WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

Industry Agenda

Mining & Metals in a Sustainable World 2050

Prepared in collaboration with The Boston Consulting Group

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Contents

Foreword

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The mining and metals industry is an integral part of any foreseeable economy and society. As a provider of employment and essential materials, it is connected to almost all industry value chains. Yet, the industry faces major challenges and uncertainties.

The weakness in global markets following the financial crisis has been compounded by falling commodity prices and the short-termism of many shareholders. The industry is also under pressure from stakeholders, ranging from changing consumer demands to the promotion of sustainable resource use by regulatory bodies. Companies are increasingly expected to operate more sustainably and to define and implement action reflecting this priority.

This report comes as the post-2015 development agenda kicked off with the Finance for Development Summit in July and as the world prepares for the UN Summit on the Sustainable Development Goals (SDGs) in September in New York and the UN climate change conference in December in Paris. The mining and metals sector is essential to the achievement of this agenda through its activities and products and will launch a joint mapping of the sector and SDGs later in 2015.

Although many stakeholders have set objectives for more sustainable and responsible mineral development, the path towards a more sustainable world is full of uncertainties. There is an opportunity for different actors in the sector to develop solutions to these shifts and move beyond a passive acceptance of their consequences to pro-active action and innovation. A clear understanding of the potential challenges and opportunities is now key to prospering in a changing environment and finding new opportunities for growth.

The *Mining & Metals in a Sustainable World 2050* project was launched against this backdrop and with the support of the Boston Consulting Group as project advisor. The report focuses on strategies and actions for companies, and aims to enable and contribute to a discussion about the sustainable future of the planet. The goal is for companies to not only think about these issues, but also to act upon them. It also highlights the major transitions that will shape the mining and metals value chain in this new sustainable world, and to provide a framework to support the actions required.

The report is the direct result of a cooperative process with members of the private sector, governments, the academic community, civil society and multilateral organizations from around the world. The World Economic Forum is extremely grateful to many stakeholders for their input and support, and looks forward to pursuing dialogue as this work continues.

Executive Summary

The world is transforming – mining and metals can shape its own agenda

Mining and metals are essential to global economic and social development and are connected to almost all industry value chains. As an inherently long-term investment, a long-term perspective is crucial.
By 2050, the world will be different, as will the way resources will be used. Rules are changing, social pressure to act more sustainably is growing, and technological advances are disrupting all sectors. While the direction towards a more sustainable world is clear, the path is not. This is an opportunity for the mining and metals community to define the role it can play to shape the agenda and to embrace the changes to come.

- How can the sector embrace these transformations?
- What business models and strategic priorities will enable success?
- What actions do companies need to take now to better prepare themselves to be industry leaders in 30 years' time?

Building a framework for mining and metals

Under the mandate of the World Economic Forum's Mining & Metals Industry Governors Community, a framework to guide the sector in this transition to a more sustainable world has been developed. The framework aims to help navigate and shape the agenda of tomorrow, having identified a number of critical questions:

- What will the balance between primary and secondary commodity supplies look like in the future?
- Which supporting resources (such as water and energy) face the largest risks of scarcity and cost increase?
- What are the long-term downstream/end-use trends that could impact the sector most?
- Which technological developments will impact mining and metals?
- What needs to be done to ensure the industry can attract the right skills in the future?
- How is regulation being shaped and how are the different regulatory speeds being addressed?
- Which parts of the business model and overall strategy need to be adjusted in a more sustainable world?

The Forum's Global Agenda Council on Responsible Mineral Resource Management identified key drivers of change, outlining the transformations in process and to come.

Looking forward to 2050, four fundamental principles of sustainability were asserted, framing the desired end state and the way the industry should operate in a sustainable world. The four principles are grouped under: environment and climate conservation, fair value and development (responsible mineral development), transparency and human rights, health and well-being.

Looking at the mining life cycle and value chain, critical areas of transition were also identified along which change is necessary and achievable (the resource base, strategy and the operating model, technology and innovation, people and workforce, external relationships, demand – value chains). Three scenarios, each outlining a different road towards 2050, were applied to identify different potential actions and to start building a roadmap. The scenarios were developed on the basis of the report "*The Future Availability of Natural Resources: A New Paradigm for Global Resource Availability",* published by the World Economic Forum in 2014.

