IEA's six pillars of a comprehensive approach to mineral security

While each country has different motivations and approaches to the issue of critical minerals, their experiences provide useful lessons for designing frameworks to ensure reliable mineral supplies. Past approaches have varied depending on whether the country is a producer or a consumer, but this distinction is increasingly becoming blurred as producer countries strive to build a domestic industry to produce clean energy equipment, and consumer countries seek to revitalise domestic production or secure overseas production assets. This suggests that an approach to ensuring reliable mineral supplies needs to be multi-faceted, covering a wide range of aspects from supply to demand to recycling.

Based on the IEA's long-standing experience in energy security, we identify **six pillars of a broad approach to minerals security**, complementing countries' existing initiatives. They are: (i) ensuring adequate investment in diversified sources of new supply; (ii) promoting technology innovation at all points along the value chain; (iii) scaling up recycling; (iv) enhancing supply chain resilience and market transparency; (v) mainstreaming higher environmental and social standards; and (vi) strengthening international collaboration between producers and consumers.

Beginning with adequacy of supply, the supply of minerals and metals needs to keep up with the rapid pace of demand growth to ensure orderly energy transitions. This requires strong growth in investment to bring forward new supplies at the right time. Governments can take a variety of measures to attract investment into the sector, but the foremost action is to provide clear and strong signals about energy transitions. As noted in Chapter 2, the largest uncertainty around demand comes from questions about countries' real commitment to their climate ambitions. If companies do not have confidence in countries' climate policies, they are likely to make investment decisions based on much more conservative expectations. Given the long lead times for new projects, this could create a bottleneck when deployment of clean energy technologies starts to grow rapidly, as envisaged in the SDS.

Governments can also play a role in creating conditions conducive to investment in the mineral supply chain. Measures could include strengthening national geological surveys, streamlining permitting procedures to shorten lead times and, in some cases, providing financing support to de-risk strategic projects (which can be defined according to each country's own assessment of which, and how much, critical minerals they might need in the future). They can also support the unlocking of additional sources of supply by supporting enhanced metals recovery from low-grade ores and waste streams or revisiting the potential of abandoned mines. Further, governments can work together to improve data availability and comparability across regions, and raise public acceptance.

Box 3.2. What would be the right metrics to assess mineral security?

Any efforts to improve security of supply start with understanding where we stand and what progress is being made. The rising importance of critical minerals in energy transitions raises a question about the right metrics to measure the status and progress of mineral security.

The most commonly used metrics today are (i) import dependency and (ii) the level of supplier concentration. Import dependency is calculated as the amount of imported material as a percentage of domestic consumption. The level of supplier concentration is often measured using the Herfindahl–Hirschman Index, a widely used metric to assess the level of market concentration. In some cases, these are complemented by measurement of the economic importance of a certain mineral, such as the contribution of minerals to the value added of end-use sectors. Many countries have defined a list of critical minerals using variations of this approach.

While these remain highly valuable, most of the metrics naturally focus on the sovereign boundary, and the question remains as to how these measures can trigger action to improve security of supply. Given the need for a wider security approach, there may be scope to develop metrics that encompass wider aspects of supply, demand, resilience and sustainability to complement the traditional criticality indicators.

For example, to assess the adequacy of future supply, the actual level of investment spending against the level required to meet long-term demand could be measured, as has been done for the energy sector in the IEA's *World Energy Investment* reports. This could give an indication of possible market tightness.

Public R&D spending on technologies that can reduce material intensity, allow substitution and unlock new supplies can be assessed. The IEA's *Energy Technology RD&D Budgets* report assesses this for energy technologies in IEA member countries. There is scope to track material intensity in clean energy technologies in a systematic manner. This will be crucial for a more accurate view about future material requirements.

On supply chain resiliency, the measurement of supplier concentration could be expanded to include the processing and refining value chain. Some countries assess the political and social risks of the major producers, which can be a useful complement. Finally, progress on recycling (e.g. collection rates and the share of secondary production) can be an important part of security metrics.

Both traditional and complementary metrics will require greater data transparency. Governments have a role in collecting and disseminating reliable data in this regard.

Stepping up efforts for technology innovation and recycling can yield multiple benefits

History suggests that innovation in demand-side technology can play a major role in alleviating strains on supply and reducing material costs, which could in turn help enhance the affordability of clean energy technologies. As noted in Chapter 2, costs associated with raw materials are likely to represent a larger portion of total investment costs for clean energy technologies in the future as other cost components continue to decline thanks to technology learning and economies of scale. This underscores the important role of innovation in demand-side technology to mitigate upward cost pressure.

There are many positive examples. Efforts to reduce the use of silver and silicon in solar cells have helped to enable a spectacular rise in solar PV deployment in recent years. Technology advances in aluminium helped ease strains on copper supply in the 1950s and tin supply in the 1980s. A host of emerging technologies have the potential to reduce the use of critical minerals, if successfully commercialised (e.g. induction motors or switched reluctance motors to reduce REE consumption). There is, however, a need to assess trade-offs that substitution could trigger (e.g. all solid-state batteries reduce the need for nickel and cobalt, but require more lithium).

The possible contributions of technology are not confined to the demand side. Innovation in production and processing technologies can unlock sizeable amounts of new supplies and contribute to reducing primary supply requirements. The emergence of Sx-Ew processes in the 1970s opened up the possibility to tap into extensive copper oxide resources. More recently, emerging technologies such as direct lithium extraction, or enhanced metal recovery from waste streams or low-grade ores, could lead to a step change in future supply volumes. Technologies that help reduce water use or energy consumption can also bring additional environmental and operational benefits. In 2021 the US Department of Energy announced USD 30 million in funding research to secure domestic supply chains. Countries endowed with huge resources are naturally putting more effort into supply-side technology innovation, but consumer countries can also benefit from reduced import dependency.

Policy support to scale up recycling efforts can bring multiple benefits. It can help reduce primary supply requirements and alleviate the environmental burdens associated with primary supply. Also, the security benefits of recycling can be far greater for regions with wider deployment of clean energy technology, as they stand to benefit from greater economies of scale. Government support may be necessary to incentivise recycling at the end-of-life stage of products, support collection and sorting activities and fund R&D into new recycling technologies. In the last section of this chapter, we examine the prospects and policy approaches to scaling up recycling in more detail, with a focus on batteries and electricity network

Governments can play a role in enhancing supply chain resilience and market transparency

Ensuring that critical minerals enable clean energy transitions requires a broad view of the supply chains, from mining to processing. Even if raw materials from mining are well supplied, a bottleneck in processing capacity could elevate prices for refined products and affect clean energy investment. In addition, a higher degree of concentration of production implies that disruption can have wider ripple impacts on the entire value chain.

Periodic stress-tests coupled with emergency response exercises can help policy makers identify points of potential weakness, assess potential impacts and devise necessary actions. For example, some European countries conduct a regular “N-1” stress test to assess the resiliency of gas supply infrastructure. The test assumes the loss of the single largest element of supply infrastructure and evaluates the impact on the country’s energy supply. Another example is the emergency response exercises the IEA regularly organises with its member countries to ensure quick and effective responses to major supply disruptions. Safeguarding security of oil supply has been the main focus so far, but the concept is expanding to encompass other areas as well. In 2016 the IEA worked with the Japanese government to conduct a gas resiliency assessment, aimed at identifying risks and challenges related to natural gas supply in Japan.

Voluntary strategic stockpiling, where applicable, can also help countries weather short-term supply disruption. Some countries have been operating stockpiling schemes for many years as a tool to ensure supply security. Such programmes need to be carefully designed, based on a periodic review of potential vulnerabilities. In general, such schemes can be more effective for minerals with smaller markets, opaque pricing and a concentrated supply structure than those with well-developed markets and ample liquidity.

