Sustainability and Second Life:

The case for cobalt and lithium recycling

IISD
International Institute for Sustainable Development

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Written by Clare Church and Laurin Wuennenberg

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Executive Summary

To support the transition to a low-carbon economy, governments, businesses and consumers around the world are investing considerable amounts in renewable energy technologies, including electric vehicles (EVs), solar panels and wind turbines. Cobalt and lithium are central to the development and deployments of these technologies—largely due to their use in lithium-ion batteries—and as such, the demand for both minerals has and is predicted to increase substantially. The supplies of both minerals, however, is not projected to meet the demand, with shortfalls expected in the coming decade. Concerns along the supply chains of both minerals—including the potential use of child labour in cobalt extraction and the intensive use of water and energy in lithium production—place additional strain on the responsible sourcing of both.

The circular economy entails "gradually decoupling economic activity from the consumption of finite resources, and designing [permanent] waste out of the system." Cobalt and lithium recycling, as part of the circular economy, offers a solution to overcome these supply chain issues by extracting metals and minerals from products and infrastructure no longer in use. Moreover, increased mineral recycling could contribute to the commitments set out by the Paris Agreement and the 2030 Agenda for Sustainable Development.

Despite these advantages, current recycling rates for cobalt are relatively low, while those for lithium are historically insignificant. Through desk-based research, case study analysis and consultations with mineral recycling stakeholders and businesses, this report explores the potential of cobalt and lithium recycling. It examines existing and perceived barriers to mineral recycling, answering why current recycling rates for cobalt and lithium are so low. It follows by identifying opportunities and solutions along the supply chains of both minerals to increase recycling. This is justified within the context of the circular economy and the Sustainable Development Goals (SDGs).

Key Findings

- Increased mineral recycling could fulfill some of the goals of the circular economy by reducing reliance on finite resources and mitigating permanent waste disposal. It could also directly contribute to SDGs 7, 8, 9, 12, 13, and 16, among others.
- Many of the barriers that exist to cobalt and lithium recycling originate in the primary supply chain. These challenges may include conflict or corruption at extraction sites, raw material price fluctuations, design of the product without consideration of second-life uses and the hibernation of electronics.
- Inefficient collection infrastructure, technological and safety concerns, and transparency issues regarding secondary processes may also act as barriers to the increased recycling of cobalt and lithium. Moreover, the stockpiles of end-of-life products containing cobalt and lithium may not be large or homogenous enough to mandate investments in more efficient collection infrastructure and recycling technologies.
- Lithium-ion battery recycling processes on the market today do not recover the lithium, and instead tend to retrieve only the cobalt or nickel therein. Many actors do not deem lithium recovery economically viable.
- Increased collaboration is required between the public sector, private actors and civil society to overcome market and regulatory barriers. This coordination is essential to ensure that new or revised investments and regulations are reflective of the changing needs of the recycling industry.
- In particular, efforts should be made by the public sector to develop and understand applicable definitions of recycling and other secondary processes, clearly designate the actors responsible and liable for recycling materials, communicate these regulations to businesses and consumers, and evaluate the risks and benefits of mineral recycling using multiple values.

Recycling has long been a central tenet of circular business models and sustainable development. But its adoption in the mining sector has not been widespread or comprehensive. It is paramount that recycling be incorporated into metal and mineral supply chains—and especially those of cobalt and lithium—in order to ensure a responsible, sustainable and stable transition to a low-carbon economy.

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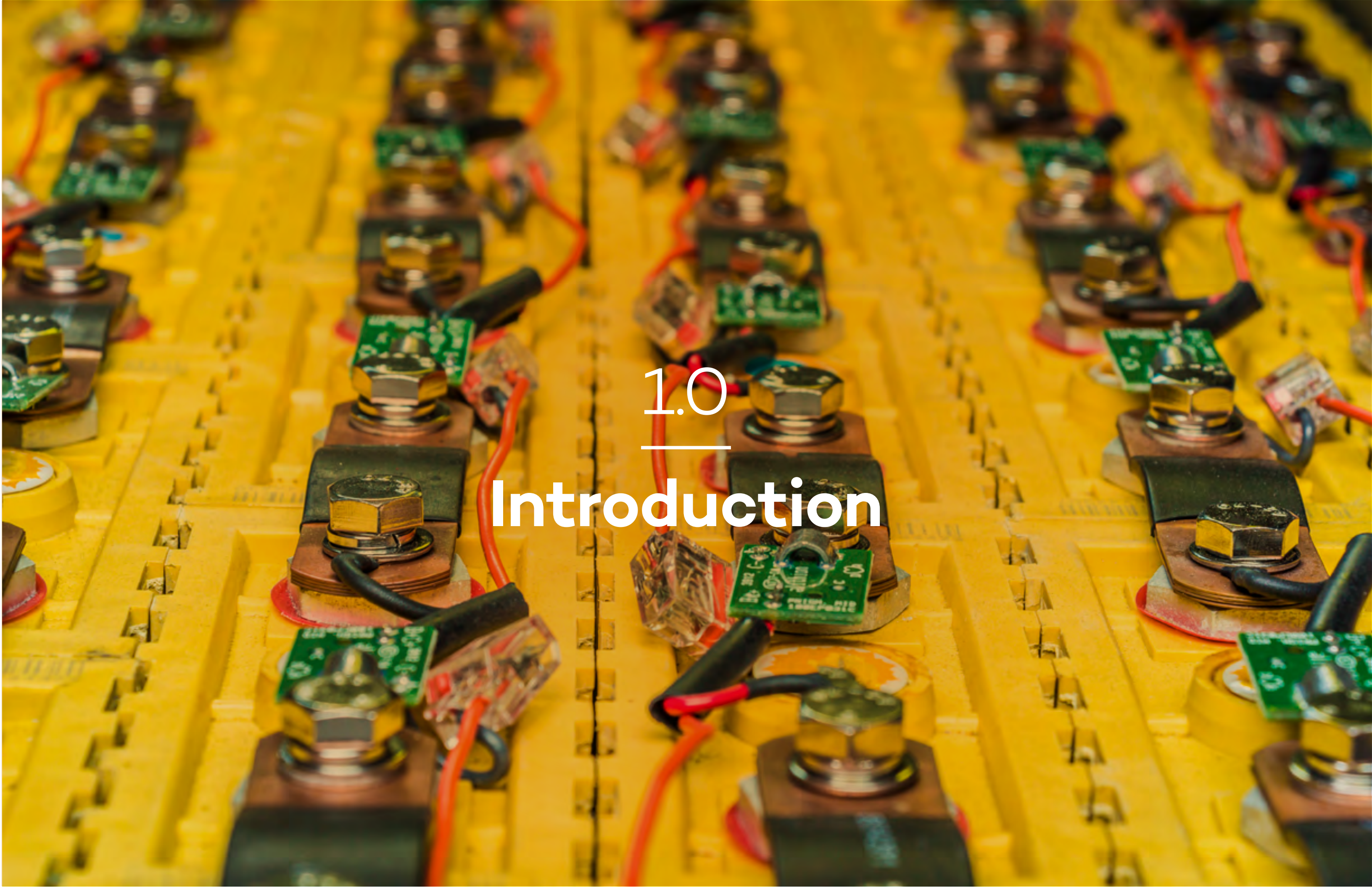
Acronyms and Abbreviations

CCME	Canadian Council of Ministers of the Environment
DRC	Democratic Republic of Congo
EPR	Extended Producer Responsibility
EU	European Union
EV	electric vehicle
E-Waste	electronic waste
OECD	Organisation for Economic Co-operation and Development
R&D	research and development
SAVi	Sustainable Asset Valuation
SDG	Sustainable Development Goal
UN	United Nations
WEEE	Waste of Electrical and Electronic Equipment



1.0

Introduction

Key Messages:

- To support the transition to a low-carbon economy, governments, businesses and consumers around the world are investing considerable amounts in renewable energy technologies—including wind turbines, solar panels, and electric vehicles.
- Lithium and cobalt are central to the development and deployment of renewable energy technologies. Estimates project, however, that both will experience supply shortages in the coming decades.
- Mineral recycling, as part of the circular economy, has the potential to overcome these shortages and other supply chain challenges by extracting metals and minerals from products and infrastructure no longer in use.

Renewable energy technologies—including wind turbines, solar panels, and electric vehicles (EVs)—are a necessary part of a sustainable future. The UN's Sustainable Development Goals (SDGs), adopted by the UN General Assembly in 2015, stress the importance of these technologies; Goal 7 calls for Affordable and Clean Energy, aiming to increase substantially the global share of renewable energy by 2030 (United Nations, 2018). To meet the Paris Climate Agreement's target of keeping global temperature rise below 2ºC, climate change mitigation actions will need to be scaled up and reliance on fossil fuels reduced.

"Mineral recycling, as part of the circular economy, has the potential to overcome these supply chain issues by extracting metals and minerals from products and infrastructure no longer in use."

To support this transition, governments, businesses and consumers around the world are investing considerable amounts in renewable energy technologies, rapidly growing these markets and increasing demand for their inputs. France has stated it will end the sale of gas and diesel vehicles by 2040, while the United Kingdom has pledged that half of all new cars will be hybrid or electric by 2030 (Chrisafis & Vaughan, 2017; Hook, Pickard, & Raval, 2018). EVs are expected to make up 55 per cent of all new cars and 33 per cent of the global fleet by 2040, with the Chinese market leading the way (BloombergNEF, 2018). In Norway, more than 28 per cent of vehicle sales are EVs (Clean Energy Canada, 2017). Countries including the Netherlands, Sweden, France and the United Kingdom are also beginning to see increased consumer purchases of EVs. And while EVs have less impact on the environment than traditional combustion engines, the upsurge in EV purchases will place increasing demand on mineral supply chains, most notably those of lithium, nickel, cobalt, manganese, aluminum and steel.

Lithium-ion batteries dominate the EV market, due to their excellent energy-to-weight ratio and increasingly attractive price (Arrobas, Hund, McCormick, Ningthoujam, & Drexhage, 2017).[1] Lithium-ion batteries have a number of uses beyond EVs; they are widely used in consumer electronics like laptops and smartphones, and can effectively store energy from intermittent sources like wind and solar for later use. As demand for these batteries has increased, so has demand for both cobalt and lithium, minerals critical to the development of renewable energy and digitization, failing considerable substitution (Draper, 2019; NetworkNewsWire, 2017).[2] Between 2017 and 2025, cobalt and lithium carbonate demand is expected to increase by more than 60 and 300 per cent, respectively, driven largely by growth in the EV market (Azevedo, et al., 2018; Draper, 2019). The

[1] Specifically, lithium cobalt oxide batteries lead the EV market, but other compositions include lithium nickel manganese cobalt oxide, lithium nickel cobalt aluminum oxide, lithium iron phosphate, lithium titanite, and lithium manganese oxides (Levin Sources, 2017; Synergy Files, 2016).

[2] Lithium is also used in armour plating, glasses and glass ceramics, and medicine. Cobalt is also used commonly in alloys, electroplating, and nutrition (Rowan, 2017; Royal Society of Chemistry, 2019).

supply of both minerals, however, may not be able to meet this demand, with shortfalls expected in the coming decade (Greenwood, 2018; Holmes, 2018). Concerns along the supply chains of both minerals—including the potential use of child labour, conflict, and corruption in the extraction of cobalt and the intensive use of water and lack of community consultation in the extraction of lithium, among others—place an additional strain on the security of these supplies.

The circular economy may offer a solution to these market challenges. It entails "gradually decoupling economic activity from the consumption of finite resources, and designing [permanent] waste out of the system" (Ellen MacArthur Foundation, 2017). Mineral recycling, as part of the circular economy, has the potential to overcome these supply chain issues by extracting metals and minerals from products and infrastructure no longer in use. As a growing number of EVs and electronics reach the end of their first life, increased mineral recycling can address these supply shortfalls on a global scale. Despite these advantages, current recycling rates for cobalt are relatively low, while those for lithium are historically insignificant (U.S. Geological Survey, 2018). And while battery recycling for cobalt extraction is projected to increase significantly by 2035, additional investments and more comprehensive regulation will be required (Ribeiro, Kinch, Zhang, Franke, & Goldenberg, 2018).

This report examines the potential role of the lithium and cobalt recycling within the context of the circular economy and the SDGs. It builds on extensive desk-based research, case studies and findings from consultations with mineral recycling stakeholders and businesses. The research highlights the existing and perceived barriers to the increased use of recycled minerals in the economy, and identifies interventions and opportunities to overcome these barriers.

Section 2 provides the context to lithium and cobalt recycling, highlighting its background, importance and significance to the circular economy and the SDGs. Sections 3 elaborates on the existing and perceived obstacles to lithium and cobalt recycling, as articulated by various stakeholders and case studies. Section 4 expands on these obstacles, highlighting potential interventions to overcome these barriers and increase lithium and cobalt recycling. Section 5 offers conclusions.

