabled by platinum group metals (PGMs) being such powerful catalysts: you need very little platinum to accomplish the necessary electrochemical reactions in the stack. Typically, this is about 20g in a market-leading fuel cell car – orders of magnitude less than the quantities of base metals needed in a battery. In contrast, the large battery pack on the BEV makes it a relatively inefficient (and more expensive[9]) use of critical metals.

The differences in critical metals efficiency also apply to medium and heavy-duty commercial vehicles. Figure 9 gives an assessment by S&P Global of copper content in vehicles with different powertrains, showing FCEVs being much more copper-efficient than BEVs – particularly for the largest vehicles.

The feasibility of using hundreds of kilograms of copper in each battery truck is highly questionable when large numbers of zero-emissions trucks are required, and huge amounts of copper will be needed in new cables to carry more of our energy as we shift to 'energy-by-wire'.

These comparisons show that BEVs deliver energy efficiency and FCEVs deliver critical metals efficiency. Using them alongside each other, targeted according to the best use of each, will result in a zero-emissions vehicle fleet that optimises the balance of energy and critical metals efficiency.

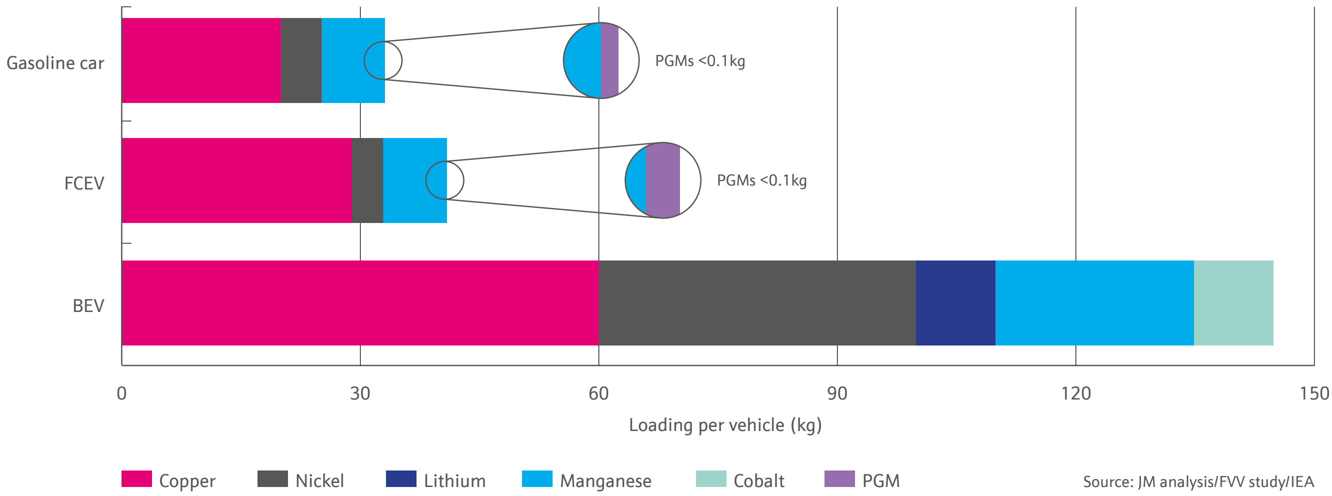

Figure 8 Typical powertrain critical metal content per medium passenger car, kg/vehicle