There is scope to improve market transparency. Many base metals such as copper are widely traded in the market with reliable pricing mechanisms. However, this is not the case for some energy transition minerals with smaller markets, such as lithium and cobalt (see Box 3.3). These minerals have been historically regarded as “minor minerals” and traded on a bilateral basis, resulting in low pricing transparency and liquidity. Buyers need to rely on information provided by suppliers, making it difficult to manage price risks and affecting investment decisions down the value chain. However, as demand grows, end users will increasingly call for more transparency around pricing to hedge risks. Establishing reliable price benchmarks will be an important step towards enhancing market transparency and supporting market development. While this process takes time, the experience in the LNG market shows the potential benefits: the rise of hub-based pricing for LNG, alongside long-term supply contracts, has made gas markets more responsive to changes in global and regional supply-demand balances.

Box 3.3. Towards a transparent pricing system: A story of lithium and cobalt

The predominant approach to trading lithium has not changed much over the past few years. Lithium has not been listed on an exchange and does not have a reliable benchmark price. The vast majority of lithium raw materials and chemicals are sold under bilateral long-term contracts between suppliers and end users. There is a spot price index based on Chinese custom data, but a question mark remains as to whether the index reflects market dynamics in an accurate and timely manner. It is rarely used for large-scale negotiation or hedging in practice (McKinsey, 2018).

However, there are signs of change. The duration of contracts is becoming shorter, and the London Metal Exchange (LME) introduced a tradeable price benchmark in partnership with Fastmarkets, a price reporting agency. The LME also plans to launch the LME lithium futures contract in the first half of 2021 – the first of its kind. These developments are expected to allow stakeholders to mitigate against price volatility.

There are, however, challenges. While a growing number of buyers are entering the market, only four companies supply the majority of lithium raw materials. The ambiguity of standards and classifications is another obstacle. Lithium is a speciality chemical that comes in a variety of material grades. This calls for a standardised methodology to enable comparability and accuracy of prices.

Cobalt is currently traded on the LME and the Chicago Mercantile Exchange (CME). The LME launched a physically settled contract in 2010, followed by a financially settled contract in 2019. CME launched new cash-settled cobalt futures contract in 2020. So far, the LME's physically settled cobalt contract has not been widely accepted by industry participants as a tool for hedging. The financially settled contracts faced similar issues. The major barriers to cobalt trade have been the lack of liquidity in the spot market, as well as cargo heterogeneity.

However, the situation is clearly improving with more pricing information being available. Fastmarkets releases a daily metal price and twice-weekly hydroxide payable assessment. These have been adopted into the majority of cobalt contracts. Some companies started to hedge cobalt exposure through financial swaps and banks are also getting involved.

Over time, as demand grows and more market participants enter the market, more liquid contracts are likely to be evident in the market. The development of new financial instruments will be important to provide some level of risk mitigation and increased levels of transparency (Lee et al., 2020).

Improved environmental and social performance contributes to enhanced mineral security

As a sector, mining is often cited as having the greatest exposure to ESG risks (S&P Global, 2019b). Recognising this, investors, consumers and civil society increasingly push companies to source minerals that are sustainably and responsibly produced, with institutional investors particularly visible in these efforts. It is becoming increasingly difficult for mining companies to ignore these concerns. Higher environmental and social performance is also crucial for governments to gain public acceptance for project development.

There is a significant degree of variation in environmental and social performance in the market. This makes it challenging for consumers to exclude poor-performing minerals as there may not be sufficient quantities of high-performing minerals to meet demand. Efforts to improve environmental and social performance can therefore contribute to enhanced mineral security by increasing volumes produced with higher environmental and social standards and lowering the cost of sourcing them.

Poor environmental and social performance can also lead to supply disruption. Production sites may be shut down or disrupted due to disputes over water access or as a consequence of regulatory actions to enforce child labour or human rights violations. Meanwhile, dam failures at tailings storage facilities can lead to extended shutdowns and large remediation and repair costs. At the same time, criminal and civil liability related to environmental damage or corrupt practices can raise the cost of production, with severe reputational and financial implications for the companies concerned.

A level playing field

Environmental and social performance tends to be better for minerals produced in countries with well-developed regulatory systems, strong enforcement and institutionalised transparency practices. At the same time, some of the worst social impacts caused by mining, such as child labour, are ultimately a product of widespread poverty. To address these impacts, co-ordinated policy efforts will be needed: (i) to provide technical and political support to countries seeking to improve legal and regulatory practices; (ii) to incentivise producers to adopt more sustainable operational practices; and (iii) to ensure that companies across the supply chain undertake due diligence to identify, assess and mitigate these risks (see Chapter 4).

Establishing a level playing field may also help to support innovative strategies to address these risks, which can ultimately lead to greater diversification among supply. If strong environmental and social performance is rewarded in the marketplace, new entrants will have an incentive to develop new approaches to addressing these risks.

International co-operation is vital for ensuring reliable and sustainable mineral supply

As noted above, many governments have developed strategies to ensure the reliable and sustainable supply of minerals. While encouraging, given the complex nature of the mineral supply chains spanning across the globe and involving multiple minerals, no individual country will be able to drive the necessary changes on its own. For example, in the case of REEs, while there is growing interest in securing diversified supply options, it would be challenging and cost-prohibitive for a single country to build a presence along the entire value chain and some efforts so far have given rise to trade disputes (see Box 3.4).

Governments can steer better market outcomes and improve the security of mineral supply by working together. For the moment, there is no overarching international governance framework for critical minerals and co-ordinated policy action is lacking. Individual efforts are often fragmented and tend to focus on narrow issues. There is a strong case for strengthened international co-operation to ensure reliable and sustainable mineral supply. To this end, the UN Environmental Programme's International Resource Panel highlighted the need for a framework to inform policy strategies and co-ordinate international efforts surrounding mineral security (IRP, 2020).

There are many ways in which a multilateral framework could play a role in ensuring reliable and sustainable mineral supply:

- Provide clear market signals on decarbonisation targets to reduce demand uncertainty and help de-risk investment decisions.
- Facilitate a dialogue between producers and consumers to identify key bottlenecks and co-ordinate investment decisions.
- Mobilise public funds to accelerate R&D efforts for technology innovation.
- Conduct regular assessments of potential vulnerabilities across the supply chains and discuss collective action to respond to potential disruption.
- Promote knowledge and capacity transfer to spread sustainable and responsible development practices to a wide range of countries.
- Strengthen environmental and social performance standards through international standardisation and other mechanisms, to maintain a social license and ensure a level playing field.
- Co-ordinate diplomatic efforts to prevent restrictive export policies.
- Collect reliable data to assess the level of risk and help informed decision-making.

Box 3.4. Export restrictions on critical minerals

As security of supply comes into sharper focus, potential distortions to the free trade of critical minerals become increasingly sensitive. Export restrictions introduced by China, Indonesia and the DRC reflect the varying objectives being pursued, and the mixed results achieved. Quantitative restrictions are largely prohibited under GATT article XI, but may be justified under certain limited exceptions such as environmental conservation or national security.

China started introducing export restrictions on REEs in 2006, which resulted in an increase in prices and the United States filing a WTO case in 2012. Plaintiffs argued that the export controls were part of a deliberate industrial policy, and not resource conservation efforts. In 2014 the WTO Appellate Body ruled in their favour and China lifted the measures (WTO, 2015). Moves by third countries to invest in non-Chinese sourcing, the subsequent collapse in prices and the ultimate WTO ruling underline the mixed benefits of such measures. In January 2021 the Chinese government issued its draft version of the Regulations on Rare Earth Management. The regulations aim to protect national security and prohibit unsustainable practices such as illegal mining and environmental degradation. Exports would become subject to government approval through the Chinese Export Control Law (China Briefing, 2021). The compatibility of any potential measures with WTO provisions remains unclear.