2.0

The Context for Lithium and Cobalt Recycling

Key Messages:

- Mineral recycling plays an active role in the global supply chain, with approximately 400 million tonnes of metals recycled worldwide every year.
- Recycling rates for lithium and cobalt, however, are low: for lithium-ion batteries specifically, an increasingly major use for the two minerals, less than 5 per cent are recycled at their end of life.
- Increased lithium and cobalt recycling can contribute to both the circular economy agenda and the UN Sustainable Development Goals (SDGs), most directly impacting goals 7, 8, 9, 12, 13 and 16.

2.1 Background and Terminology

In a simplified mineral supply chain, a given mineral moves along the following points before it reaches the end of its first life: mineral extraction (mining), trading, smelting, refining, manufacturing, sales, and then finally, use by the end consumer. Mineral supply chains can be more complex, with considerably more steps and actors along the process. Regardless of their complexity, however, many metals and minerals end up as permanent waste—oftentimes exported to developing countries—once the consumer is finished using the product (McVeigh, 2018; Vidal, 2013). The circular economy, if widely adopted, could challenge this model, as products are repurposed for secondary (or post-first-life) use. Instead of treating the used products as permanent waste, mineral recycling in a circular economy model involves collecting products containing valuable minerals, sending them to processors, metal recovery specialists and manufacturers and then reaching end users as new products (see Figure 1). Minerals can also enter post-first-life uses through reuse or remanufacturing. Reuse refers to using a product again for either its original purpose or one similar without significant modification. Remanufacturing refers to the process of retrieving the individual components of a product and restoring them to as-new condition (World Steel Association, 2016; Kampker, et al., 2016). Under these models, valuable minerals avoid permanent waste disposal and remain an active part of the world economy.

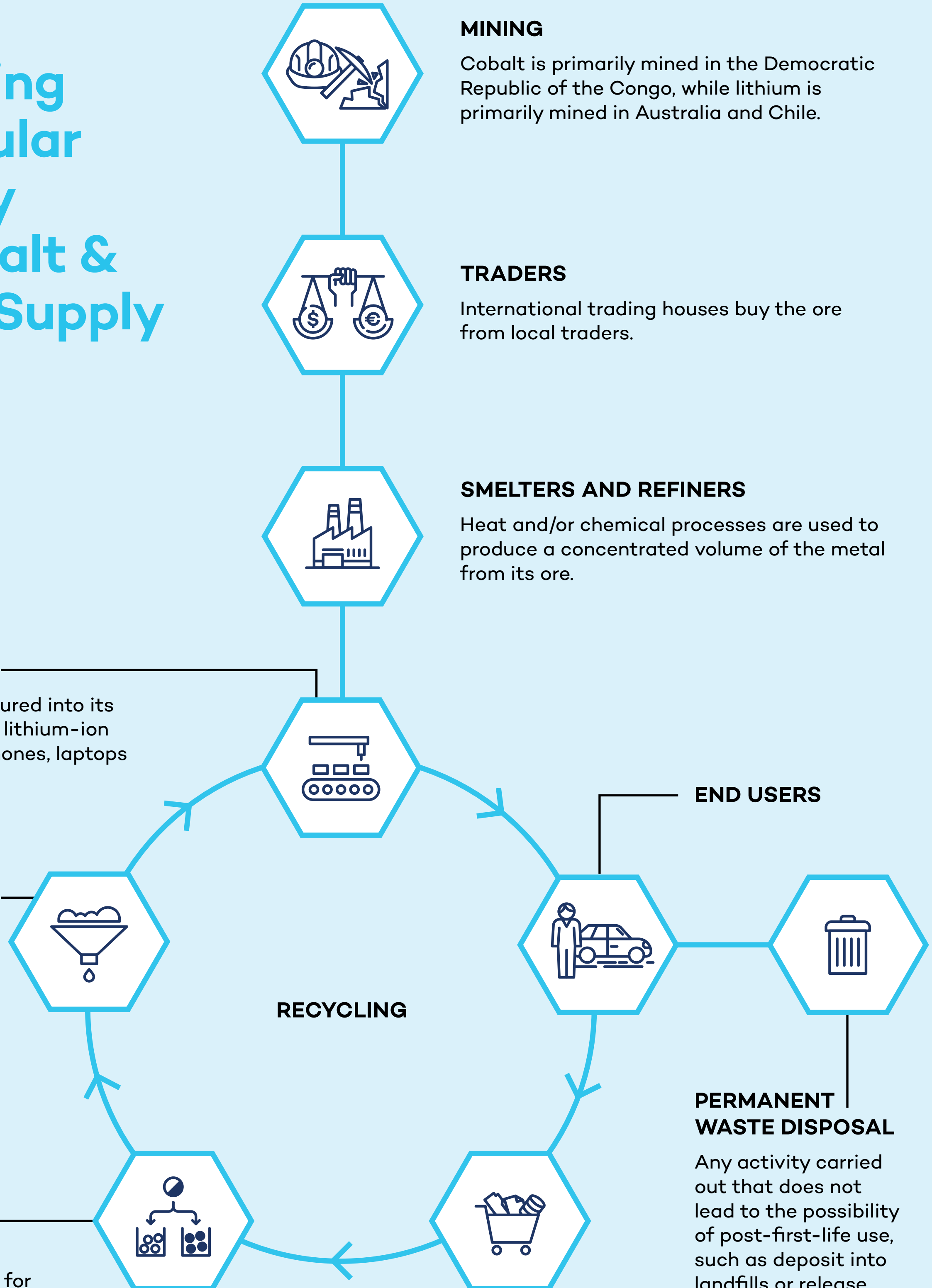
"Mineral recycling already plays an active role in global supply chains. Approximately 400 million tonnes of metal are recycled worldwide every year."

Mineral recycling already plays an active role in global supply chains (for more on how these processes are governed, refer to Box 2 and/or Annex 1). Approximately 400 million tonnes of metal are recycled worldwide every year: in the United States alone, recycling provides approximately 40 to 50 per cent of the national metal supply (LeBlanc, 2018; Mandler, 2017). The main sources of current mineral recycling are post-consumer products and scrap from manufacturing processes (Mandler, 2017). Scrap from the automobile sector, for example, accounted for 106 per cent of the United States' iron and steel scrap supply in 2014, demonstrating that the steel industry recycled more metal than it produced domestically (U.S. Geological Survey, 2018). In addition, approximately 99 per cent of lead-based car batteries are collected and recycled in North America and Europe, making them the most recycled of any major consumer product (Binks, 2015; Gaines, 2014).

The same rates do not apply to lithium-ion battery recycling, or even lithium and cobalt recycling in general. Less than 5 per cent of lithium-ion end-of-life batteries are recycled today (Li-Cycle Corp., 2018). For lithium in general, recycling rates have been deemed "historically insignificant" by the US Geological Survey (U.S. Geological Survey, 2018). Despite projected shortages in lithium supply, forecasts suggest that the recycling infrastructure required to increase lithium recycling rates remains insufficient and will continue to be (Gardiner, 2017). Cobalt has considerably

Figure 1

Integrating the Circular Economy Into Cobalt & Lithium Supply Chains



better rates of recycling than lithium, with an estimated end-of-life recycling rate of 32 per cent (OECD, 2019b). Scrap cobalt accounted for 33 per cent of the overall U.S. supply in 2017, but these rates still lag significantly behind what is economically possible and required to meet the predicted supply shortfalls (U.S. Geological Survey, 2018). This is partly due to the complex and costly processes involved in lithium and cobalt recycling—and lithium-ion battery recycling in particular, which involves a number of stages, including: collection, the burning of flammable electrolytes, the neutralization of the hazardous internal chemistry, the smelting of metallic components, the refining and purifying of high value metals, and finally the disposal of non-recoverable waste (Peterson, 2011).

Despite this complexity, the overall materials recycling sector is projected to triple by 2060 (OECD, 2019b). As such, there are already a growing number of actors in the lithium and cobalt recycling industries. The materials technology and recycling company Umicore, in partnership with Tesla and Toyota, recently invested EUR 25 million in an industrial pilot plant in Antwerp to recover cobalt and nickel from the recycling of lithium-ion batteries (Gardiner, 2017). In 2009, the US Department of Energy awarded USD 9.5 million to Retriev Technologies for the country's first lithium-ion recycling facility, which began operation in 2015 (U.S. Geological Survey, 2018) (for more on this award, refer to Case Study 4). As more electronics and EVs reach their typical end of life, political interests and new business opportunities might increase the demand for more operations such as these to proliferate.

While there are no agreed upon or regulated definitions for lithium and cobalt recycling, it is important to note that the term *post-first-life* use could have a number of meanings. Each of the terms *secondary use*, *reused*, *remanufactured* and *recycled* can be used to describe a product in its post-first-life use. For the purpose of this paper, definitions of key terms are outlined in Box 1.

“Less than 5 per cent of lithium-ion end-of-life batteries are recycled today.”

BOX 1. DEFINITIONS OF KEY TERMS

Waste: According to the UN Basel Convention, waste refers to those substances or objects that are disposed of, intended to be disposed of, or required to be disposed of per national law (UNEP, 1989).

Waste disposal operations: Under the UN Basel Convention, disposal can be categorized into operations that lead to the possibility of resource recovery, recycling, reclamation, direct reuse or alternative uses, and those operations that do not (UNEP, 1989).

Permanent waste disposal: Activities carried out that do not lead to the possibility of post-first-life use (Statistics Canada, 2008). This can include deposit into landfills, release into bodies of water, and incineration. (UNEP, 1989).

Post-first-life use: Activities that carry out the agenda of the circular economy to minimize waste, reduce system risks, and optimize resource yields (Standridge & Corneal, 2014). This is the umbrella term for recycling, remanufacturing and reuse processes (Kampker, et al., 2016).

Secondary processes: Processes applied to a product after its first-life use, excluding waste disposal. These can include reuse, processing, metal recovery, recycling and remanufacturing.

Reuse: The complete product is used again—either for its original purpose or for one similar—without significant alterations (World Steel Association, 2016; Kampker, et al., 2016). Like remanufacturing, this process extends the product's life.

Remanufacturing: Retrieving individual components of a product at the end of its first life, restoring the components to as-new condition through manufacturing, usually as the same or a similar end product (World Steel Association, 2016; Kampker, et al., 2016). Like reusing, this process extends the product's life.

Mineral recycling: Sending a product to a post-first-life market in order to retrieve and refine its mineral components, altering the physical form of the product so a new application can be created (Cascade Alliance, 2018; World Steel Association, 2016; Kampker, et al., 2016). The mechanisms to recycle can also be referred to as *resource-recovery technologies*.

2.2 Motivations for Mineral Recycling

Although lithium and cobalt recycling is not currently undertaken at a significant global scale, doing so could contribute to the agendas of both the circular economy and the SDGs. The potential roles and benefits of increased lithium and cobalt recycling are outlined in the sections below as pertaining to both frameworks.

2.2.1 Significance to the Circular Economy

The circular economy is based around three core principles: designing waste out of the system; keeping products and materials in use; and regenerating natural systems (Ellen MacArthur Foundation, 2017). As with the SDGs, the shift to the circular economy will require systemic and transformational change in order to build long-term resilience and sustainability. The definition of the circular economy can be broken into two parts to show how mineral recycling contributes to this agenda: how lithium and cobalt recycling fulfills the goal to decouple economic activity from the consumption of finite resources; and how it contributes to the aim of designing waste out of the global system.

DECOUPLING ECONOMIC ACTIVITY FROM THE CONSUMPTION OF FINITE RESOURCES

Cobalt and lithium are finite, valuable resources. Not only this, both are projected to experience significant supply shortages in the coming decade, due to incoming demand from the electronics and automobile industries (Greenwood, 2018; Holmes, 2018). According to the British Geological Survey, cobalt and lithium are given a supply risk index score of 8.1 and 7.6, respectively, indicating that the relative production of both is concentrated in only a few countries and is subject to disruption and potential instability (British Geological Survey, 2015). Not only are these resources finite, they are also part of supply chains that are identified as risky as compared to other minerals and metals. It is imperative then, that the supply chains of lithium and cobalt are transformed to reduce a reliance on finite resources.

"The circular economy entails 'gradually decoupling economic activity from the consumption of finite resources, and designing [permanent] waste out of the system.'"

For some markets, including Europe, increased mineral recycling could reduce reliance on imports from foreign primary markets. European lithium and cobalt supplies are mainly imported from Asia, and therefore increased recycling operations could reduce carbon dioxide emissions resulting from transportation of the minerals and cultivate a domestic post-first-life supply of valuable resources (Gaines, 2014). Estimates also suggest that production of an EV lithium-ion battery pack from recycled materials could reduce their total cost from USD 416 to an average of USD 332, based on cost data from 2016 (Ribeiro, et al., 2018). Recycling lithium and cobalt could be a key economic opportunity then for markets to disengage with the consumption of finite resources and maintain a secure post-first-life supply of the critical minerals needed to meet surging demand for clean electrification and digitization.

> "By 2030, approximately 1.2 million EV batteries are expected to reach the end of their first-list. How they are disposed of will influence the success of the SDGs and the circular economy agenda."