Pilot case study: Circular use of commodities and metals

The framework was tested with a pilot case study on the circular use of commodities and metals, focusing on the balance between primary and secondary resources and a potential transition towards circularity. Across different scenarios key findings of the pilot included:

- A strong move towards recycling and circularity is likely, but fundamental changes are required to support this transition, including appropriate infrastructure, regulation and legislation, and competitive cost economics.
- Mining will not disappear. Primary extraction will continue but volumes are unlikely to grow in line with GDP growth. This means that pressure to realize scale effects and cost efficiency will remain in the foreseeable future. Demands for cost effectiveness will exist in parallel with demand for environmentally and socially responsible actions, leading to new partnership and operating models.
- Metals will not disappear. Metals companies will act as a liaison between commodity producers and end industries. Opportunities will exist to adapt business model transformations and reposition as materials providers.
- Technology will be key. Mining companies have an opportunity to focus on waste treatment optimization and metal companies on the improvement of low-grade processing capabilities.
- It will become increasingly important to better understand supply chains and consumer preferences.

Next steps

This report serves as a foundation for further explorations of the challenges and opportunities for the mining and metals agenda in 2050. In a first step, companies and other stakeholders can apply the framework as a tool to analyse existing strategies and actions across the areas for transition and identify missing elements and key opportunities critical for the journey towards a sustainable world. We hope this will help to trigger new ideas, actions and partnerships that will be required for collaborative action by various stakeholders. Continuing our efforts to help create industry-specific insights through focussed research work, the next area the World Economic Forum will explore in more depth with be the role of technology, and especially the digital transformation of the industry.

Mining & Metals in a Sustainable World 2050 – A Case for Action

Mining and metals are essential to the global economy and societal development. Standing at the beginning of most value chains, the sector is a critical supplier of essential materials and products and a global generator of trade, employment and economic development.

To be essential is not, however, to be immune from pressure or criticism. The mining and metals sector faces significant demands and expectations from across the value chain and stakeholder groups – from shareholders and customers, to governments, communities and consumers. In a constantly changing world, global disruptions and transformations towards a more sustainable and equitable future are challenging the traditional way of doing business.

Sustainable development is a well-documented challenge for the planet in the years leading up to 2050, and beyond. More recently, 2015 has been a critical year as the world convenes to collectively agree on pathways forward on goals for sustainable development (UN Summit on Sustainable Development Goals), financing of development (International Conference on Financing for Development) and on climate change (UN climate change conference).[1]

It is estimated that between now and 2050 the world's population will grow from just over 7 billion to 9.6 billion,[2] along with further growth in consumption per capita. The bulk of that growth will take place in Africa and Asia, where the demand for an improved quality of life will drive the need to access goods and services. Africa, for example, now has the fastest-growing middle class in the world. Some 313 million people, 34% of Africa's population, spend $2-20 a day, a 100% rise in less than 20 years, according to the African Development Bank. How to accommodate those demands and needs within planetary boundaries is one of the great challenges facing decision-makers in all regions and industrial sectors.

The World Economic Forum's recent report, *The Future Availability of Natural Resources*, shows that opinions vary on the speed with which natural resources are depleting.[3] Irrespective of the speed of use or depletion, it has become critical to use the planet's resources more sustainably.

The mining and metals sector is central to the success of meeting the demand of global growth in a more sustainable world. The industry has responded, shifting its mindset, strategies and activities; 80% of senior executives believe that sustainability-oriented strategies are essential for current and future competitive advantage[4] while 63% of chief executives expect sustainability to transform their industry within five years.[5] Between 2011 and 2013, the number of commodity companies reporting proactively on sustainability strategy and criteria has increased by almost 58%.[6]

At the same time, governments are introducing and improving regulation and legislation on relevant areas such as water, social benefits and biodiversity; climate change alone has more than 300 legislative measures worldwide already.[7] However, the level at which such regulations have been conceived and administered varies widely in different countries. This presents a need to harmonize regulatory frameworks globally to avoid possible clash of interests. This is increasingly being witnessed in countries which have joined free trade agreements, and, contractually, are no longer able to ban the importation of mineral commodities produced under less stringent environmental regulation than their own national laws mandate. Domestic firms that incur costs by complying with regulations and by producing in an environmentally sound manner could be put at a competitive disadvantage.