Policies aimed at adding local value are also subject to economic conditions and WTO rules. For instance, while Indonesia’s nickel ore export prohibition has been successful at enticing the construction of smelters (UNCTAD, 2017), it has not attracted a diverse investment profile, with mostly Chinese companies investing so far, and the European Union is now challenging it at the WTO (DG Trade, 2021). The DRC pursued a similar strategy through an export ban on copper and cobalt concentrates starting in 2013. However, this ban has largely stalled due to operators’ inability to develop local processing facilities (Africa Oil & Power, 2020). This reflects the inherent challenges to interventionist trade policies in commodity-dependent countries.

These examples illustrate how growing concerns over local development and environmental conservation could lead to an increase in export restrictions. However, importing countries are likely to dispute them as a proxy for industrial or geopolitical strategies. Empirical evidence also shows that despite the limited geographic scope of production and/or processing of certain minerals, export restrictions often have limited effect in the long run due to potential diversification of supply (IRENA, 2019).

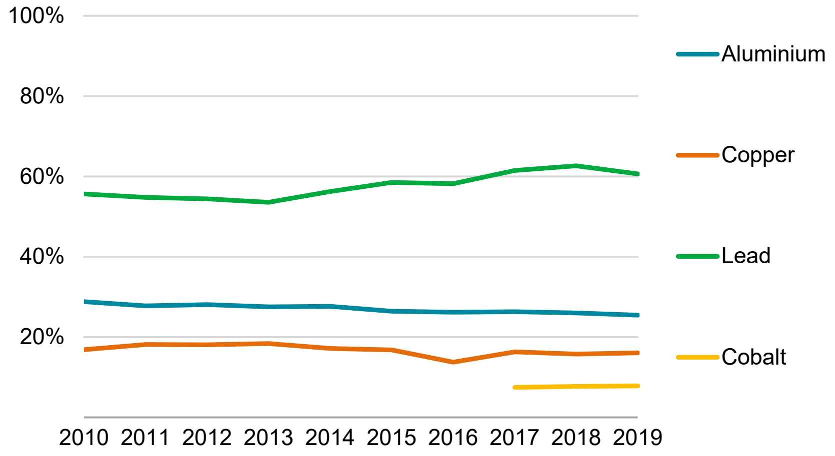
Focus on recycling

Growing recycled volumes have only managed to keep up with demand growth

Metal recycling has the potential to be a significant source of secondary supply, although it comes with its own set of challenges. Recycling comprises the physical collection and separation of metals, and metallurgical processing to recover them. Taken together, these combine multiple pathways with a wide range of technologies and practices. Potential sources for recycling include tailings from processing, scrap used in manufacturing and fabrication and scrap from end-of-life products. For some metals, such as aluminium and copper, global stock and recycling pathways are relatively well established. However, for many metals, global stock assessments are scant or only examine discrete sub-sectoral applications, making recycling potential difficult to assess.

As noted in Chapter 1, recycling rates are typically measured by end-of-life recycling rates and recycled input rates. End-of-life recycling rates refer to the share of material in waste flows that is actually recycled, and recycled input rates assess the share of secondary sources in total supply. Both rates differ substantially by metal and region. Higher end-of-life recycling rates do not necessarily mean higher recycled input rates, as each end-use product has a different lifetime and shows a varying pace of demand growth. For example, a beverage can typically enters the waste stream within a month after consumption, whereas building materials take over 40 years to be collected. The fact that collected products are often reused in a semi-fabricated form makes an additional difference. For many metals such as copper and aluminium, recycled input rates have not changed much in recent years, meaning that improved recycling activities have only managed to keep up with demand growth.

Recycled input rates for selected metals and minerals



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Notes: Share of secondary production in total refined product consumption. Does not include scrap volumes that are reused in end-use applications.
Source: World Bureau of Metal Statistics (2020).

Scaling up recycling can bring considerable security and environmental benefits

Physical collection is a primary limiting factor on the level of recycling. Metals such as aluminium, iron, nickel and often copper have been able to achieve high rates of recycling for simple, bulk products or for industrial applications that are easier to collect and more homogeneous in nature. As a result, these metals have a higher potential for continuous recycling and maintaining global stock.

Many new products such as personal electronics or alloyed materials make physical and metallurgical separation difficult. New iron and copper alloys, for example, bring superior functionalities but result in energy-intensive recycling pathways. Recycling of these products may require the physical, chemical and metallurgical separation of over 50 materials with different thermodynamic and metallurgic considerations from a single product.

Recycling technologies need to take into account current available stock and anticipate stock changes. Minerals that enter stock today may not be recoverable for decades depending on product life. Technologies must adapt to the stock life and the nature of the stock's evolving thermodynamic and metallurgical properties. While stock descriptions are moderately robust for copper, aluminium and nickel at a global level, most critical minerals lack information and description of stock at country, regional or global levels. For many energy transition minerals, stock descriptions and estimates are needed to inform policy measures to efficiently support the development of new markets (Nicolli et al, 2012).

But the potential for increased secondary supply from recycling, while challenging, is apparent. Recent analysis indicates that recovery of key minerals (copper, palladium, gold and silver) from printed circuit boards could require as little as 5% of the energy as compared to primary supply from mining (Seabra and Caldeira-Pires, 2020). In a world increasingly looking to reduce emissions, this is an important advantage. Critical to achieving these potential rates are increased collection rates, developing knowledge of global and regional stocks, market incentives, and collaboration, often beyond country borders, to encourage secondary market development. The digital revolution is also seeing its mark across recycling processes. Approaches span from the use of data analytics to track and understand global and regional metal stocks to the use of new sensors to improve physical collection and separation.

In addition to established waste streams (e.g. industrial applications), emerging waste streams from clean energy technologies (e.g. batteries, solar panels) could be a significant source of secondary supply after the 2030s, although they do not eliminate the need for continued investment in the primary supply of minerals.

Enhanced metal recovery from mining and processing waste provides additional opportunities for secondary supply

Enhanced metals recovery from mining and processing waste (e.g. mining residues, slag, sludges and tailings) provides a clear opportunity to increase supply. Better treatment of waste streams can also reduce the risk of hazardous materials entering the environment. Governments are increasingly taking notice of the opportunities to improve metal recovery from waste streams, as shown by Australia's recently announced National Manufacturing Priority roadmap (DISER, 2021) aimed at increasing the country's share of critical mineral supply.

New technologies, coupled with in-depth assessments of the potential from mining and processing waste, can help generate further supply and reduce the dependence on imported materials. For example, the Kiruna iron ore mine tailings in Sweden are estimated to contain approximately 5 000 parts per million of REEs after beneficiation and are considered a new REE resource for the European Union (Peelman et al., 2016). US scientists found that waste rock from long-closed iron ore mines in the eastern Adirondack Mountains, New York, may provide valuable REEs. This is triggering further analysis of the potential of waste rock and tailings from old mines, although there are challenges associated with the proper handling of radioactive elements (e.g. thorium) (USGS, 2020). Rio Tinto is tapping an opportunity to extract lithium from waste rocks at its Boron mine in the United States (see section on lithium). Several laboratory studies demonstrated the potential of bioleaching to recover copper, cobalt, nickel and others from mine tailings and other secondary sources (e.g. electronic waste) in Germany, Spain, Serbia, Iran, China and Uganda (Schippers et al., 2014, Zhang et al., 2020).