DESIGNING WASTE OUT OF THE SYSTEM

By 2030, approximately 1.2 million EV batteries are expected to reach the end of their first-life (Ribeiro, et al., 2018). How they are disposed of will influence the success of the SDGs – especially SDG 12 for Responsible Consumption and Production – and the circular economy agenda. Annual accumulation of global electronic waste (e-waste) is already an estimated 49.3 million tonnes, and is expected to continue to grow as more electronics reach their perceived end of life (Larmer, 2018; Teck Resources Limited, 2011). The minerals found in this e-waste—lithium and cobalt but also gold, silver, copper and others—often go into permanent waste disposal processes, despite their value. According to current e-waste disposal rates, consumers in the United States alone throw out smartphones worth approximately USD 60 million in gold and silver every year (Larmer, 2018). Beyond this potential loss of value, the disposal of e-waste and scrap batteries can be destructive to the environment, becoming a significant cause of soil contamination and water pollution (Ribeiro, et al., 2018). According to Transparency Market Research, an increase in awareness about the environmentally harmful disposal of batteries at the end of their first life is expected to be a key driver for secondary processes (Transparency Market Research, 2018). Recycling can significantly extend the efficient use of lithium and cobalt, reducing pressure on landfills and incinerators (Natural Resources Canada, 2017). This contributes to goals purported by both the circular economy and the SDGs.

2.2.2 Significance to the Sustainable Development Goals

Increased recycling of lithium and cobalt contributes to the attainment of many of the SDGs in both direct and indirect ways, most directly SDGs 7, 8, 9, 12, 13 and 16.

SDG 7: ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE AND MODERN ENERGY FOR ALL.

As discussed in the introduction, Target 7.2 of SDG 7 for Affordable and Clean Energy aims to increase the share of renewable energy in the global energy mix (United Nations, 2018). Because lithium and cobalt are both critical to the development and deployment of green energy technologies, securing their sustainable and affordable supply—through the integration of mineral recycling—could contribute to this target.

By the end of the first life of most EVs, their lithium-ion batteries still retain 70 to 80 per cent of their initial capacity (Willuhn, 2018). Target 7.3 of SDG 7 is focused on doubling the global rate of improvement in energy efficiency (United Nations, 2018). Reusing, remanufacturing or recycling EV batteries will be imperative to achieving energy efficiency, and is supplemented by the fact that metals recycling requires 80 per cent less energy compared to primary production practices (Ribeiro, et al., 2018).

> “By the end of the first life of most EVs, their lithium-ion batteries still retain 70 to 80 per cent of their initial capacity.”

This efficiency is demonstrated currently in both the steel and aluminum industries, in which recycling leads to 60–75 per cent and 90–97 per cent energy savings, respectively, when compared to primary mining (Johansson, 2016). While current lithium-ion battery recycling processes remain energy-intensive, more efficient methods are being tested and piloted, which could directly align this practice with SDG 7 (Shi, Chen, & Chen, 2018).

SDG 8: PROMOTE SUSTAINED, INCLUSIVE AND SUSTAINABLE ECONOMIC GROWTH, FULL AND PRODUCTIVE EMPLOYMENT AND DECENT WORK FOR ALL.

Engaging in enhanced lithium and cobalt recycling services could contribute to SDG 8 for Decent Work and Economic Growth by generating sustainable jobs, improving the safety of waste treatment employment, and decoupling economic growth from environmental degradation. Specifically, Target 8.3 aims to promote policies and projects that formalize and grow micro-, small- and medium-sized enterprises (MSMEs), including through access to financial services (United Nations, 2018). Secondary processes are labour-intensive, and entail additional employment creation for collection services, dismantling, processing, metal recovery, manufacturing and sales operations (Drabik & Rizos, 2018). In fact, mineral recycling—especially as it pertains to post-first-life electronics—far surpasses waste disposal in terms of job creation potential (Colorado Association for Recycling, 2011). According to Hummingbird International, materials recycling from e-waste could generate more than 32 times more jobs than are required for traditional disposal operations (Sampson, 2015). The safe and controlled recycling of lithium and cobalt could generate considerable jobs within MSMEs, thereby contributing to Target 8.3.

SDG 9: BUILD RESILIENT INFRASTRUCTURE, PROMOTE INCLUSIVE AND SUSTAINABLE INDUSTRIALIZATION AND FOSTER INNOVATION.

Targets 9.4 and 9.5 of SDG 9 aim to promote sustainability through retrofitting industries for increased resource-use efficiency and enhancing the technological capabilities of industrial sectors in all countries, respectively (United Nations, 2018). One of the key advantages of mineral recycling is that, if operators work proficiently, the minerals can be reused almost endlessly, thereby extending resource-use efficiency (Natural Resources Canada, 2017). Applying current, well-established recycling models—such as those used in the lead-acid battery recycling industry—to lithium and cobalt recycling would contribute significantly to Target 9.4.[3] Moreover, incentivizing lithium and cobalt recycling would foster innovation in industrial sectors, as more actors seek to make the process economically viable and environmentally friendly, ultimately influencing Target 9.5. The Canadian recycling company Li-Cycle, for example, is piloting a project that lowers the cost and increases the sustainability of lithium-ion battery recycling (Li-Cycle, 2019). Projects like these, motivated by the need for lithium and cobalt recycling, would aid in accomplishing SDG 9 for Industry, Innovation and Infrastructure.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

SDG 12: ENSURE SUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS.

Targets 12.4 and 12.5 of SDG 12 for Responsible Consumption and Production aim to reduce waste generation and ensure the sound management of chemicals and waste (United Nations, 2018). Primary extraction—or mining—can be associated with higher levels of waste production when compared to recycling processes. The levels of waste can be very significant; in the European Union (EU), for example, mines have generated more waste than households (Johansson, 2016). If poorly managed, lithium and cobalt mining, like other forms of mining, can also cause environmental and health problems related to the waste generated. Beyond waste, mining can also place considerable demands on the local resource base; lithium extraction, for example, can use up to 500,000 gallons of water per tonne of lithium extracted (Katwala, 2018). This can create tensions at the local level and can also be associated with water pollution due to toxic chemical leakage; incidents of hydrochloric acid polluting water sources in Tibet have been associated with nearby lithium mining (Katwala, 2018). Due to the finite, non-renewable nature of these minerals, continued consumption at current (and expected) demand levels could create considerable waste, exacerbate grievances regarding natural resource use, and jeopardize global supply chains and production patterns.

13 CLIMATE ACTION

SDG 13: TAKE URGENT ACTION TO COMBAT CLIMATE CHANGE AND ITS IMPACTS.

As discussed in the Introduction, climate change mitigation measures are essential to accomplishing the commitments set out by both SDG 13 for Climate Action and the Paris Climate Agreement. Renewable energy sources—like solar and wind—will contribute greatly to mitigation by providing options for lowering greenhouse gas emissions from the overall energy system, while still satisfying the global demand for energy services (IPCC, 2011). At the same time, these energy sources require significant mineral and metal inputs, cobalt and lithium among them (Arrobas, et al., 2017). In the face of impending projected supply shortages of both minerals and failing any significant substitution, recycling has the potential to contribute to a stable supply of lithium and cobalt, thereby enabling these energy sources and their required infrastructure (Greenwood, 2018; Holmes, 2018).

[3] This is not to say, however, that the same recovery processes should be used in both lead-acid and lithium-ion recycling, but that the collection infrastructure and services of lead-acid batteries should serve as a model to increase and scale up lithium-ion battery recycling.

In the past two decades, mines around the world have been impacted by significant climate events, including rainfall variability, droughts and floods, and extreme storms (Pearce, Ford, Prno, & Duerden, 2009). Increased mineral recycling will also contribute to the adaptation-related targets of SDG 13, by reducing a reliance on mines vulnerable to climate change. In addition, the mining sector is water- and energy-intensive. A greater reliance on the recycling industry could serve to reallocate some of these resources to nearby communities in their adaptation and development efforts.

SDG 16: PROMOTE PEACEFUL AND INCLUSIVE SOCIETIES FOR SUSTAINABLE DEVELOPMENT, PROVIDE ACCESS TO JUSTICE FOR ALL AND BUILD EFFECTIVE, ACCOUNTABLE AND INCLUSIVE INSTITUTIONS AT ALL LEVELS.

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

While mining can bring socioeconomic benefits and prosperity to local communities and regions, if poorly managed and governed it can be associated with fragility, conflict and violence. Approximately 50 per cent of world reserves of cobalt are located in the Democratic Republic of Congo (DRC), the 6th most fragile and 17th most corrupt state in the world (U.S. Geological Survey, 2018; The Fund for Peace, 2018; Transparency International, 2017). Although a lot of cobalt extraction takes place in a safe environment and contributes positively to socioeconomic development, some cobalt mines in the south of the DRC have employed young children and been associated with extortion, abuse, and dangerous working conditions with minimal safety equipment (Amnesty International & African Resources Watch, 2016; Amnesty International, 2017). In the case of lithium, an estimated 54 per cent of world reserves are located in what is known as the Lithium Triangle—a region intersecting Chile, Argentina, and Bolivia (Dickson, 2018). Most of the primary extraction takes place without issue; however, some of the mines in the area have become embroiled in ongoing grievances and local conflicts over land and water rights (Environmental Justice Atlas, 2018; Environmental Justice Atlas, 2017; Environmental Justice Atlas, 2015). Moreover, recent reports have focused on concerns in the Lithium Triangle—especially in Bolivia—surrounding an uneven distribution of mining benefits and lack of community consultation and buy-in, a cause for potential fragility and tension if not governed responsibly (Draper, 2019).

Increased conflicts in both locations could put a strain on the primary supply chains of lithium and cobalt, jeopardizing the national programs toward the achievement of SDG 16. Increased recycling of these two minerals could relieve some of the pressure on primary extraction sites and thus reduce conflict pressures. Moreover, competition caused by successful mineral recycling may present an incentive for mining companies to address supply chain issues in order to strengthen their reputation and gain back market shares. However, it is important to note that mineral and battery recycling has also been associated with child labour and dangerous working conditions in some impoverished areas of Bangladesh, India, and China (Gaines, 2014). This lack of transparency will be explored further in Section 3.

BOX 2. WASTE DISPOSAL AND RECYCLING GOVERNANCE MECHANISMS

In recent decades, a range of governance mechanisms have been developed on waste disposal and mineral recycling processes for electronics and batteries. While the designation of who is responsible for secondary processes varies based on sector, the “polluter pays” and its derived principle of “extended producer responsibility” (EPR) have increasingly gained traction. EPR requires targeted producers to assume some or full administrative, financial, and/or physical responsibility for collection, recycling, and waste disposal operations (OECD, 2001). Cobalt and lithium recycling is (and will continue to be) shaped by these national and international regulations, policies and international conventions, some of which are listed below. These governance mechanisms are expanded upon further in Annex 1.

The European Union:

The EU Batteries Directive, the EU Raw Materials Initiative, and the EU Waste of Electrical and Electronic Equipment (WEEE) Directive govern the waste disposal operations for lithium-ion batteries, and the mineral contents they contain. For these Directives, targets are set by the EU and interpreted into national law by each member state.

Canada and the United States:

Neither Canada nor the United States has adopted national laws to govern the recycling of WEEE. However, recycling regulations on a provincial and state level are spreading in both countries; all 10 Canadian provinces have implemented programs and regulations for waste batteries, and 28 US states have adopted WEEE recycling laws.

China:

China is the largest EV market in the world and generates the highest amount of WEEE globally (Bloomberg News, 2018; Doyle, 2017). In response to these demands, China has announced some pilot programs to repurpose and recycle EV batteries in 17 major regions and cities (Reuters, 2018). China has also adopted several national regulations for the collection and recycling of some WEEE product groups, including TVs, computers, refrigerators, washing machines and air conditioners—steadily growing the recycling sector.

Asia:

The recycling governance landscape for WEEE and waste batteries for the rest of Asia is highly diverse. Some countries in Southeast Asia, South Asia and Western Asia have started to promote and adopt legislation, while other countries—including Sri Lanka and Bangladesh—have no formal governance mechanisms. The informal recycling sector remains dominant in many countries in the region.

Latin America:

Seven countries in Latin American enforce national regulations on WEEE, apply the EPR principle and are active in implementing formal recycling systems: Bolivia, Chile, Colombia, Costa Rica, Ecuador, Mexico and Peru. While there is progress in many countries to adopting specific legislation for WEEE and waste batteries, challenges remain with respect to establishing and enforcing formal collection infrastructure and recycling systems.

Africa:

Historically, few countries in Africa have implemented regulations to govern WEEE. Instead, many countries host a large, informal recycling sector, in which government control and oversight is minimal. However, the interest to adopt regulations to formally govern WEEE is increasing. Ghana, Madagascar and Kenya, for example, have formally passed draft bills on WEEE into law, with other countries, including Cameroon, Nigeria, South Africa and Zambia, following suit.

International Mechanisms:

The UN Basel Convention was adopted in 1989 to protect human health and the environment against the adverse effects of hazardous wastes, household wastes and incinerator ash (Basel Convention, 2011). The Convention defines what can be counted internationally as waste and aims to uphold the core objectives of reducing the generation of hazardous wastes, promoting their environmentally sound management, and restricting the transboundary movements of wastes (Basel Convention, 2011).