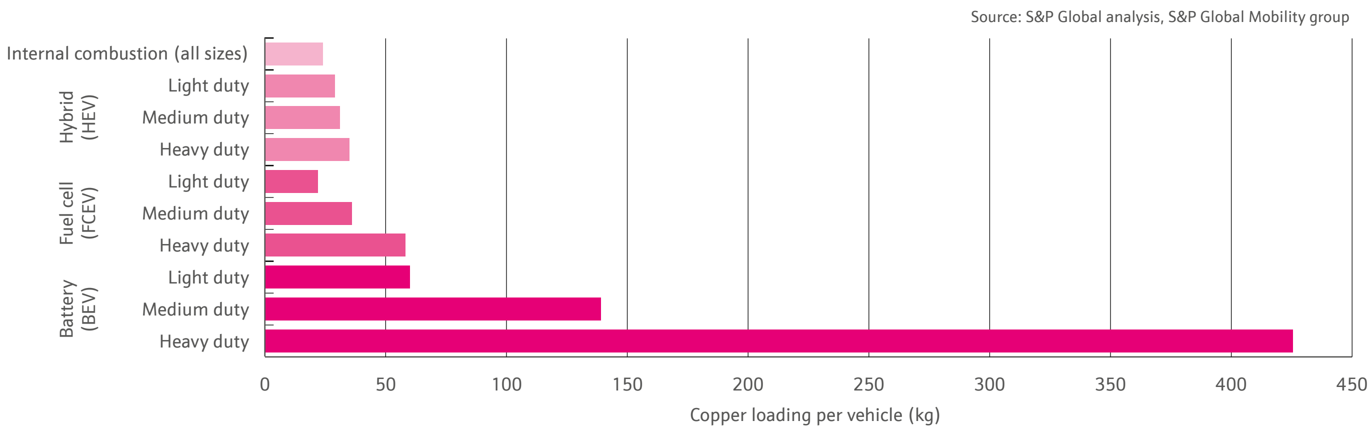

Figure 9 Current copper content by vehicle for key powertrains

Metals efficient energy distribution

The shift in how energy is carried also needs to take critical metals efficiency into account. Currently, only about a fifth of global energy use is transmitted as electricity by wire (Figure 3). Expanding this beyond the 40–50% already projected by the IEA is unlikely to be sustainable in terms of copper extraction.

Therefore, we need additional energy vectors which rely on materials that are not under the same supply pressure as copper (Figure 10). If we continue to move a proportion of our energy 'by pipe', in the form of low-carbon and renewable hydrogen, hydrogen-based derivatives such as ammonia and methanol, and advanced biofuels, this will help to increase critical metals efficiency in the energy system. Crucially, it will moderate copper demand to a level that is more likely to be met.

In addition, this pipeline infrastructure could repurpose parts of the fossil fuel infrastructure, which is otherwise obsolete. This has the benefit of recycling the bulk materials such as steel in use today and minimising the overall environmental impact of the net-zero infrastructure transformation.

"Using a mix of technologies alongside each other will optimise the balance of energy and critical metals efficiency"

Figure 10 Metals intensity in energy carrying infrastructure (kg/MW/km)[ii]

Synergies in the energy system

Employing a mixture of technologies to optimise the balance between critical metals efficiency and energy efficiency has other important benefits for the energy system.

Increasing the efficiency of renewable power generation

Using hydrogen and sustainable fuels will increase the critical metals efficiency of future energy consumption and infrastructure, relative to a scenario that is over-reliant on direct electrification. However, producing these energy vectors involves a conversion step, and any energy conversion inevitably results in some loss of energy. For example, the production of green hydrogen from renewable electricity typically involves a 20% loss, so energy efficiency is at best 80%[10].

The presumption might be that this loss means that 20% more input energy is required, requiring 20% more critical metals to generate, and therefore offsetting the benefits of increased critical metals efficiency elsewhere. But this is not necessarily the case.

The first aspect to consider here is the efficiency of the renewable power generation itself. Solar panels and wind turbines have different load factors depending on the intensity of the wind and sun they are exposed to. A solar panel located in sunny Algeria, for example, will generate more electricity than an identical panel located in Germany and is therefore more energy efficient.[11] A similar argument applies to deep offshore wind power, which typically has higher load factors than onshore wind.[12]

This improved generation efficiency can offset the apparent loss in efficiency from energy conversion. An illustrative study by the Hydrogen Council shows a similar final energy efficiency between charging a BEV in Germany using a local solar panel and powering an FCEV in the same location with imported renewable hydrogen produced in a sunny region, such as the Middle East.[13]

"Hydrogen can enable increased efficiency of renewable power generation, offsetting the loss from conversion"

Linked to this is a second aspect: the time mismatches between energy demand and renewable power supply, which is inherently variable, intermittent, and cannot be turned on or off as needed. Substantial energy storage capacity will be needed to smooth out seasonal and other time-mismatches,[14] and to capture renewable power that might otherwise go to waste because it isn't needed immediately.

Among other considerations, critical metals constraints mean that it is not possible for more than a fraction of this storage to be accomplished by grid batteries. But renewable hydrogen and its derivatives are an effective and metals-efficient means of energy storage in large quantities over long periods, and of moving energy over long distances, such as between continents.

Employing hydrogen and hydrogen-based derivatives such as ammonia relieves capacity constraints resulting from renewable power having to be sited close to the point of consumption and directly tied into the electricity grid. Instead, renewables capacity can be sited where it is most efficient and has fewer land-use constraints. These considerations will be increasingly pressing as renewables scale up from the very low levels of penetration we have today (Figure 2).