Similarly, stockpiled and annually produced bauxite residue can be considered a resource for extracting REEs, titanium and vanadium. In the European Union the combination of enhanced metal recovery from low-grade ores, fine grained landfilled sludges, iron-rich sludges from metal production (from zinc production) and fayalitic slag (mostly from primary and secondary copper production) could yield additional volumes of zinc, nickel, copper, cobalt and others, with a combined market value estimated at EUR 2.9 billion per year (Eurometaux, 2019).

While secondary supply from waste streams is becoming increasingly cost-competitive with primary sources (Spooren, 2020), challenges remain to be addressed such as minimising emissions from recycling processes and removing hazardous substances.

Policy intervention may be necessary to build demand for secondary supply…

In certain contexts, secondary markets for specific metals have developed in recent years even in the absence of policy support. This has occurred where market prices were high enough to encourage investment in recycling and a sizeable, readily available supply of waste stock existed. This is not currently the case for many minerals and metals that are vital for energy transitions. Barriers to further development of secondary supplies include competition from primary supply (the prices of which often do not account for negative environmental externalities), information deficits and limited waste collection (Nicolli et al, 2012; Söderholm, 2020). In these cases, a range of policy options can support the development of secondary supply markets and consequently reduce many of the environmental and social impacts associated with mining.

Support for secondary supply markets

Many countries have set overall recycling rate targets for consumer products – particularly for end-of-life vehicles and electronic waste. However, these product-specific recycling targets are less likely to encourage recycling of energy transition metals than more targeted, metal-specific policies. Weight- and volume-based metrics that are not metal-specific may allow companies to meet the targets by focusing on high-volume materials that are more readily recyclable than those found in small or trace quantities (UNEP, 2013).

Targeted policies, including minimum recycled content requirements, tradeable recycling credits and virgin material taxes all have potential to incentivise recycling and drive growth of secondary supplies (Söderholm, 2020). Alternatively, governments can consider direct subsidies for recycling. California’s Covered Electronic Waste programme, for example, charges a fee to consumers on purchases of electronics, which is used to offset the cost of recovery and recycling. Each of these policy options increases the cost of using non-recycled materials vis-à-vis secondary supplies.

While these policies can, in theory, all yield similar outcomes, their impacts may vary in practice depending on the specific market dynamics (e.g. how a certain tax level would affect prices for primary products and in turn the uptake of secondary supply in each market). It is therefore crucial for policy makers to choose policy tools based on an understanding of the specific market context in order to adequately account for the costs of negative externalities.

International co-ordination will be critical because of the global nature of metal markets. If policies designed to stimulate demand for secondary supply are enacted unilaterally, they may have unintended consequences that lead only to a geographical change in use rather than a change in market supply. In addition, collaboration between countries or regions may be needed to sufficiently understand market stock, costs and dynamics.

...and to ensure a sufficiently large waste stream to justify infrastructure investment

In addition to policies driving demand for secondary supplies, it will be important for policy makers to address other potential externalities associated with secondary supplies. They include supporting the development of collection and sorting programmes and incentivising manufacturers to develop products that are easier to recycle.

Enhanced support for collection and recycling

Economies of scale play a major role in improving the economic viability of recycling, and increasing collection and sorting rates is a crucial starting point. In this context, government policies can play a major role in facilitating waste collection. For example, although traditionally applied to drinks containers, deposit-refund schemes may have potential to increase collection rates of electronics and batteries. Denmark introduced such a system in the 1990s to increase collection of nickel-cadmium batteries (OECD, 2014). Lower-volume minerals, such as cobalt, lithium or REEs, may require collaboration across country boundaries, for example across the European Union, to drive sufficient waste streams to warrant infrastructure investment. Furthermore, concerted action may be needed to discourage waste from being exported for the purpose of avoiding recycling requirements and to ensure that products exported for secondary use are held to similar end-of-life standards in the destination country – for example, batteries contained in exported used cars.

Extended producer responsibility

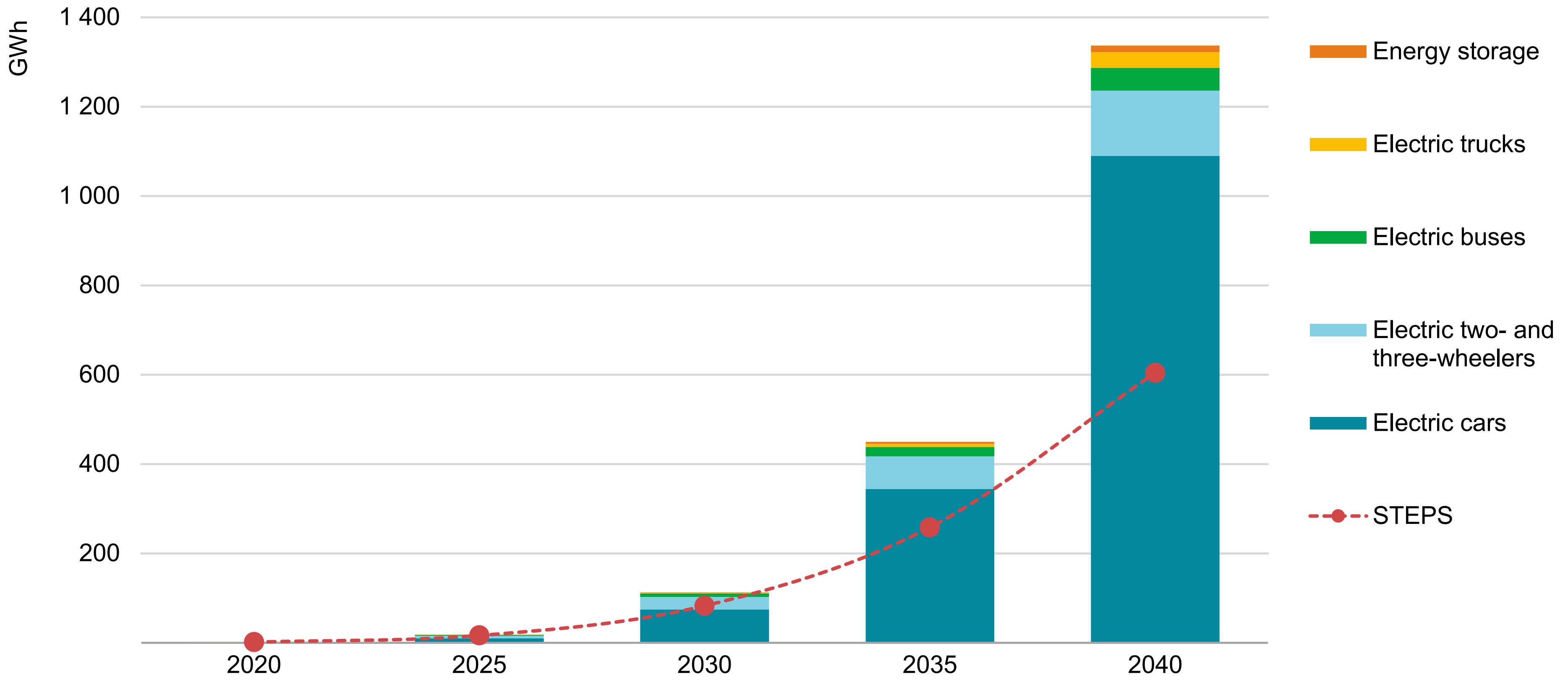
Waste collection can also be encouraged by making the manufacturer responsible for the treatment or disposal of post-consumer products. In addition to incentivising collection, this encourages manufacturers to reduce waste and to adopt product designs that facilitate recycling processes. Schemes like these have been deployed across a number of different product types, including batteries, tyres, vehicles, packaging and electronic waste. Although some extended producer responsibility schemes have led to very high recycling rates, there can be major differences in performance depending on policy design (Bio by Deloitte, 2014). Therefore, it is important that policy makers set clear definitions and objectives, apply those criteria equally to all market players, and take an active role in enforcement.