3.0

Existing and Perceived Barriers to Mineral Recycling

Key Messages:

- While lithium and cobalt recycling has major benefits to the circular economy and the SDGs, there are a number of barriers that inhibit the expansion and improvement of the mineral recycling industry.
- These barriers exist along the primary supply chain, the recycling supply chain, and manifest as cross-cutting regulatory barriers.

Increased and improved lithium and cobalt recycling will be required for the transition to a low-carbon economy. There remain however, a number of key barriers to securing, processing and distributing post-first-life supplies of lithium and cobalt (see Figure 1). While significant barriers persist at the recycling stage in the supply chain (from collection of the post-first-life products, to processors, metal recovery specialists, manufacturers, and finally end users), additional barriers can be identified at earlier stages in the supply chain during primary extraction and production. More broadly, additional regulatory barriers, applicable across the entire mineral recycling supply chain, from primary extraction to secondary end users, must be also addressed.

The list of barriers presented here is not meant to be comprehensive, but representative of some of the more pressing issues as expressed through the literature review and the stakeholder consultations. Section 4 will offer direct interventions and solutions to these barriers, as well as offering case studies and recommendations.

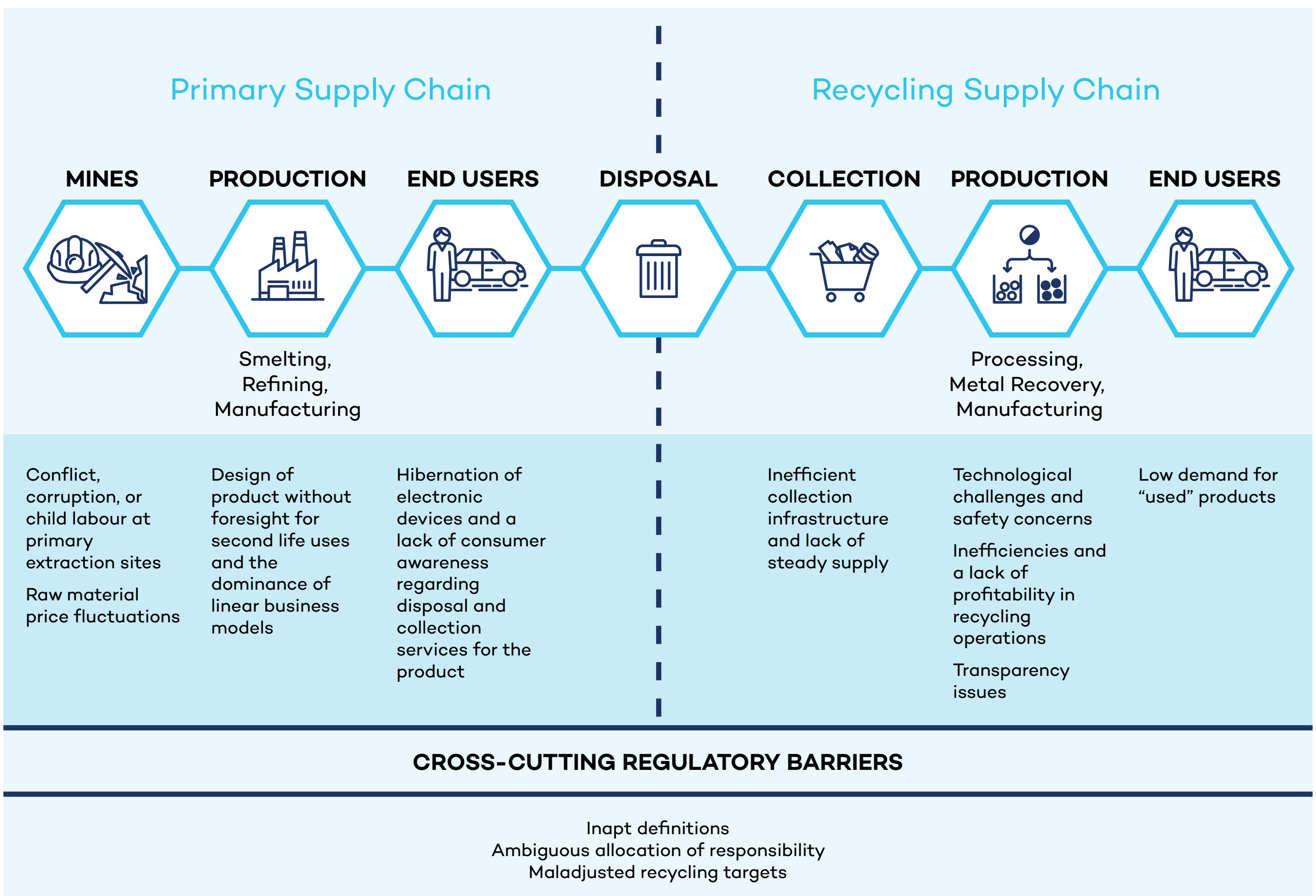


Figure 2. Barriers to lithium and cobalt recycling along the supply chains[4]

[4] The stages of the supply chain have been simplified.

"While cobalt substitution has not been significant to date, it reflects the genuine concerns of stakeholders of price increases and the opaque extraction of the two minerals – and especially for cobalt."

3.1 Barriers Along the Primary Supply Chain

CONFLICT, CORRUPTION, OR CHILD LABOUR AT PRIMARY EXTRACTION SITES

Although separate from the recycling processes of lithium and cobalt, several barriers to increased recycling originate in the primary supply chains of these minerals. In interviews, some stakeholders from the lithium and cobalt recycling industry expressed concern regarding the origins of post-first-life products, noting that they would be uncomfortable using products if they originated from areas affected by violence. Cobalt sourcing in particular has been called into question recently due to some mine sites' connections with child labour, human rights abuses and corruption (Callaway, 2018). Cobalt extraction is primarily concentrated in the DRC, where political fragility, conflict and violence continue to affect the mining sector (Church & Crawford, 2018). In 2017, Amnesty International conducted an assessment of 26 companies that sourced cobalt from the DRC and found that none of the surveyed companies had conducted due diligence measures in line with international standards (Amnesty International, 2017). And while conflict and political fragility at primary extraction sites can be an incentive for increased mineral recycling (as seen in Section 2.2.2), a lack of transparency about the origins of a product could influence whether or not the post-first-life product enters secondary processes.

RAW MATERIAL PRICE FLUCTUATIONS

The prices of cobalt and lithium are projected to increase in line with growing EV battery demand (Barrera, 2018; Els, 2018). This has a dichotomous effect. If prices for raw materials increase, this makes recycled, secondary minerals more price competitive and provides economic grounds for investing in research and development (R&D) for second-life innovations. On the other hand, increasing raw material prices and the possibility of persistent political fragility, conflict or violence along the supply chains of lithium and cobalt extraction, motivates manufacturers of electronic equipment to substitute the affected minerals. In the case of cobalt especially, this substitution is already taking place. In the last six years, Tesla has reduced its cobalt dependency for EV batteries by approximately 60 per cent (Chen, 2018). Battery companies like Panasonic and Goodenough are also working to develop EV batteries that contain higher shares of manganese or iron to substitute cobalt (Airhart, 2018). If manufacturers begin designing lithium-ion batteries with low-value materials capable of replacing cobalt, these products may not be economically worthwhile to recycle, designating them instead for permanent waste disposal and harming the profitability of recycling operations (McMahon, 2018). While cobalt substitution has not been significant to date, it reflects the genuine concerns of stakeholders in both primary and recycling supply chains of price increases and the opaque extraction of the two minerals—and especially for cobalt.

DESIGN OF PRODUCT WITHOUT FORESIGHT FOR SECOND-LIFE USES AND THE DOMINANCE OF LINEAR BUSINESS MODELS

> "The design of products can limit the ability of lithium and cobalt to be recovered and recycled."

Product design can limit the ability of lithium and cobalt to be recovered and recycled. Permanent assembly methods, like spot-welding, present a significant challenge to mineral recovery processes (Paul Jennings, personal communication, 2018). Current recycling techniques may be unable to recover the lithium and cobalt in products manufactured with these methods without damaging the components within. Insufficient labelling on products and their components at the primary production stage places an additional burden on collection services and secondary producers (Larry Reaugh, personal communication, 2018). Lithium-ion battery recyclers, for example, would have to first test and assess the batteries before designating them for reuse, remanufacture or recycling, based upon which minerals are in the battery and their quantities. This process could be time consuming, energy-intensive and costly. However, it is not only a lack of clear regulatory eco-design incentives that prevents products from being of value for post-first-life phases. The widespread presence of linear business models in private industries that do not entail clear economic incentives for businesses to assume responsibility beyond the point of sale. Product risks, with the exception of limited warranties and some after-sale services, are often allocated to the consumer once the product is sold. There is a need to develop and adapt new business models by product manufacturers that take advantage of economic opportunities associated with circular solutions.

"Hibernation refers to the period of time when a product is not recycled or thrown away, but instead kept after it has been used."

HIBERNATION AND LACK OF CONSUMER AWARENESS

At the consumer level, the retention of products no longer being used—like laptops, mobile phones and other electronics—can be a major obstacle to increased recycling. Hibernation refers to the period of time when a product is not recycled or thrown away, but instead kept after it has been used. A survey of 181 mobile phone owners in the United Kingdom found that only 33 per cent of the phones were returned for recycling (Wilson, et al., 2017). In addition, the survey found that on average, phones were used for less than two years before hibernating in storage for three (Wilson, et al., 2017). While this practice prevents the proliferation of e-waste, it also limits the potential supply of usable electronics—and the valuable minerals they contain—for recycling. In Japan, for example, estimates suggest that if all used mobile phones were collected and recycled, it would reduce Japanese annual consumption of gold, silver, and palladium by approximately 2–3 per cent (Mishima, Rosano, Mishima, & Nishimura, 2016). The components of used electronics often retain most of their battery capacity. A study by Brunel University collected 148 out-of-use laptops and found that only four of the batteries were completely unusable, with most retaining 89 per cent of their original capacity (Furtkamp, 2017). These statistics represent the potential of e-waste for reuse, remanufacture or recycling. A lack of consumer awareness regarding what to do with electronics at the end of their first-life presents major barriers to the increased recycling of lithium and cobalt.

3.2 Barriers Along the Recycling Supply Chain

If at the end of its first life the product does not end up in permanent waste disposal processes or remain in hibernation, as outlined above, lithium, cobalt and other valuable minerals can possibly be recycled. This would involve collection services, processing, metal recovery, manufacturing and distribution to consumers in what could be called the recycling supply chain. However, numerous barriers that can inhibit this process exist at the business, government and consumer levels.

INEFFICIENT COLLECTION INFRASTRUCTURE AND LACK OF STEADY SUPPLY

Primarily, current collection services and infrastructure may be out of date or inadequate to meet the possible supply. Stakeholders highlighted that this was especially the case for portable batteries as used in mobile phones, laptops or other electronics. Collection services for these products are currently available in some regions, but consumers often lack awareness about where to drop off devices and what the societal benefits of this service may be. For rechargeable batteries in EVs, stakeholders outlined that collection infrastructure is relatively improved and sometimes mandated, but still requires more efficient sorting processes to separate the batteries based on their chemistries.

> "Current collection services and infrastructure may be out of date or inadequate to meet the possible supply."

The development of improved collection systems and recycling facilities may be constrained by lack of a reliable supply of the batteries or related products, making the investment in and development of recycling infrastructure not economically worthwhile. The unstable supply is influenced by the variable direction of market development and the resulting heterogeneity of products. In the lithium-ion battery market, for example, stakeholders identified that the type and compositions of batteries could differ depending on future market trends, therefore contributing to uncertainty on which types of collection services to develop and offer. Currently, lithium cobalt oxide batteries lead the EV market, but other compositions include lithium nickel manganese cobalt oxide, lithium nickel cobalt aluminum oxide, lithium iron phosphate, lithium titanite and lithium manganese oxides (Levin Sources, 2017; Synergy Files, 2016). While lithium cobalt oxide's excellent energy-to-weight ratio gives it a competitive advantage in EV markets, the inherent safety and reduced risk of overheating of lithium iron phosphate or lithium nickel manganese cobalt oxide batteries could present competition (Arrobas, et al., 2017; Synergy Files, 2016). Further, some producers are exploring new types of battery chemistries that avoid the use of cobalt altogether. Representatives from Tesla, for example, have indicated that the next generation of EVs would ideally contain no cobalt at all (Chen, 2018). Effective collection services require a stable supply of batteries and other lithium- and cobalt-intensive products before they can be commercialized; this may be hindered if the batteries being supplied are not of similar composition or chemistry.