Organizations such as the World Business Council on Sustainable Development (WBSCD) and the International Council on Mining and Metals (ICMM) have helped shape the industry agenda by ensuring that the mining, minerals and metals industry is responsive to global needs and challenges. Although not primarily focused on mining, WBCSD has been promoting more systematic and integrated environmental management by companies. Its Vision 2050 outlines a new agenda to achieve a sustainable future with an action plan for 2020 identifying how business can positively influence environmental and social trends while strengthening their own resilience to issues like climate change, demographic dynamics and skills shortages. Towards the same end, ICMM is working with leading mining and metals companies and others to strengthen the sector's contribution to sustainable development by improving environmental and social performance.

The will to contribute is clear. The question of how remains a significant challenge for the sector and will require the alignment of the operations of a large and complex industry in a sustainable direction for the long term while maximizing the short and medium-term benefits, in terms of both products and employment, which it brings to its many stakeholders.

This study by the World Economic Forum, in partnership with The Boston Consulting Group, takes those discussions further. Building on the knowledge from within and beyond the sector, an industry framework was developed to guide and support a company and the sector in a successful transition towards a more sustainable world by 2050. Identifying the critical drivers of change in a changing world and areas where transition is required, the framework helps explore how mining and metals value chains could be impacted and what roadmap of actions will be necessary for success.

This report is presented in two sections: first, the framework to guide actions for the mining and metals sector in a sustainable world 2050 is presented, and second, an in-depth case study applies the framework to the circular use of metals. Forward thinking is key to industry leadership and success. The more sustainable world examined in this report could have profound long-term implications for how this industry performs; today's preparation will determine tomorrow's achievements.

A Framework for Mining & Metals in a Sustainable World 2050

In 2013, the World Economic Forum and its Global Agenda Council on Responsible Mineral Resource Management[8] published a scoping paper[9] examining the potential implications of a sustainable world for the mining and metals community. The paper, outlining the drivers of fundamental change facing the world and their possible impact on the industry, was presented at the World Economic Forum Annual Meeting 2014 in Davos, Switzerland, and identified as a priority topic for the industry and to which the Forum could add value.

A launch workshop, in June 2014, brought together 35 multistakeholder leaders from across regions, and who identified the need for an overarching framework specific to the mining and metals sector. An advisory group of global experts representing different stakeholder groups supported the development of this framework and its application to the case study on the circular use of metals.

The goal in developing a framework is to facilitate a long-term view of the business landscape and evaluate the role mining and metals companies could play in ensuring that resources are leveraged efficiently and responsibly. It offers a strategic foresight into the transformations which are likely to define the industry's journey towards a sustainable world. Mining and metals companies can apply the framework to conduct "pulse checks" to evaluate if their existing strategy is well-positioned to maximize sustainable value creation as the world transitions. By identifying missing or underdeveloped elements that are critical for the journey towards a sustainable world, organizations can evaluate and adjust their existing approach or trigger new action plans.

Principles of a sustainable world in 2050

Principles of sustainability developed by organizations such as the WBCSD,[10] the Natural Step,[11] the ICMM[12] and others[13] provide important thought leadership and guidance for businesses and government. Since the world, and any desired state, in 2050 will vary for different stakeholders and through time as we advance towards the second half of this century, a specific end goal is difficult to define. Instead, a set of overarching principles have been identified to set the direction of the sector to a more sustainable world and allow for goals and actions to be adapted as contexts change. It is from this desired end state that it is possible to backcast to today's context and begin to assess what is required for that journey to be successful.

Environment and climate conservation
Conserving the environment and climate means that the mining and metals sector operates within the physical and environmental boundaries of the planet. The systematic extraction of concentrated substances from the earth's crust cannot be sustained indefinitely on a finite planet.[14] Developing processes and technologies, which enable a lower carbon footprint along the value chain and which facilitate a more circular economy, are core business.[15]

Fair value and development
The value created by mining and metals is done so fairly, enabling sustainable development and improved livelihoods.[16] Value is shared between different stakeholders – communities, shareholders, investors, national and local government – and between different countries.[17]