Ultimately, a mix of policies will be necessary to ensure that companies across the value chain incorporate recycling into their business activities. Depending on the market and national/regional considerations, combinations of trading credits, subsidies and other policy instruments can successfully support regional secondary supply value chains that ultimately influence global markets.

In the remainder of this section, we will consider two potential recycling cases in greater depth: batteries and electricity networks.

Battery recycling: The amount of spent EV and storage batteries reaching the end of their first life is expected to surge after 2030, reaching 1.3 TWh by 2040 in the SDS

Amount of spent lithium-ion batteries for EVs and storage by application in the SDS



Note: GWh = gigawatt hour.

Battery recycling: The battery recycling industry is in its nascent stages, but the picture is set to change significantly from 2030 as an influx of spent batteries arrives

Although the volume of lithium-ion batteries available for recycling or reuse today is modest and largely dominated by batteries in waste electronic products, the fast-paced growth of EV sales and the demand for energy storage are poised to alter this situation significantly by the end of the decade. As the share of electric cars in the total car stock grows from today's 1% to 18% in the STEPS and 50% in the SDS by 2040, an influx of spent batteries is expected to arrive in the market, and is likely to pose serious waste management challenges. For example, when all the electric cars sold in 2019 reach the end of their lifetime, this would result in 500 000 tonnes of unprocessed battery pack waste (Harper et al., 2019).

The total amount of spent batteries from EV and storage applications is under 2 GWh today. Under the *WEO 2020* EV and energy storage deployment trajectories, the volume reaching the end of their first life rises modestly over the period to 2030 to the tune of 100 GWh, and grows rapidly thereafter to reach 600 GWh in the STEPS and over 1.3 TWh in the SDS by 2040. This represents over 20% of new battery requirements in that year. At over 80%, the majority of these spent batteries under the SDS in 2040 come from electric cars, while over 10% will be from electric two- and three-wheelers, more than 5% from buses and trucks, and just over 1% or about 15 GWh from the energy storage domain.

There are two main ways to deal with the stream of spent lithium-ion batteries – recycling and reuse. The first route involves recycling the used batteries to recover the valuable minerals like cobalt, lithium and nickel. This approach has several advantages. Recycling materials can curb the volatility of the supply chain and prices of raw materials for battery manufacturing, and can therefore play a pivotal role in alleviating the energy security concerns of countries that are heavily dependent on imports of these minerals.

It could also reduce the environmental, social and health impacts arising from mining large quantities of these minerals that are needed to meet the expanding demand for batteries. Further benefits of recycling include reducing the energy used for and emissions from the production of lithium-ion cells. Argonne National Laboratory found that the use of recycled materials reduces both (Gaines et al., 2018). The study reported that the most sizeable reductions in energy use come from the recovery of the metals, whose initial extraction from low-concentration ores is very energy-intensive. Additionally, sulfur dioxide emissions arising from cobalt, nickel and copper develoments can be reduced by 65% to 90% depending on the recycling process employed.

Battery recycling: The projected surge in spent volumes suggests immense scope for recycling

Several methods for recycling lithium-ion batteries are currently in use either commercially or at the pilot level. Before being recycled, battery packs must be first discharged, stabilised and then dismantled to at least the module level. Once discharged, the cell components can be separated into different material streams for further processing. Three broad categories of techniques, either employed alone or in combination, are currently used for battery recycling. These are mechanical pretreatment, pyrometallurgical processes and hydrometallurgical processes.

Mechanical pretreatment primarily involves shredding and sorting plastic fluff from metal-enriched liquid and metal solids. However, it must be combined with other methods (usually with hydrometallurgy) to recover most cathode materials, other than copper, aluminium and steel casings. Few companies focus on this process: they include AkkuSer (Finland), Retriev Technologies (United States) and Li-cycle (Canada).

Pyrometallurgical recovery uses high-temperature smelting to reduce the component to an alloy of cobalt, nickel and copper. It is a frequently used method to extract valuable metals such as cobalt and nickel, despite its environmental drawbacks (such as the production of toxic gases) and high energy costs. Hydrometallurgical recovery uses aqueous solutions to leach metals from the cathode. This could be followed by solvent extraction and/or chemical precipitation to recover lithium, nickel and cobalt. Umicore (Belgium) and JX Nippon Mining and Metals (Japan) are some of the representative companies that use both pyrometallurgical and hydrometallurgical technology, while Brunp (China) and Valdi (France) use mechanical and hydrometallurgical technology.

Additionally, an emerging recycling method known as direct recycling removes the cathode or anode from the electrode for reconditioning and reuse in a remanufactured lithium-ion battery without breaking them down into individual materials elements. Although this has the major benefit of avoiding long and expensive purification steps, there is a limitation that recovered cathodes can only be used for the manufacturing of the same battery type (Northvolt, 2019; IEA, 2020; Harper et al., 2019).

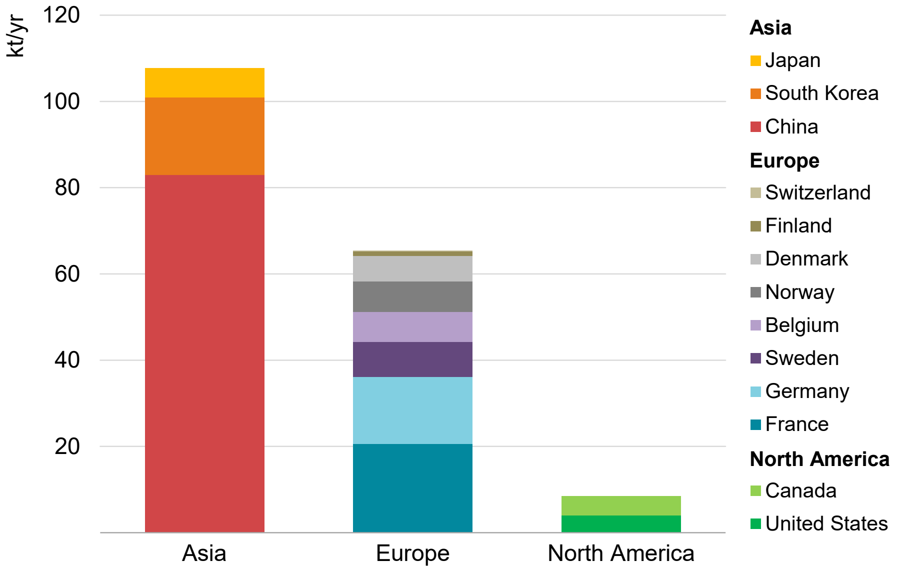
Currently, the global capacity for battery recycling is around 180 kilotonnes per year (kt/yr). China accounts for almost 50% of this capacity and it is expected to retain its dominant position given the large amount of additional capacity it has announced, amounting to 1 000 kt/y (BloombergNEF, 2019). Most of the companies involved today are independent refiners, but a broad spectrum of players from battery manufacturers, original equipment manufacturers, miners and processors are beginning to show interest in entering the market, especially in Europe.