The expansion of collection services may also be delayed by the lag time between when a product is with the consumer to when it is available for recycling. Although 1.2 million EV batteries are expected to reach the end of their first life by 2030, EV batteries could be first reused or remanufactured for other purposes, such as grid

> "Effective collection services require a stable supply of batteries and other lithium- and cobalt-intensive products before they can be commercialized."

storage, due to their remaining energy capacity at the end of their first life (Ribeiro, et al., 2018). The expected stockpiles of these end-of-life batteries—and when they will become available for mineral recycling—is uncertain. Stakeholders suggested that this wait time reduces any pressing incentive for actors involved in secondary processes to improve collection infrastructure (Ribeiro, et al., 2018; Mandler, 2017).

"Current lithium-ion batteries only contain a small fraction of lithium carbonate as a percentage of weight, and therefore the mineral is bypassed in recovery processes to mitigate costs."

TECHNOLOGICAL CHALLENGES AND SAFETY CONCERNS

Similar to current collective services, the infrastructure for secondary processing and production may be ineffective or out of date for lithium and cobalt recycling, especially as it pertains to lithium-ion batteries. A lot of the existing vehicle recycling infrastructure is geared towards lead-acid battery recycling. According to several interviewed stakeholders, fires have been increasingly reported at lead-acid battery recycling operations because lithium-ion batteries were mixed into these processes. These fires occurred due to the chemical composition of lithium-ion batteries, which can cause a runaway thermal reaction if exposed to excessive heat from inside or outside the cell (White & Adams, 2011). A 2013 survey found that 26 of the 27 assessed secondary smelters reported incidents caused by lithium-ion batteries ending up in facilities not designed for their properties (Binks, 2015). A more tailored approach to lithium and cobalt recycling is therefore required to avoid fires or overheating in the collection, retrieval and refining processes.

INEFFICIENCIES AND A LACK OF PROFITABILITY OF RECYCLING OPERATIONS

There are also significant barriers relating to the current low recovery rates and the potentially high expense of lithium and cobalt recycling. Thermal technologies are more typically used to recycle lithium-ion batteries, which recover only about 40 to 50 per cent of the materials. They also tend to recover only cobalt and nickel and not any of the other critical minerals in the batteries, notably lithium. Current lithium-ion batteries only contain a small fraction of lithium carbonate as a percentage of weight, and therefore the mineral is bypassed in recovery processes to mitigate costs (British Geological Survey, 2017; Kumar, 2011). This is not to say that the lithium cannot be recovered, but that it has not been considered economically feasible to do so. Should cobalt or nickel be replaced in current EV batteries with cheaper materials, it is unclear if battery recycling processes would be deemed financially viable by investors and policy-makers.

> "There is an ongoing perception that recycled materials may not be of the same quality as virgin minerals and metals."

TRANSPARENCY ISSUES

As noted in Section 2.2.2, a lack of transparency in the recycling supply chain—especially at the extraction and production stage—may also present a barrier to sustainable mineral recycling. The majority of hazardous waste is exported from developed countries to developing countries, which may have lower health, safety and environmental standards (Lorenzo & Gómez, 2019). In the case of e-waste specifically, estimates suggest that up to 90 per cent is illegally traded or dumped (Nichols, 2015). Informal operations of lead-acid battery recycling are estimated to be one of the largest sources of chemical pollution for some of the least developed countries (Carrington, 2016). Other reports cite the prevalence of child labour and unsafe working conditions in the informal battery recycling sectors of Bangladesh, China and India (Khan, 2014; NL-Aid, 2013). While there are few reports of these conditions in existing lithium-ion battery recycling processes, end-consumer stakeholders expressed concern regarding the level of opaqueness in post-first-life battery supply chains. A recent report from Levin Sources, for example, noted that mined cobalt may be falsely identified as scrap cobalt for recycling, in order to disguise cobalt that would not meet international standards, including the Organisation for Economic Co-operation and Development (OECD) Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (CAHRAs) (Lorenzo & Gómez, 2019). Efforts should be stepped up to increase transparency in the supply chains of all battery secondary processes, to ensure human rights are observed and reputational risks are avoided.

LOW DEMAND FOR "USED" PRODUCTS

Finally, barriers also exist at the secondary end-consumer stage of the materials. There is an ongoing perception, for example, that recycled materials may not be of the same quality as virgin minerals and metals (Michael Green, personal communication, 2018). According to many interviewed stakeholders, poor marketing of second-life materials and a lack of consumer awareness may prevent the sale of products made from recycled materials, due to the misconception that they are not as efficient or safe. Ongoing testing, however, has demonstrated that post-first-life batteries often retain much of their energy capacity and can be of the same quality—and sometimes better quality—than virgin materials (Furtkamp, 2017). Without demand for used materials from end consumers however, increased lithium and cobalt recycling (and the potential benefits it holds for the SDGs and the circular economy) will face considerable obstacles.

3.3 Cross-Cutting Regulatory Barriers

While some barriers can be pinpointed to a specific stage in either the primary or recycling supply chain, there are a number of cross-cutting regulatory barriers to effective lithium and cobalt recycling. Although considerable progress has been made with regards to mineral recycling regulation more broadly, many of the policies in place (outlined in Box 2 and Annex 1) may be outdated or inappropriate for lithium and cobalt recycling specifically, presenting obstacles to the proliferation of these processes.

INAPT DEFINITIONS

Inapt and outdated definitions of recycling and other post-first-life processes, for one, may result in uneven or ineffective implementation of the policies. Some of the main governing policies concerning lithium and cobalt waste disposal operations include the EU Raw Materials Initiative, the EU Batteries Directive, the UN Basel Convention, the EU Waste of Electrical and Electronic Equipment Directive, as well as several ongoing pilot policies on EV batteries in China (summarized in Box 2 and outlined in detail in Annex 1 on Governance Mechanisms). Adopted in 1989, the UN Basel Convention's main aim is to "protect human health and the environment against the adverse effects of hazardous waste" (Secretariat of the Basel Convention, 2011). It defines waste as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law" (UNEP, 1989). Under this definition, used lithium and cobalt are defined as "waste," whether they are destined for recycling processes or not. This classification can and has inhibited their later use (Natural Resources Canada, 2017).

Annex IV of the Convention defines disposal operations that may lead to resource recovery, recycling, reclamation or reuse, but does not define any of these processes (UNEP, 1989). This lack of an established definition has been a major barrier to developing a common understanding and subsequently a business case for these processes. Several of the stakeholders interviewed cited this lack of understanding of the relevant terminology—especially in regard to what constitutes remanufacturing, repurposing, reusing and recycling. As a result of this lack of clarity, policy-makers and practitioners would be less likely to raise these issues and address inefficiencies and barriers in the recycling process. Additionally, the interpretation of regulations like the Basel Convention or EU Batteries Directive can vary differently from state to state, often to the detriment of improved and coordinated lithium and cobalt recycling processes.

Finally, international agreements like the UN Basel Convention may not be able to accommodate for the changing trade patterns that may emerge from a transition to a circular economy. Trade barriers, for example, have been presented by the OECD as a challenge to the circular economy, most notably restricting the flow of products for reuse, recycling, or remanufacturing processes (OECD, 2019a).

AMBIGUOUS ALLOCATION OF RESPONSIBILITIES

Many of the current regulations—in addition to lacking an up-to-date definition of secondary processes—also struggle to designate which actors are responsible and liable for recycling processes. Should it be the responsibility of the mobile phone manufacturer to ensure its efficient recycling at end of life (as is the case for some of the automotive sector)? If a recycled lithium-ion EV battery malfunctions in its second-use, is the primary or secondary manufacturer liable for damages? The answers to these questions are currently unclear or unspecified by many of the governing regulations. As mentioned, the expense of lithium and cobalt recycling can be significant; clear definitions on the responsible producer and recycling party therefore need to be in place for each sector to ensure these materials do not end up in permanent waste disposal. There is also a considerable economic opportunity in lithium and cobalt recycling due to their growing demand; defining those responsible for post-first-life reuse, remanufacture or recycling also designates who will benefit from the mineral resale.

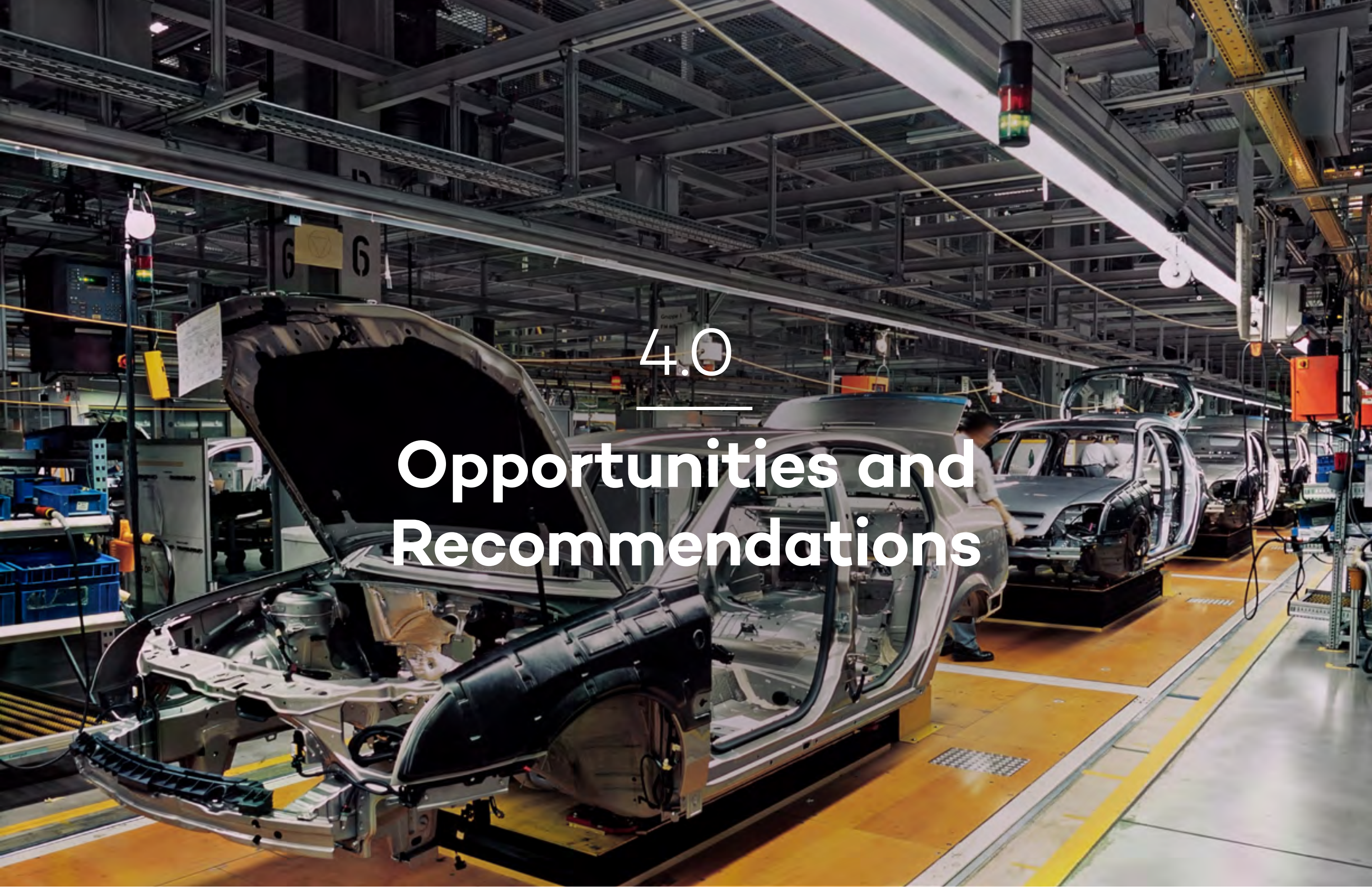
"Many of the current regulations – in addition to lacking an up-to-date definition of secondary processes – also struggle to designate which actors are responsible and liable for recycling processes."

MALADJUSTED RECYCLING TARGETS

Lastly, although many of the current regulations in place have been able to significantly improve the recycling rates of minerals, many of these targets are out of date and unable to meet the changing needs of the lithium and cobalt industries. The EU Batteries Directive, for example, mandates recycling efficiency targets for automotive, industrial, and portable batteries (European Parliament, 2006). However, these targets are set per battery chemistry, not per their application: 75 per cent for nickel cadmium batteries; 65 per cent for lead-acid batteries; and 50 per cent for all other batteries (Green, 2017). Lithium-ion batteries subsequently fall under the 50 per cent recycling efficiency target, and while admirable, many stakeholders have highlighted that this target is too low and does little to encourage comprehensive recycling (Michael Green, personal communication, 2018). In some cases, the weight of the casing of the battery or the cobalt itself will suffice to reach the target, ultimately disincentivizing the recycling of other valuable minerals in the battery, including lithium (Michael Green, personal communication, 2018). However, regulations that designate targets by the category of battery as opposed to chemistry would not necessarily solve this discrepancy. Mandating targets by application would mean that the automotive sector could easily meet its targets through recycling lead-acid batteries—which is already done at a near closed-loop rate today—while ignoring its obligations to lithium-ion battery recycling. In both cases, the recycling of any portable electronics containing lithium and cobalt falls short of the recycling taking place in the automotive sector.