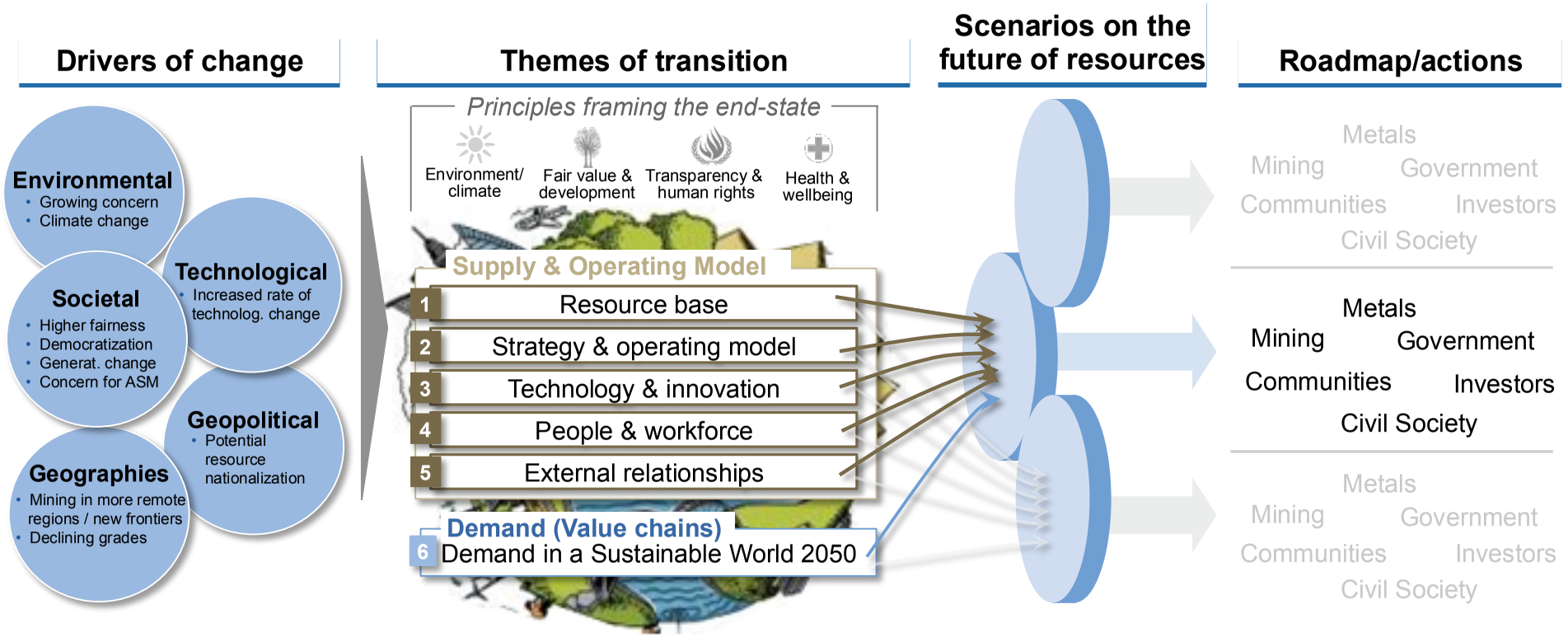
Transparency and human rights
Governments and businesses operating with respect for human rights and equality, committed to anti-corruption and being transparent with payments and information. Trust, dialogue and partnerships are key to business success.

Health and well-being
Ensuring the health, well-being and safety of workers, their families and surrounding communities remains a foundational value.

The framework for Mining & Metals in a Sustainable World 2050 consists of the following four components (Figure 1):

1. Drivers of change
2. Areas of transition
3. Scenarios on the future of resources
4. Roadmap/actions

Figure 1: The Mining & Metals in a Sustainable World 2050 framework



Drivers of Change

Significant changes are expected during this journey to a sustainable world. In 2013, the Global Agenda Council on Responsible Mineral Resource Management identified critical global drivers of change impacting and influencing the sector now and driving transformations of the future. The drivers of these changes are clustered under five pillars, representing the key dimensions of the mining and metals industry ecosystem: environmental, technological, societal, geopolitical and geographies (Figure 2).

For any mining and metals company, understanding the drivers of change in their context today (geography, commodity, partnership model, etc.) and tracking of related trends is important to allow them to proactively prepare and adapt to a transforming business environment.

Areas of Transition

The drivers of change help us understand the surrounding and influencing context, and the principles of a sustainable world frame our ambition. How do we ensure a successful transition between this context and the desired state?