Battery recycling: The reuse of EV batteries for second-life applications offers additional scope for reducing primary supply requirements

A complementary measure to recycling is the reuse of the rapidly growing pool of EV batteries for “second-life” applications. Spent EV batteries tend to have terawatt hours of unused energy that no longer meet the standards for usage in an EV, although they typically maintain up to 80% of their total usable capacity (IEA, 2020). Repurposing used EV batteries could generate significant value and ultimately help bring down the cost of EV charging stations, residential and even utility-scale energy storage to enable further penetration of renewable power into electricity grids. Initial trials for second-life batteries have already begun. For example, in January 2020 Nissan Motor Co. and American Electric Power launched a pilot study in Ohio that reuses expired Nissan Leaf batteries to test their stationary storage characteristics. BMW introduced a plan to sell stationary storage products for peak load reduction and backup power storage in homes by reusing batteries from the i3 EV model.

However, a number of technological and regulatory challenges remain for second-life applications to grow at scale. Chief among them is their ability to compete on price given the rapidly falling cost of new systems. Retired batteries need to undergo costly refurbishing processes to be used in new applications, and a lack of transparency regarding the state of used batteries (e.g. storage condition, remaining capacity) further complicates the economics. Clear guidance on repackaging, certification, standardisation and warranty liability of used EV batteries would be needed to overcome these challenges.

Existing and announced lithium-ion battery recycling capacity to come online by 2021 by region



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Sources: IEA analysis based on company announcements, press research and Swedish Energy Agency (2019).

Battery recycling: Scaling up battery recycling needs to overcome various technological and commercial challenges

While many companies are active or showing interest in the field, lithium-ion battery recycling has yet to reach the maturity of technology needed to scale up sufficiently and become economically profitable. The commercial viability of recycling depends on the costs of collecting and disassembling the batteries, as well as the value of the materials recycled. Unlike the lead-acid battery recycling industry, which is already mature, the lithium-ion battery recycling industry still needs to address several challenges in order to reach scale and profitability. Some of these are technical constraints, and others involve economics, logistics and a lack of streamlined policies.

Although some companies and organisations collect spent batteries, there are no comprehensive systems that dictate and guide the material collection processes at a national level in most countries. In 2006 the Battery Directive proposed by the European Union was an important step in this direction, but not all members have reached the mandated collection targets and the directive did not include specific targets for each mineral present in spent EV batteries. In December 2020, the European Commission proposed a new Batteries Regulation as an update to the older directive, which placed a particular emphasis on lithium-ion batteries. The proposed new regulation suggests mandatory sustainability and safety requirements (e.g. carbon footprint rules, minimum recycled content, labelling and information) and end-of-life management obligations (e.g. producer responsibility, collection targets and obligations, recycling efficiency targets) (see Box 3.5).

Specific guidelines or regulations for discharging, disassembling and storing spent batteries are also lacking in most countries. China is one of the few with some technical guidelines on dismantling and restoring spent EV batteries, and retraining staff at carmakers (MIIT, 2018).

Transport logistics for end-of-life lithium-ion batteries pose another challenge. The high energy density of their cells, coupled with the presence of flammable organic electrolytes, creates a risk of thermal runaway. This requires more stringent safety measures to handle and transport spent EV battery packs.

Technology bottlenecks include the lack of standardisation of designs for battery packs, modules and cells. Different vehicle manufacturers have adopted different battery chemistries, especially for the cathode, and they tend not to disclose information on their cell designs and chemistries. This wide variety of cell types and chemistries in the market poses a major challenge to recycling, and especially to the automation of recycling processes, as each battery pack and module type requires different approaches for disassembly.

Battery recycling: Policy can play a pivotal role in preparing for the exponential growth in volumes of waste EV and storage batteries

While there is no standard policy framework that governs the end-of-life management of lithium-ion batteries globally, several policies have been announced, mainly in the European Union, China, Japan and at a state level in the United States. Recent progress also includes the founding of the Global Battery Alliance in 2017, which aims to establish a sustainable battery value chain, from sourcing, to repurposing and recycling.

Policy makers can consider three specific actions: (i) facilitating the efficient collection and transport of spent batteries; (ii) fostering product design and labelling that help streamline the recycling process; and (iii) harmonising regulations on international movement of batteries.

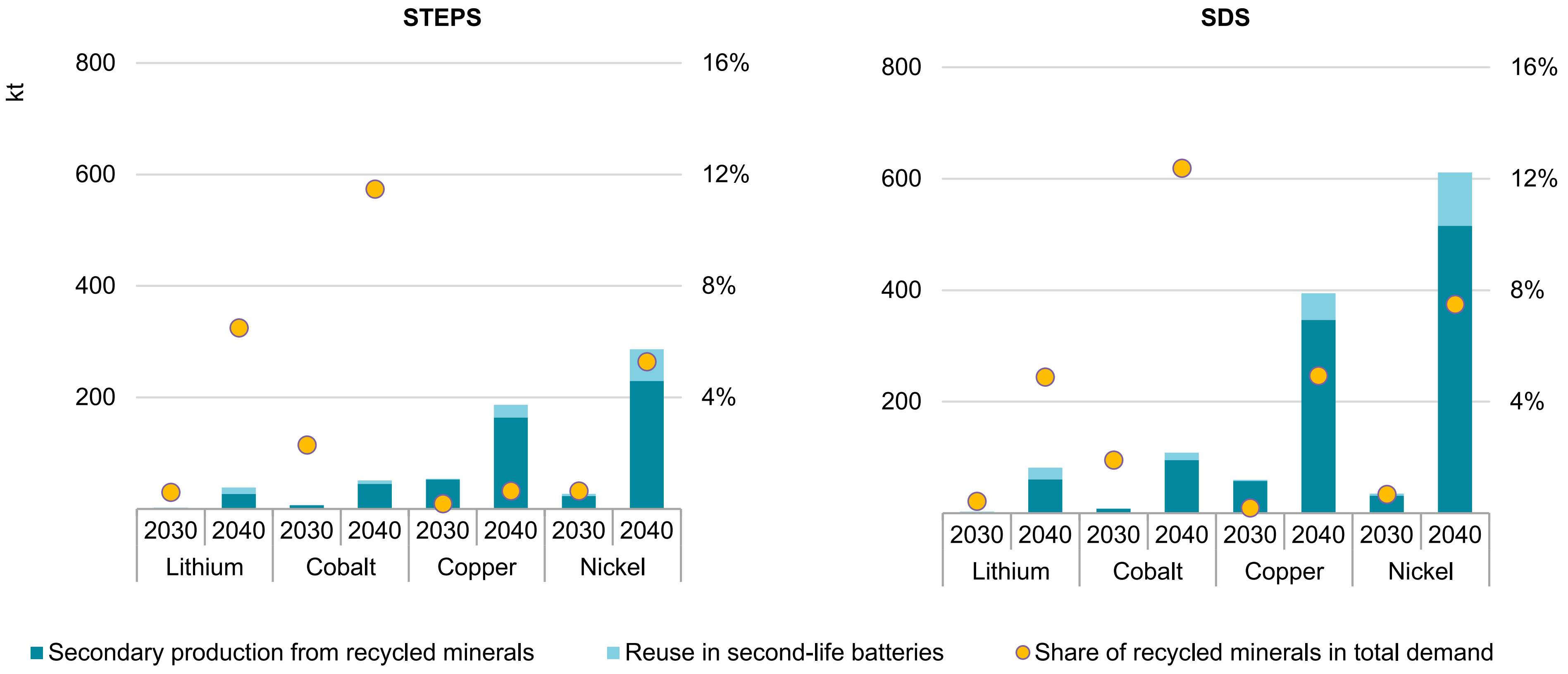
Firstly, clear guidance on collection, transport and storage of end-of-life lithium-ion batteries is crucial. Policies enabling the exchange of data between key stakeholders in the process, including original equipment manufacturers, will be necessary. For example, BMW, Umicore and Northvolt have recently embarked on a joint project that aims to create a “closed life cycle loop” for battery cells. In this technology consortium, the EV maker (BMW) collects and deposits its end-of-life batteries directly at the recycler (Umicore), then the recycler uses the recovered material to produce active cathode material. This material is then shipped to the cell maker (Northvolt), which closes the loop by supplying batteries to the OEM (Umicore, 2018).