Other regulatory barriers highlighted by stakeholders include a limited knowledge on the part of policy-makers and practitioners of where the main stocks and flows of used lithium and cobalt are in the world and who owns them. This prevents any sort of targeted policy approach, or assessment of the economic value of used lithium and cobalt. Also, stakeholders outlined that in many policy and business spheres, there is a focus on a single positive or negative consequence of the mineral recycling industry (the environmental value, for example) which ultimately fails to evaluate the comprehensive benefits of the investment. An integrated and systemic assessment and evaluation of all a recycling project's advantages and disadvantages—including cost, environmental value, job creation, permanent waste reduction, health benefits and reduced resource dependency as well as potential risks—would therefore be more beneficial to current regulatory and commercial decision-making processes.[5]

[5] The Sustainable Asset Valuation (SAVi) methodology developed by IISD, which integrates system dynamics simulation and project finance modelling, would be a suitable approach for this endeavour. SAVi is currently customized to a range of asset types (roads, buildings, energy generation, irrigation and wastewater treatment, natural infrastructure) and will be extended to waste infrastructure in 2019.



4.0

Opportunities and Recommendations

Key Messages:

- Private actors, the public sector and civil society can help overcome barriers to lithium and cobalt recycling by making key interventions along the primary supply chain, recycling supply chain, and regulatory environment.
- Coordination between these actors and stakeholders is essential to ensure that the new or revised interventions, investments and regulations reflect the changing needs of the industry.

Just as there are barriers to improved lithium and cobalt recycling processes, so too are there opportunities and interventions that can be made (and in some cases have already been made on a smaller or more localized scale) to overcome these obstacles. The following solutions, displayed in Figure 2 and elaborated on further below, derive from interviews with key stakeholders, the literature review, and case studies of projects and companies who have made effective and meaningful interventions to address the aforementioned barriers. This list is not meant to be comprehensive, but representative of some of the more promising opportunities along the primary and recycling supply chains.

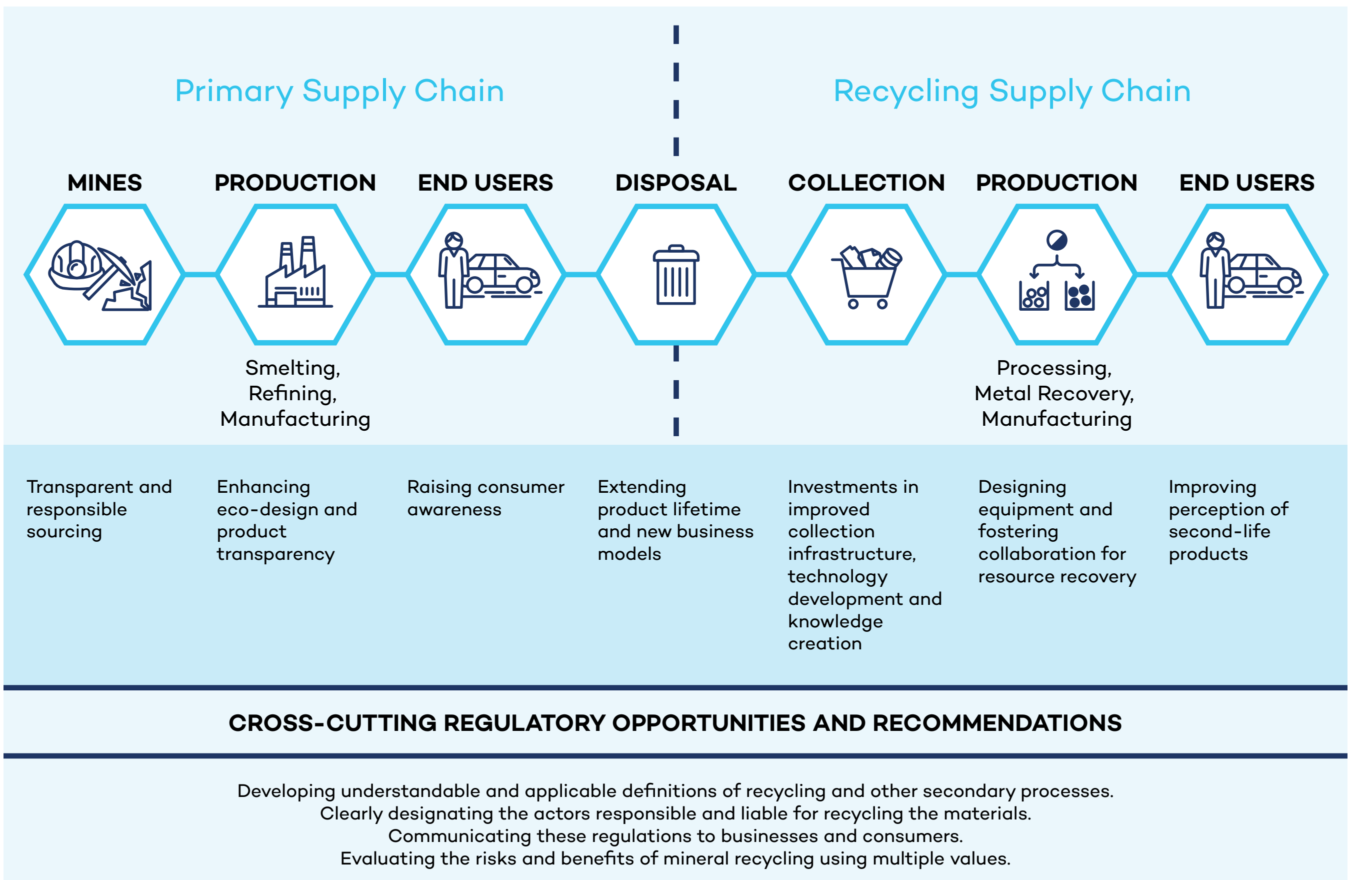


Figure 3. Opportunities to address the barriers in the lithium and cobalt recycling supply chains[6]

[6] The stages of the supply chain have been simplified.

4.1 Opportunities Along the Primary Supply Chain

TRANSPARENT AND RESPONSIBLE SOURCING

A lack of responsible sourcing along primary supply chains for lithium and cobalt could be an incentive for increased mineral recycling, encouraging the retrieval of minerals from existing products instead of mining sites in CAHRAs. However, this is not to say that the correlation is always positive. A lack of responsible sourcing at extraction sites can also be a barrier to improved recycling services, with implications for the local economy in areas where reserves are found. This risk has also become one of the main motivations for manufacturers to substitute cobalt for other minerals, thereby decreasing the overall value of and market for lithium-ion battery recycling. Ensuring that minerals are sourced in a conflict-free and environmentally friendly way is critical to maintaining stability in the supply chains of lithium and cobalt and establishing their value and legitimacy in later material recovery processes, while supporting livelihoods in regions where key reserves are found. Further, avoiding CAHRAs altogether is not a sustainable solution to sourcing the minerals required for the green energy transition. Responsible sourcing is an integral component of the success and sustainability to the mineral recycling industry.

> "Ensuring that minerals are sourced in a conflict-free and environmentally friendly way is critical to maintaining stability in supply chains."

There are several mechanisms currently in place that can contribute to the responsible sourcing of lithium and cobalt. The OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from CAHRAs, for example, applies to all minerals and details recommendations to help companies respect human rights and avoid actions that contribute to conflict (OECD, 2016). The Due Diligence Guidance provides support for any company sourcing minerals and metals from CAHRAs, and has been referenced in a number of international and national declarations, including the EU's Conflict Mineral Regulation, the Chinese Due Diligence Guidelines and the Lusaka Declaration (OECD, 2016).

Other mechanisms and programs, such as the Global Battery Alliance, the Responsible Minerals Initiative and the Cobalt Institute, encourage and support the responsible sourcing of both cobalt and lithium. The Global Battery Alliance focuses specifically on lithium-ion batteries, providing an international platform to address the human and environmental costs associated with extraction, as well as the lack of systems in place to enable the reuse and recycling of batteries (World Economic Forum, 2019). Further, the Cobalt Institute has impacts on the lithium-ion battery industry, aiming to strengthen engagement and coordination in the cobalt supply chain as well as to establish industry-wide risk management guidance (Cobalt Institute, 2017). The Responsible Minerals Initiative looks at the mineral industry more broadly, and supports transparency in the supply chains of lithium and cobalt by delivering resources to companies seeking to address their sourcing practices; notably, offering companies third party audits to determine which smelters and refiners are verified as complying

"Manufacturers should be encouraged to consider the eventual recyclability in the initial design of their products."

with global standards (Responsible Minerals Initiative, 2019). By observing and bolstering mechanisms like these, among others, the primary supply chains of lithium and cobalt can become more transparent, enabling greater stability and sustainability in the market for secondary materials. Moreover, mechanisms like this should be expanded to reduce the opaqueness of the recycling supply chain, especially at the material retrieval and recovery stages.

ENHANCING ECO-DESIGN AND PRODUCT TRANSPARENCY

Manufacturers should be encouraged to consider eventual recyclability in the initial design of their products. Designing products without the use of permanent assembly methods, for instance, would ease the dismantling process and subsequent material recovery and retrieval services (British Geological Survey, 2017). This will make it more economically viable to recover minerals used in smaller quantities—like lithium and cobalt—through recycling. The clean technology company Aceleron has patented a compression assembly method that simplifies disassembly and dismantling processes, allowing for single parts of the battery to be replaced, as opposed to disposing of the entire product (for more on Aceleron, see Case Study 1) (Paul Jennings, personal communication, 2018). It would also be useful and valuable if lithium-ion batteries were standardized in size and if battery chemistries were labelled on the outside of their casing (Larry Reaugh, personal communication, 2018). Accounting for recyclability in primary design has been encouraged by some government policies already (such as the Minerals and Metals Policy of the Government of Canada) but should be incentivized more globally, to account for the international nature of the lithium and cobalt markets (Natural Resources Canada, 2017).

RAISING CONSUMER AWARENESS

End users may present a barrier to increased lithium and cobalt recycling by keeping their used electronics in hibernation. When end users keep them out of the resource recovery stream the electronics—and the valuable minerals they contain—do not enter permanent waste disposal processes or collection services for potential reuse, remanufacture or recycling; they simply gather dust in drawers and closets (Mishima, et al., 2016). Awareness must be raised and incentives applied to encourage consumers to take their used electronics out of hibernation and into current collection and recycling schemes. This could involve offering a financial incentive to consumers for handing in their used mobile phones, laptops (and other electronics) or improving current collection mechanisms. Further, the private and public sector should work to alter public perception as to what is considered permanent waste, as opposed to what can be recycled: this is strongly related to enhanced eco-design and its labelling on respective products. While the retention of electronics presents a barrier to collection and subsequent post-first-life uses, some stakeholders identified this hibernation period as an opportunity; in the absence of more efficient recycling systems, hibernation offers temporary, low-cost storage. Just as it is critical to develop and raise awareness for more efficient collection services to mitigate hibernation, it is also important to take advantage of this temporary hibernation period—using the extra time to develop more sustainable and economically viable recycling processes while not misusing it as an excuse to continuously delay investments.

EXTENDING PRODUCT LIFETIME AND NEW BUSINESS MODELS

There are further alternatives to permanent waste disposal or mineral recycling, notably repair, reuse or remanufacture (for definitions of reuse and remanufacture, see Box 1). Product reuse, for example, both domestically and internationally, can be as effective at reducing the consumption of virgin materials, extending the life of products and decreasing permanent waste (Mishima, et al., 2016). Even if, for example, the product has not retained all of its energy efficiency, it could potentially be reused or remanufactured for less energy-intensive purposes. The clean technology company Aceleron is working to repackage used EV lithium-ion batteries for less-demanding applications, expanded further upon in Case Study 1. This is an example of a more circular business model that entails economic incentives for the manufacturing company to retain product responsibility after its first use.

> "Awareness must be raised and incentives applied in order to encourage consumers to take their used electronics out of hibernation, and into current collection and recycling schemes."

Case Study 1: Reusing End-Of-Life EV Batteries for Less-Demanding Applications

When a lithium-ion battery reaches the end of its first life, typically the entire pack will either enter permanent waste disposal or secondary processes. Often though, it is only a few cells within the battery pack that aren't fit for purpose (Idle, 2017). This means that many functioning battery cells enter waste disposal processes, when they in fact could be reused or remanufactured if the battery packs were designed in a way that allowed for easy disassembly.

The UK-based clean technology company Aceleron is looking to address this by designing lithium-ion batteries—with their patented compression assembly method—that are easier to disassemble and dismantle (Aceleron, 2019). This allows for single parts or cells of their batteries to be repaired or replaced when they no longer function. Aceleron also tests the battery packs, to determine which cells can still be used. Once this is determined, the company will repackage the cells for whichever application the battery pack is most suited (Harrison, 2018; Thomas, 2018). Second-life batteries, for example, can be reused for renewable energy storage, as this purpose is often less demanding than for EVs or electronics (Paul Jennings, personal communication, 2018). To this end, Aceleron is currently targeting electronic bikes, canal boats, caravans, coaches and home energy storage applications for their batteries (Thomas, 2018). It is estimated that once repurposed, many EV battery packs could be used for another 10 years in energy storage operations (Harrison, 2018). In accounting for the battery's potential post-first-life use at the design stage of production, Aceleron is able to reuse and remanufacture its batteries at their typical end of life, thereby extending the battery pack's use and mitigating waste.