The use of hydrogen and its derivatives will therefore facilitate more effective renewables infrastructure, warranting the energy 'loss' incurred by conversion.

Optimising infrastructure cost

Some would argue that having two different infrastructures, energy-by-wire and energy-by-pipe, will be more expensive than just one. But there are good reasons to believe the opposite.

We can again use road vehicles as an example. An illustrative study by McKinsey for the Hydrogen Council[15] (Figure 11) shows how the combination of the two distribution infrastructures allows for cost optimisation. In the case of zero-emission vehicles, using FCEVs rather than BEVs for the most energy-intensive duties (larger vehicles with longer ranges) removes the need for the largest battery packs. This shifts vehicles that would need the highest voltage and therefore most expensive cables and charging infrastructure onto an alternative 'pipe-based' hydrogen infrastructure.

The hydrogen infrastructure also removes the need for the most challenging and expensive parts of BEV charging infrastructure, for example in remote places or within high-density city centres, where adding electrical infrastructure for fast charging is particularly challenging. The hydrogen infrastructure to serve these needs costs less than the additional electrical infrastructure would, leading to lower total infrastructure cost overall.

"Using FCEVs rather than BEVs for the most energy-intensive duties leads to lower total infrastructure cost overall"

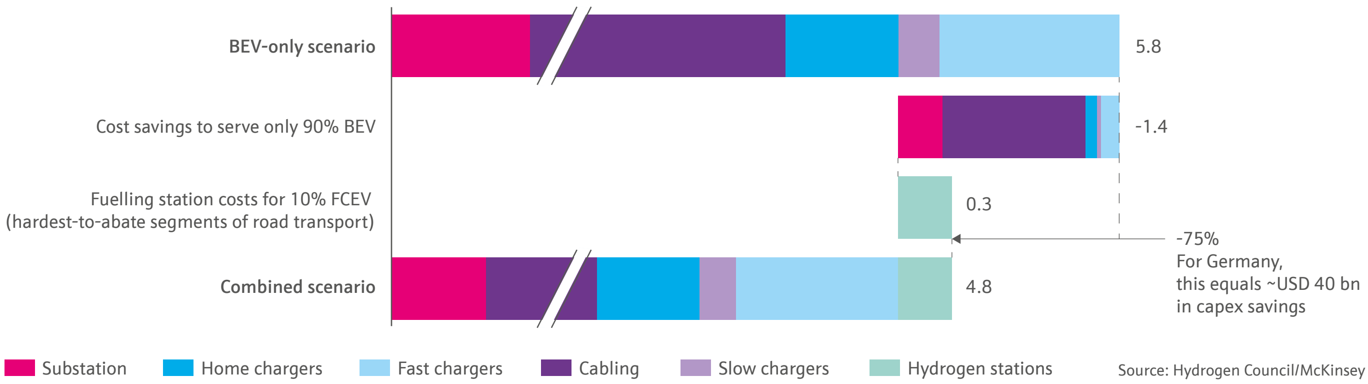

Figure 11 Comparison of incremental investment for recharging of BEVs vs refuelling of FCEVs[vii] (capex to serve 1,000 passenger vehicles, USD million, 2050) (Note: cabling larger than scale shown)

Conclusion

This paper has outlined why a consideration of critical metals efficiency in the energy transition is overdue. This does not negate the importance of energy efficiency but requires a shift in thinking away from a one-dimensional analysis to consider the wider system.

The foreseeable future for the global energy system entails a huge increase in renewable power generation together with increasing electrification of certain sectors of energy consumption. But a future with more renewable energy use is still not a renewable future, because the enabling clean energy technologies make intensive use of critical metals. We remain reliant on an extractive industry exploiting finite resources and we must use those resources carefully.

And even the most ambitious net-zero scenarios do not suggest that electrification is a complete solution. Complementary technologies will be needed to enable increasing penetration of renewable power, to address those sectors that electrification cannot reach, and – crucially – to improve the critical metals efficiency of the energy transition.

Those technologies exist: low-carbon and renewable hydrogen, hydrogen-based synthetic fuels, and advanced biofuels. It is not sensible to argue against their use because of misperceptions around energy inefficiency while increasingly unsustainable attempts are made to secure metals for 'efficient' electrification.

Using these solutions alongside direct electrification ensures that the future energy system as a whole can be optimised, considering both energy and critical metals efficiency. Most importantly, it puts us within reach of an achievable energy transition.

"Complementary technologies are needed to work alongside electrification and improve the critical metals efficiency of the energy transition"

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