Secondly, early action in the product engineering and design phase can help facilitate an efficient recycling process. The current design of battery packs is not optimised for easy disassembly. A more standardised battery design with recycling in mind will allow easier dismantling and automation. Measures such as including labels or QR codes on battery cells or battery packs, with information on the battery components, chemistries and substructures, would not only help streamline the recycling process, but also enhance safety by better preventing fire hazards and explosions during battery disassembly and smelting (SAE International, 2016; USABC, 2014).

Lastly, concerted regulatory action across countries to ensure the safe, eco-friendly and affordable transport of batteries is essential. The Global Battery Alliance has launched the concept of a “battery passport,” which is a digital representation of a battery that contains information about all applicable lifecycle requirements of a sustainable battery, making it easier to identify and track batteries throughout their lifecycle. This could not only support data sharing on battery chemistries, origin and the state-of-health of spent batteries, but also help countries harmonise their regulatory actions on transboundary movement of spent lithium-ion batteries (WEF, 2020).

Battery recycling: By 2040 recycling and reuse of EV and storage batteries could reduce the primary supply requirement for minerals by up to 12%

Contribution of recycling and reuse of batteries to reducing primary supply requirement for selected minerals by scenario



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Battery recycling: Recycling and reuse of batteries can bring significant security and environmental benefits, although the need for continued investment in primary supply remains

We analysed the possible contributions from recycling and reuse of spent batteries to reducing primary supply requirements for lithium, nickel, cobalt and copper under base-case chemistry assumptions. Key inputs to the model are the lifetime of the different batteries, the battery collection rate, the yield rate for each mineral, the reuse rate and the reuse efficiency. We assumed the collection rate to increase gradually to 80% by 2040, and the yield rate to vary according to the technical limitations for the extraction of each mineral using the currently available recycling methods. The reuse rates are much lower than the collection rate for recycling as the use of second-life batteries faces many technical and regulatory obstacles.

The recycled mineral volumes are negligible in the 2020s, but they start to make larger contributions to the total supply from 2030 and become much more significant by 2040. While recycling and reuse assumptions are identical in the STEPS and the SDS, the higher absolute deployment of EV and storage in the SDS makes the contribution of the recycled minerals far more sizeable than under the STEPS.

In the SDS, recycled quantities of nickel, copper, cobalt and lithium from spent EV and storage batteries in 2040 are around 500 kt, 350 kt, 100 kt and 60 kt respectively. By 2040 secondary production from recycled minerals accounts for up to 12% of total supply requirements for cobalt, around 7% for nickel, and 5% for lithium and copper. The projected contribution of reused batteries is relatively smaller, reaching only 1-2% of total supply requirements for each mineral in 2040.

This implies that the recycling of end-of-life lithium-ion batteries to recover the valuable minerals, and to a smaller extent their reuse as second-life batteries, can relieve a proportion of the burden from mining them from virgin ores. Although this does not eliminate the need for continued investment in primary supply of minerals, the contributions from recycled minerals could be even more prominent in the total supply if effective recycling policies are adopted more widely across the globe, with larger benefits particularly for the regions with higher EV deployment.

Box 3.5. EU Sustainable Batteries Regulation

In line with the European Union's circular economy and European Battery Alliance objectives, the proposed regulation addresses the social, economic and environmental issues related to all types of batteries, including those imported into the bloc. The proposal covers the entire battery life cycle, and directly applies to lithium, cobalt, nickel and copper supply chains. The shift from a directive to a regulation is aimed at increasing harmonisation and legal certainty by giving the instrument binding legal force in all member states. The Commission states that the regulation sets out "mandatory requirements for the greenest, safest and most sustainable batteries on this planet" (EURACTIV, 2020). It is scheduled to enter into force on 1 January 2022.

Proposals for mandatory requirements range from sustainability and safety, end-of-life management, labelling, electronic exchange of information and digital passports. The aim is to enhance separate collection of portable batteries to achieve 70% collection by 2030, against less than 50% in 2018 (EUROSTAT, 2020) and prohibit any landfilling. It also places obligations on economic operators for product requirements and supply chain due diligence. The OECD Due Diligence Guidance is incorporated into the legal instrument, ensuring that sustainable batteries do not come at the expense of responsible and sustainable supply chains (see Box 4.8).

The regulation's general objective is to mitigate the environmental impact of batteries and their effects on climate change and public health by controlling toxic substances and mandating waste management. As part of the EU Sustainable and Smart Mobility Initiative, it aims to facilitate the transition to cleaner mobility by contributing to a 90% reduction in transport-related GHG emissions by 2050. The deployment of clean batteries reduces GHG emissions while improving air quality. The proposal sets out minimum levels of recycled content (12% cobalt, 4% lithium and 4% nickel by 2030) and material recovery (90% cobalt, 90% copper, 35% lithium and 90% nickel by 2026) which will gradually increase. Batteries sold in the European Union will have to carry a carbon intensity performance label and comply with carbon footprint thresholds. The carbon footprint, recycled content and responsible sourcing will be verified by recognised third-party entities. The Commission is supporting research on batteries in line with these objectives, in particular through H2020 projects receiving approximately EUR 500 million (European Commission, 2020b).

The regulation is a critical step towards achieving both clean mobility and high penetration of renewables, ensuring a fully circular economic model. By facilitating a market for recycled products and waste, it lays the groundwork for sustainable minerals development.

Grid recycling: Unlocking copper and aluminium from today's electricity networks

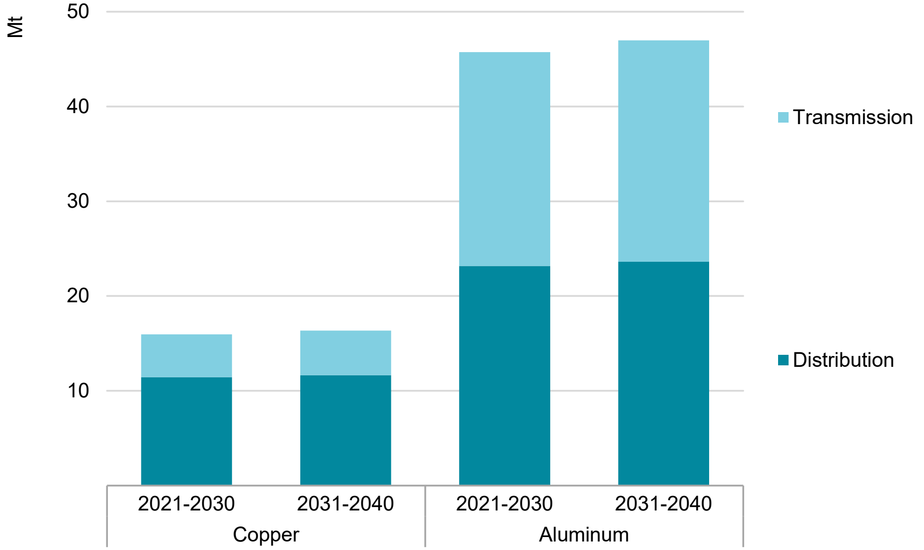
Transmission and distribution systems contain a large amount of "locked-in" copper and aluminium. Analysis of the globally installed base of overhead lines, underground cables and transformers suggests that 150 Mt of copper and over 220 Mt of aluminium are present in these grids today. These volumes are roughly seven times higher than current annual copper demand and three times higher than that for aluminium. With current technologies, the locked-in volume is projected to grow by almost 60% in the STEPS and some 75% in the SDS by 2040. When efficient collection and processing operations are put in place, these volumes can provide a sizeable source of supply to the market, via recycling or reuse.