4.2 Opportunities Along the Recycling Supply Chain

INVESTMENTS IN IMPROVED COLLECTION INFRASTRUCTURE, TECHNOLOGY DEVELOPMENT AND KNOWLEDGE CREATION

Along the recycling supply chain, there are many opportunities and solutions to overcome the barriers outlined in Section 3. For one, it is imperative that collection infrastructure and services are expanded and designed to handle lithium-ion batteries, especially in the electronics sector. The collection rates for laptops and mobile phones have so far been relatively low (Tojo & Manomaivibool, 2011). Efforts should be made to increase awareness of (and access to) collection services for electronics both at the end of their first life and for those in hibernation. Further, in order to avoid fires, these collection services must employ expert handling in order to safely store and transport the batteries (One Call Collection, 2016). Finally, a greater understanding of where post-first-life reserves of minerals are located, their

“It is imperative that collection infrastructure and services are expanded and designed to handle lithium-ion batteries.”

quantities and how accessible they are, is required to facilitate better collection services. Governments, the private sector, and civil society should invest in long-term knowledge and technology development to gain a better understanding of these circumstances, in order to build the appropriate mineral collection and retrieval infrastructure. Researchers at Linköping University are answering some of these questions in their ongoing work on urban and landfill mining in Sweden, expanded upon further in Case Study 2.

Case Study 2: Urban and Landfill Mining in Sweden

According to researchers at Linköping University based in Sweden, almost half of all extracted natural resources are no longer in use, but can be found in various obsolete material stocks, such as disconnected power and telecom networks, pipe infrastructure and abandoned buildings (Linköping University, 2019). Urban and landfill mining offers a potential to recover these natural resources—including lithium and cobalt, but mainly base minerals like copper and iron—by scouring disconnected infrastructure and retrieving the minerals therein for recycling. The motivation for urban mining is typically driven by the need to recover a certain mineral; the value and quantity of which, however, can sometimes be difficult to ascertain (Joakim Krook, personal communication, 2019).

Like traditional mining, urban mining requires first a mapping and prospecting phase, in order to determine where the mineral stocks are, who owns them, their quantities and how they can be accessed (Joakim Krook, personal communication, 2019). This is the task of team members at Linköping University, who are developing knowledge on when, where, how and by whom mineral recovery from subsurface infrastructure can be justified from both an environmental and economic perspective (Linköping University, 2019). This research will also extend to stocks of hibernating electronics and will assess gaps in consumers’ knowledge and behaviours regarding mobile phone disposal (Joakim Krook, personal communication, 2019). This knowledge development will supplement data on the existing used stocks of minerals like lithium and cobalt, thereby informing the business case for better collection services and infrastructure.

"Even the most sophisticated electronics recycling plants recover only a small fraction of the materials in mobile phones – all of which, on current commercial markets, bypass lithium recovery completely."

DESIGNING EQUIPMENT AND FOSTERING COLLABORATION FOR RESOURCE RECOVERY

Once products are collected, it is not guaranteed that the different minerals they contain will be recovered. Even the most sophisticated electronics recycling plants recover only a small fraction of the materials in mobile phones, all of which, on current commercial markets, bypass lithium recovery completely (Scott, 2014; Michael Green, personal communication, 2018). But several actors at the production stage of the lithium and cobalt recycling industry are working to overcome this barrier, by making the recycling process more economically viable, efficient and tailored to lithium-ion batteries. Moreover, better testing of the efficiency of batteries and identification of the minerals therein is essential to this stage. Currently, most battery recycling facilities are customized for lead-acid battery recycling and are therefore not set up to meet the demands of the EV boom. Companies like Li-Cycle, based in Canada, are working to improve the recovery rates of lithium-ion batteries through the use of mechanical and hydrometallurgical methods, in order to recover both the cobalt and the lithium (see more in Case Study 3).

To ease this stage in the supply chain, some actors—collection services, battery testers, recycling companies manufactures—are partnering to establish a single point of contact for end users. This collaboration reduces complexity in recycling supply chain and can help to provide specialized processes where the industry may be underdeveloped. In 2018, for example, UK-based companies Axion, Aspire and Aceleron partnered to target together the growing number of end-of-life EV batteries. Aspire first processes the batteries; Aceleron then tests the batteries and repurposes them based on their efficiency; finally, if the they cannot be repurposed, reused or remanufactured, Axion will collect the batteries for recycling (Gopie, 2018). In this joint venture, costs and benefits are shared.

To scale collaboration and foster investments into process innovations to recover a range of minerals efficiently and effectively from products and advance approaches like remanufacturing, a stable and long-term investment climate for the recycling supply chain is needed. As discussed in Section 3.1, raw material price fluctuations impede a stable investment climate. Policy measures could aim at ensuring more certainty to investors by providing grants, co-financing and R&D investments through, for example, pre-commercial procurement. Long-term purchase agreements could be used once recycling facilities are commercially viable and want to secure that manufacturers are buying secondary minerals instead of shifting to the primary raw material market when prices drop there.

Case Study 3: Recovering the Lithium in Lithium-Ion Batteries

Although some recycling companies may engage in lithium-ion battery recycling, few ever recover the lithium itself. Traditional battery recycling uses pyrometallurgical technology, applying thermal treatment to recover the materials. While effective, this method typically only recovers 40 to 50 per cent of the materials, excluding the graphite, aluminum, lithium, and plastic also found in batteries (Li-Cycle, 2019). These minerals then become permanent waste that cannot be reused. Li-Cycle however, a Canadian recycling company, uses mechanical and hydrometallurgical technology to extract materials from lithium-ion batteries, recovering approximately 80 to 100 per cent of the materials – including the lithium (Ajay Kochhar, personal communication, 2018).

Not only does this method recover more of the minerals, the technology is also less energy-intensive than current lithium-ion battery recycling on an industrial scale (Li-Cycle, 2019). The process is tailored exactly to lithium-ion batteries, to ensure safe working conditions during recovery. According to representatives from the company, this method will incentivize a higher rate of recycling because associated costs will be brought down significantly (Ajay Kochhar, personal communication, 2018). Li-Cycle is in the pilot and commercial demonstration phase of their project. (Ajay Kochhar, personal communication, 2018).

IMPROVING PUBLIC PERCEPTION OF SECOND-LIFE PRODUCTS

The public perception of used batteries and other second-life products must be improved to enhance demand for secondary minerals. Ongoing research and testing regarding the efficiency of used battery cells should be scaled and disseminated to broad audiences so that minerals in their post-first-life use are viewed by end-consumers—and policy-makers and businesses—as reputable and legitimate.

4.3 Cross-Cutting Regulatory Opportunities and Recommendations

Many of the solutions outlined above will be ineffective if the appropriate policy and market conditions do not reflect the corresponding demands of the circular economy and SDGs. While recycling rates for some minerals and metals—including iron, steel and chromium—are quite high, policy efforts will be needed to expand the scope of this recycling to other minerals, including lithium and cobalt (OECD, 2019b). To spur innovation in the private sector, governments can offer economic incentives, including: tax abatements, tax revenue sharing, grants, infrastructure assistance, or no- or low-interest financing (Bakertilly, 2017) and R&D funding through pre-commercial procurement. Governments can also take advantage of their demand power for circular solutions and recycled content through public procurement. In 2009, for example, the United States offered a grant of USD 9.5 million to a recycling company to construct the first national lithium-ion battery recycling facility (see more in Case Study 4). Mechanisms such as these incentivize innovation for businesses and mitigate market barriers.

Case Study 4: Incentivizing Lithium-Ion Battery Recycling Through Grants in the United States

As stated by the recycling company Retriev Technologies, "When it comes to battery recycling, one size does not fit all." (Retriev Technologies, 2019). Retriev Technologies recycles lead-acid, NiCad + NiMH, lithium-ion, primary lithium and alkaline batteries using hydrometallurgical, pyrometallurgical, or sometimes hands-on mechanical disassembly operations (Retriev Technologies, 2019). These varying methods account for the composition of the battery, thereby maintaining safety and efficiency of recovery processes. In 2009, Retriev Technologies (then Toxco Inc.) received an award of USD 9.5 million from the US Department of Energy to construct the first recycling facility for lithium-ion batteries in the country (U.S. Geological Survey, 2018). This grant aimed to support the growth of EVs and hybrid vehicles in the United States, their appropriate waste disposal and the subsequent job creation and employment generated from the new facility. The new facility opened in Lancaster, Ohio in 2015 and is currently in operation (U.S. Geological Survey, 2018). It recycles a multitude of lithium-ion batteries, including those that have substituted cobalt for other minerals, including iron phosphate, manganese spinal, and nickel manganese (Retriev Technologies, 2019). Its current recycling process mainly recovers copper, aluminum and cobalt.

In addition to economic incentives, the public sector can also help overcome regulatory barriers through the evaluation of current policy and legislation. This evaluation should be done in collaboration with the private sector and civil society, in order to account for what is economically feasible and ensure that any regulations

are reflective of—and iterative to—the changing needs of the recycling industry. Many of the regulations were developed and adjusted for traditional mining practices or the recycling of lead-acid batteries, neither of which account for the increased use, production and waste of lithium-ion batteries. As such, actors in the public sector should take action to draft and update waste management and mineral recycling regulation by:

DEVELOPING UNDERSTANDABLE AND APPLICABLE DEFINITIONS OF RECYCLING AND OTHER POST-FIRST-LIFE PROCESSES

While the UN Basel Convention references resource recovery, recycling, reclamation and reuse, it does not provide definitions for any of these processes. In the case of urban mining, “disconnected infrastructure” can be a source of valuable material stocks, but is not well defined and so it becomes more difficult to justify where, when and why excavation of these spaces should take place. Many other stakeholders identified a similar lack of clarity in post-first-life process definitions related to ineffective policy guidance. As such, clear definitions on terms including “producer,” “second life,” “remanufacture,” “reuse,” “recycle” and are required. In addition to clarifying these definitions, international agreements and the definitions therein should be strengthened to account for the lack of transparency in the flow of waste—discussed in Section 3.2—especially amid any changing trade patterns that would ensue from transitioning to a circular economy (OECD, 2019a).

CLEARLY DESIGNATING THE ACTORS RESPONSIBLE AND LIABLE FOR RECYCLING THE MATERIALS

Related to this lack of definitions regarding post-first-life processes, many stakeholders identified a lack of guidance from policy-makers on designating which actors are liable and responsible for products at their end of life. For some sectors, like the automotive industry, this designation is clearer; for others, like the electronics industry, the responsibility of who should manage products at their end of life is not consistently defined. Many stakeholders stated that the original producers of the EV or electronic product should take on more responsibility for the product at its end of life, applying the EPR principle. Doing so would create an incentive for producers to prevent waste at the source, including by designing products that are easier to dismantle and visibly labelling the material contents of their batteries.

SETTING MEANINGFUL TARGETS ON RECYCLING EFFICIENCY RATES

As discussed in Section 3.3, some existing regulations, like the EU Batteries Directive, have set targets for recycling efficiency rates. These recycling efficiency rates are more appropriate for lead-acid battery recycling and do not account for the upcoming EV boom fuelled by the low-carbon transition. As such, these targets should be re-evaluated (or in some cases developed from scratch), to spur higher recovery rates in lithium-ion battery recycling. These recommendations also hold true for other electrical and electronic equipment that contain minerals like lithium and cobalt.

COMMUNICATING THESE REGULATIONS TO BUSINESSES AND CONSUMERS

In order to stimulate long-term investments in the secondary processes for lithium and cobalt, these operations must be put on the policy agenda—and that agenda communicated to the public. This will stimulate transparency and openness while improving the buy-in for those who have influence over these processes.

EVALUATING THE RISKS AND BENEFITS OF MINERAL RECYCLING USING MULTIPLE VALUES, TO ESTABLISH THE BUSINESS CASE

As discussed in Section 2.2, increased lithium and cobalt recycling has significant ramifications for multiple objectives of sustainability: mitigating waste production, improving material efficiency, decreasing the reliance on finite resources, and encouraging innovation, among others. Often though, the evaluation of projects may be narrow, focusing on only one or two of these values. As such, increased coordination between those responsible for each of these objectives should be encouraged, so that lithium and cobalt recycling projects are evaluated for their overall importance to the circular economy and the SDGs.

5.0 Conclusions

Key Messages:

- While recycling has long been a central tenet of circular business models and sustainable development, it has been insufficiently adopted in lithium and cobalt supply chains.
- It is of paramount importance that recycling be incorporated into mineral and metal supply chains—and especially those of cobalt and lithium—in order to ensure a responsible, maintainable and stable transition to a low-carbon economy.

"Cobalt and lithium will play an integral role in the transition to a low-carbon economy."

Cobalt and lithium will play an integral role in the transition to a low-carbon economy. Lithium-ion batteries, which contain the two minerals, are crucial to this transition; they are used in EVs and energy storage for solar panels and wind turbines, in addition to their central role in electronics including smartphones and laptops. Each of these technologies will contribute to the global commitments set out by the Paris Agreement and the 2030 Agenda for Sustainable Development. While demand for cobalt and lithium is expected to increase substantially, driven largely by the growing EV market, global supplies of both minerals are not projected to meet this demand, with shortfalls expected in the coming decade (Greenwood, 2018; Holmes, 2018). Concerns along the supply chains of both minerals—including the potential use of child labour in cobalt extraction and the intensive use of water and energy in lithium production—place additional strain on the responsible sourcing of both.

Mineral recycling, as part of the circular economy, may mitigate these supply shortfalls and address supply chain challenges by extracting metals and minerals from products and infrastructure no longer in use. Despite this advantage, the recycling rates of cobalt and lithium are extremely low. This is due to a number of ongoing barriers along the primary and recycling supply chains of cobalt and lithium, including: raw material price fluctuations, a lack of eco-design, the hibernation of electronic devices, a lack of consumer awareness regarding collection services, inefficient collection and recycling infrastructure and equipment, safety concerns and transparency issues, among others. These barriers are exacerbated by a lack of guidance from regulators and policy-makers, most notably in defining key terms of secondary processes, the allocation of responsibility among actors in the supply chain and setting concrete recycling targets.

Civil society, private actors and the public sector must work together to overcome these barriers to ensure that supplies of cobalt and lithium meet demand while upholding human rights and environmental protections. Doing so will contribute to goals put forth by both the circular economy and the SDGs. Much can be done; in particular, actors along the primary and recycling supply chains of both minerals should:

- Bolster transparent and responsible sourcing
- Enhance eco-design and product transparency
- Raise consumer awareness regarding collection services
- Extend product lifetimes through reuse and remanufacturing processes
- Invest in improved collection and recycling infrastructure and equipment
- Foster collaboration
- Improve the perception of second-life products.

In the public sector especially, regulations should be developed that clearly define secondary processes, designate actors responsible and liable for recycled materials, and enable more comprehensive evaluations of recycling operations. These should then be communicated to businesses and consumers.

Recycling has long been a central tenet in circular business models and sustainable development. However, its adoption in the mining sector has been neither widespread nor comprehensive. It is of paramount importance that recycling be incorporated into metal and mineral supply chains—and especially those of cobalt and lithium—in order to ensure a responsible, maintainable and stable transition to a low-carbon economy.

> "Recycling has long been a central tenet in circular business models and sustainable development. But its adoption in the mining sector has not been widespread or comprehensive."

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Annex 1: Waste Disposal and Recycling Governance Mechanisms

In recent decades, a range of governance mechanisms have been developed on waste disposal and mineral recycling processes for electronics and batteries. While the designation of who is responsible for secondary processes varies based on sector, the "polluter pays" and its derived principle of "extended producer responsibility" (EPR) have increasingly gained traction. EPR requires targeted producers to assume some or full administrative, financial and/or physical responsibility for collection, recycling and waste disposal operations (OECD, 2001). Cobalt and lithium recycling is and will continue to be shaped by these national and international regulations, policies and international conventions, some of which are described in greater depth below.

THE EUROPEAN UNION

EU Batteries Directive

In the EU, lithium-ion batteries—and subsequently much of lithium and cobalt recycling—is governed under the EU Directive on batteries and accumulators and waste batteries and accumulators (Batteries Directive). This directive provides the legal framework for the manufacture and disposal of batteries in EU member countries. First launched in 1991, the Batteries Directive was later consolidated in 2006, amended in 2008 and 2013, and is currently undergoing assessment (European Commission, 2018a). EU member states are expected to integrate the Directive into national law. The Batteries Directive aims to improve the environmental performance of all actors involved in the life cycle of batteries—in particular operators responsible for the treatment and recycling of post-first-life batteries (European Commission, 2018b). It applies the principle of EPR, requiring producers of certain products to be responsible for waste disposal at the end of the product's first life. In addition, the Batteries Directive aims to ensure harmonization of the EU's internal market in regard to placing batteries and accumulators on the market. Finally, the Directive sets targets for recycling efficiency and provides measures for the establishment of schemes that foster high collection and recycling rates of batteries (European Commission, 2018b).

EU Raw Materials Initiative

The EU's Raw Materials Initiative was launched as the EU's raw material policy in 2008, and was consolidated in 2011. This strategy covers all raw materials used by European industries, except for materials from agriculture and the raw materials used as fuel. The overarching aim is to secure sustainable supplies. One core element of this integrated policy strategy promotes raw materials recycling, aiming to accelerate resource efficiency and increase the supply of post-first-life raw materials, in order to reduce the EU's dependency on primary raw materials (European Commission, 2019). This, in theory, should incentivize improved lithium and cobalt recycling. A list of critical raw materials was introduced in 2011 as part of the consolidation process of this policy. The list was updated in 2014 and 2017 and includes cobalt, among other minerals, although it did not include lithium (European Commission, 2017).

EU WEEE Directive

The EU WEEE Directive prescribes producers placing electrical or electronic products on the EU market to be responsible for the collection, treatment and recycling of these products, again applying the EPR principle. The first WEEE Directive came into force in 2003, which was amended in 2012 and launched again in 2014 (European Commission, 2018c). Because electrical and electronic equipment—such as computers, cell phones, household appliances and lighting equipment—usually contains a range of minerals, including cobalt and lithium, the Directive is of relevance for mineral recycling and reuse rates in the EU.

The new WEEE Directive defines collection targets for EU member countries: from 2019 onwards, the target is 65 per cent of equipment sold or 85 per cent of WEEE generated. Member countries are expected to comply with these targets and report on their collection rate. Additionally, the new WEEE Directive provides measures to counteract the illegal export of WEEE. Exporters are required to test and provide documentation on the nature and legality of their shipments (European Commission, 2016).

CANADA AND THE UNITED STATES

Neither Canada nor the United States have so far adopted federal laws to govern the recycling of WEEE. However, recycling regulations on a provincial and state level are spreading in both countries.

Currently, all 10 Canadian provinces have implemented regulations and programs for WEEE and waste batteries, though these approaches differ from province to province. The three Canadian territories lag behind in regard to regulations for WEEE recycling. In line with regulations in the EU, the EPR principle is applied in all Canadian provinces to steer the end-of-life management of WEEE and waste batteries (Maddock, 2017). This was promoted through a Canada-wide EPR Action Plan launched by the Canadian Council of Ministers of the Environment (CCME), an intergovernmental forum and coordination platform for the 14 environmental ministers from federal, provincial and territorial governments. The forum serves to discuss and develop national strategies, standards and guidelines to address environmental issues across Canada (Séguin, 2014).

In the US, 28 states have adopted WEEE recycling laws, most of which apply the EPR principle. States follow varying approaches to reach recycling targets, but the majority set performance levels for manufacturers for the collection of WEEE, similar to the target approach in the EU. In some states where no recycling regulations are established, WEEE collection and take-back programs are implemented voluntarily by local governments, non-profits or private companies (Initiative for Global Environmental Leadership, 2016).

The provincial and state-level recycling regulations in Canada and the United States are currently critiqued as a complicated patchwork, making compliance for manufacturers more difficult and expensive than a unified, coherent federal law (Initiative for Global Environmental Leadership, 2016). In addition, states in the US lack jurisdiction over the export of WEEE while at the same time, the United States is not part of the Basel Convention (see below). Finally, legislative governance of WEEE in Canada and the United States is criticized for failing to implement the EPR principle; instead of ensuring that individual manufacturers take on financial responsibility, manufacturers manage to allocate the financial burden of the recycling system to consumers through fee-based systems.

CHINA

China is the largest EV market in the world and as such uses a high number of EV batteries (Bloomberg News, 2018). The needs and business opportunities represented by the reuse, remanufacturing, or recycling of EVs and their component minerals at the end of their first life, including lithium and cobalt, was recently recognized by Chinese regulators. The Chinese Ministry of Industry and Information Technology announced in 2018 a pilot program for repurposing and recycling EV batteries in 17 major regions and cities (Reuters, 2018). The program applies the EPR principle and is meant to curb environmental pollution from waste batteries. Automotive companies are called to offer recycling services and are encouraged to cooperate with other supply chain actors such as car dealers, battery producers and scrap dealers to establish collection and recycling systems in the pilot regions (Reuters, 2018).

Furthermore, the regulation for a Battery Recycling and Traceability Management Platform was launched in 2018 to foster the manufacture of EVs with a longer life. The regulation introduces an ID system for EV batteries to enable the tracking of batteries during their lifecycle and supports EV companies in planning the post-first life use of EV batteries (IDTechEx, 2018).

China generates the highest amount of WEEE globally: 7.2 million metric tons in 2016. In response, the country has adopted several national regulations for collection and recycling of some WEEE product groups, including TVs, computers, refrigerators, washing machines and air conditioners. Consequently, the formal WEEE recycling sector is steadily growing and demonstrated a national collection and recycling rate of 18 per cent in recent years. Despite these improvements, the informal recycling sector is still dominant in China (Baldé, Forti, Gray, Kuehr, & Stegmann, 2017).

OTHER PARTS OF THE WORLD AND INTERNATIONAL MECHANISMS

Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal

The UN's Basel Convention was adopted in 1989 to protect human health and the environment against the adverse effects of hazardous wastes, household wastes and incinerator ash (Basel Convention, 2011). In particular, the intention was to prevent unregulated transfer of hazardous waste from developed to less developed countries. As of December 2018, there were 187 parties to the treaty (Basel Convention, 2011). The core objectives of the convention are to reduce the generation of hazardous wastes, promote their environmentally sound management at disposal and to restrict transboundary movements of hazardous wastes, especially from developing to less developed countries, unless environmentally sound management is ensured (Basel Convention, 2011). Under the Basel Convention, waste is defined as substances which are disposed of, intended to be disposed of, or required to be disposed of: it thereby applies to the disposal operations of lithium-ion batteries, and subsequently lithium and cobalt (Basel Convention, 2011). Further, the Nairobi Declaration on the Environmentally Sound Management of Electrical and Electronic Waste and decision IX/6 adopted by the COP provided a mandate to the Secretariat to develop a work plan for the environmentally sound management of WEEE. A strong focus is on supporting WEEE management in vulnerable regions, including Asia Pacific, South America and Africa (Basel Convention, 2011).

LATIN AMERICA

In Latin America, the management of WEEE and waste batteries is regulated in many countries under solid waste and hazardous waste legislation; legislation specific to these product types however, tends to be absent. The financial responsibility for end-of-life management is often allocated to the waste holder instead of implementing the EPR principle, resulting in a lack of incentives for eco-design, reuse and remanufacturing (International Telecommunications Union, et al., 2016). Seven countries in the region enforce national regulations on WEEE, apply the EPR principle and are active on implementing formal recycling systems: Bolivia, Chile, Colombia, Costa Rica, Ecuador, Mexico and Peru. While there is progress—and many countries in Latin America are expected to adopt specific legislation for WEEE and waste batteries in the coming years—there are major challenges with respect to establishing and enforcing formal recycling systems, ensuring sufficient collection of WEEE, installing the respective collection and recycling infrastructure to handle this waste stream and recover valuable components such as rare earth metals and other minerals. Today, valuable fractions of this waste stream—including waste batteries that contain lithium and cobalt—are exported to the United States, Europe or China (Alvarenga & Perrier, 2018; International Telecommunications Union, et al., 2016).

AFRICA

Very few countries in Africa have implemented regulations to govern WEEE but the concern and interest to do so is increasing. Ghana, Madagascar and Kenya have formally passed draft bills on WEEE into law. Cameroon, Nigeria, South Africa and Zambia have initiated similar legislative agendas. Uganda and Rwanda have developed official policy documents for WEEE management. However, the implementation of formal recycling systems and execution of official WEEE management is limited on the ground. Instead, in most countries a large, informal collection and recycling sector is prevalent, government control is minimal, take-back schemes are inefficient, the technical infrastructure for recycling is absent, countries are burdened by WEEE exports from other parts of the world, public budgets are strained and the viability of EPR schemes is limited due to a widespread lack of manufacturers within countries (Baldé, Forti, Gray, Kuehr, & Stegmann, 2017).

ASIA

The recycling governance landscape for WEEE and waste batteries in Asia is highly diverse. China is making considerable progress (see above) and countries like South Korea and Japan have among the most advanced formal recycling systems globally. India generates a significant amount of WEEE domestically, receives considerable amount of WEEE exports from developed countries and has one of the fastest growing electronic industries globally. While the informal recycling sector remains dominant in India, a federal electronic waste management regulation with EPR elements has been in place since 2016, and major cities have started implementing formal recycling systems. Some countries in Southeast Asia, South Asia and Western Asia have started promoting and adopting WEEE legislation, while other countries, such as Sri Lanka and Bangladesh, and the entire Central Asian region, have no formal governance mechanisms at all. More details can be found in the Global E-waste Monitor 2017 (Baldé, Forti, Gray, Kuehr, & Stegmann, 2017).

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