Overhead lines, undergound cables and transformers in electricity grids have usually a design lifetime of around 40-60 years. After this period, these assets need to be replaced. The displaced grid assets can then be reused in a semi-fabricated form or the locked-in copper and alumimium can be recycled. Over 60 Mt of aluminium and copper attached to grid infrastructure needs to be replaced by 2030 and a similar amount between 2031 and 2040.

High end-of-life recycling rates are essential to reduce primary supply requirements for grid expansion and replacement. Copper has a high end-of-life recycling rate: current estimates of copper recycling from electricity grid infrastructure are around 60% (higher than the average copper recycling rates). But the potential end-of-life recycling rate of copper is over 85% (Henckens, 2021). Achieving this would reduce primary copper supply requirements by over 9 Mt in 2040 in the SDS.

Aluminium has a global recycling rate of around 40% (UNEP, 2011). The potential end-of-life recycling rate of aluminium is estimated to be around 75% (IAI, 2020). Achieving this would reduce primary supply requirements by around 32.5 Mt in 2040 in the SDS.

Copper and aluminium demand for grid replacement



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Sustainable and responsible development of minerals

Failure to manage environmental and social impacts from minerals development will slow clean energy transitions

The growth of mineral supply not only plays a vital role in enabling clean energy transitions, but also holds great promise to lift some of the world's poorest people out of poverty. Mineral wealth can, if exploited responsibly, contribute to public revenue and provide economic livelihoods for many. However, if poorly managed, mineral development can lead to a myriad of negative consequences, including:

- Significant greenhouse gas (GHG) emissions arising from energy-intensive mining and processing activities.
- Environmental impacts, including biodiversity loss and social disruption due to land use change, water depletion and pollution, waste-related contamination and air pollution.
- Social impacts stemming from corruption and misuse of government resources, fatalities and injuries to workers and members of the public, human rights abuses including child labour and unequal impacts on women and girls.

In addition, these risks may lead to supply disruption, which could slow the pace of clean energy transitions. It is therefore imperative for both companies and governments to manage the environmental and social impacts of mineral production.

Companies have a clear business case to address these harms to reduce risk and maintain a social licence to operate. Consumers and investors are increasingly demanding that companies take these issues seriously. Failure to respond to these social demands could not only undermine reputation, but also lead to difficulties in raising capital or even to legal liability.

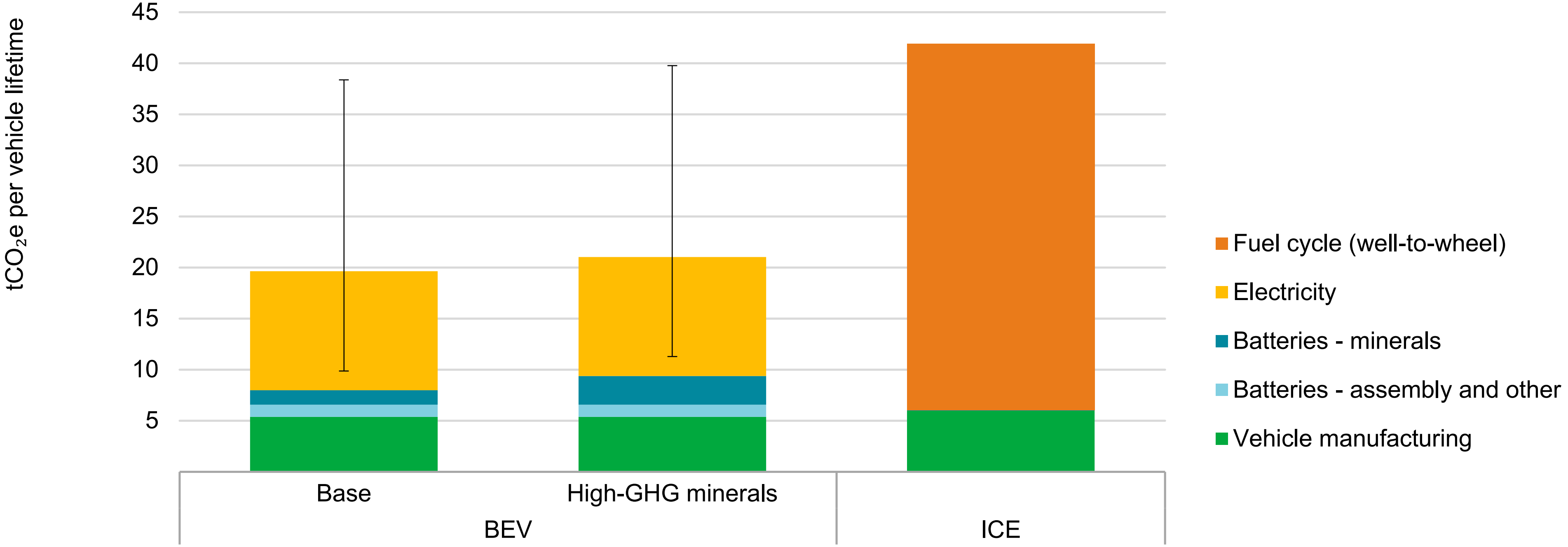
Companies have increasingly implemented responsible practices over the years. The adoption of corporate responsibility policies and processes at company level and via industry-wide initiatives has led to improvements throughout mineral supply chains. However, performance varies significantly among industry actors, with some segments showing limited effort and more progress being needed across the board. Challenges are more substantial where regulatory safeguards are inadequate, and where systemic issues such as labour informality, weak fiscal capacity and high inequalities are persistent, such as in artisanal and small-scale mining (ASM).

Governments play an important role in promoting improvements in environmental and social performance. As supply chains become more global, international co-operation to apply appropriate standards will be critical to ensuring that the extraction and trade of minerals are carried out sustainably and responsibly, and that the supply of energy transition minerals remains uninterrupted.

Mineral development and climate change

Emissions from minerals development do not negate the climate advantages of clean energy technologies

Comparative life-cycle GHG emissions of a mid-size BEV and ICE vehicle



Notes: The "High-GHG minerals" case assumes double the GHG emissions intensity for battery minerals (70 kg CO_2-eq/kWh compared to 35 kg CO_2-eq/kWh in the base case; other assumptions are the same). The values are for a vehicle manufactured from today's manufacturing lines assuming dynamic global average grid carbon intensity in the SDS (including transmission, distribution and charging losses, weighted for mileage decay over a 20-year lifetime). The ranges shown for BEV represent cases for charging with a static low-carbon (50 g CO_2-eq/kWh) and high-carbon electricity mix (800 g CO_2-eq/kWh). Vehicle assumptions: 200 000 km lifetime mileage; ICE fuel economy 6.8 Lge/100 km; BEV fuel economy 0.19 kWh/km; BEV battery 40 kWh NMC622. BEV = battery electric vehicle; ICE = internal combustion engine; NMC622 = nickel manganese cobalt in a 6:2:2 ratio; g CO_2-eq = gramme of CO_2-equivalent; kg CO_2-eq = kilogramme of CO_2-equivalent; tCO_2-eq = tonne of CO_2-equivalent; km = kilometre; kWh = kilowatt hour; Lge = litre of gasoline-equivalent.

Sources: IEA analysis based on IEA (2020a); Kelly et al. (2020); Argonne National Laboratory (2020).