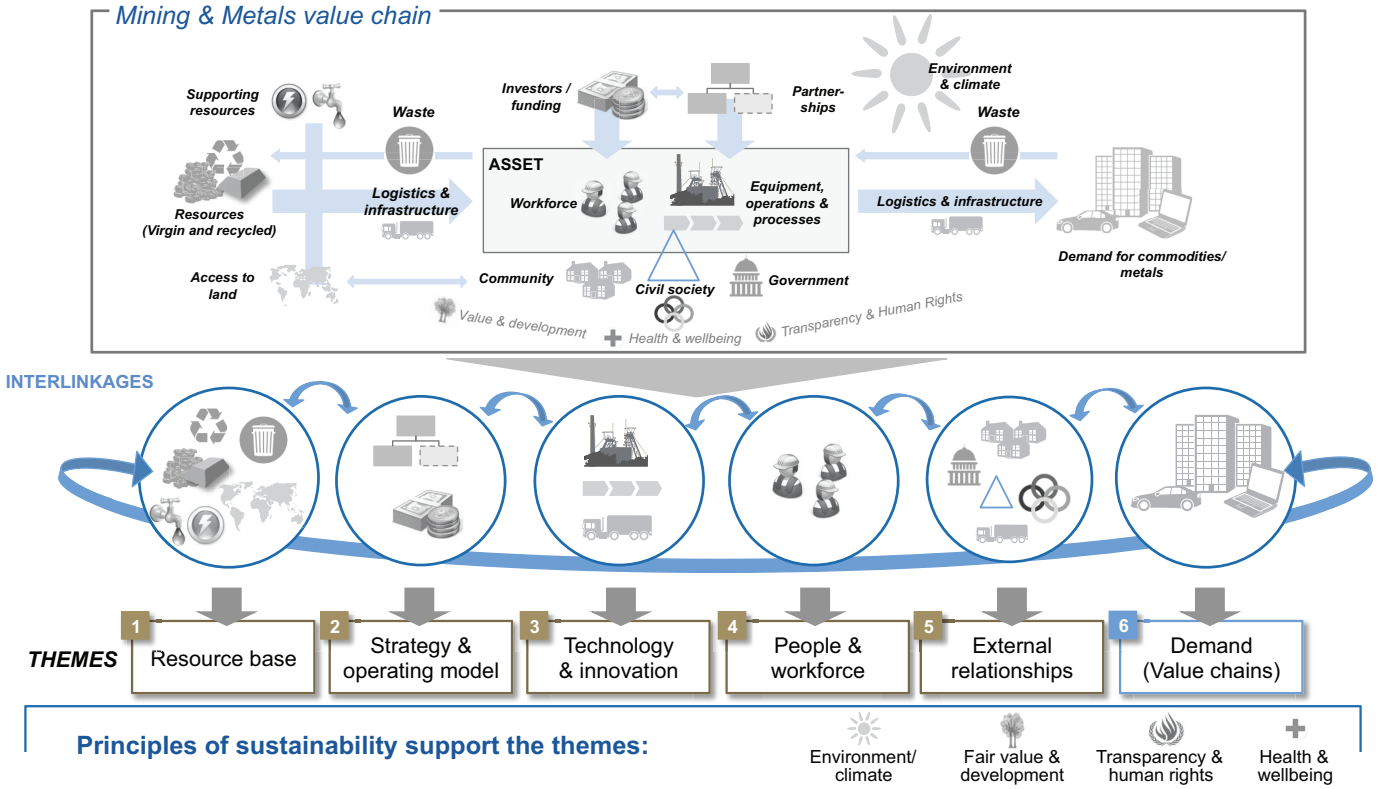
This step in the framework proposes a set of critical areas along which transitions much take place if the sector is to move towards a more sustainable world. The transitions consider the full mining and metals value chain[18] and capture the potential circular opportunities (Figure3). The complexity of sustainable development and the interlinkages across the sector value chain call for consideration across all transition areas.

While each of these transitions can be distinct, none is wholly independent of the others. There are a multitude of linkages, some leading to complexity and conflict. For example, technological changes and higher levels of automation are likely to create demand for a more highly skilled, but smaller workforce. This may conflict with the goal of creating employment and development opportunities.

Figure 2: Key drivers of change for the mining and metals sector

Drivers of change	What does it mean?
Environmental	
• Growing concern for the environment	• Sustainable management of water, biodiversity and climate
• Climate change	• Global warming impacts policy-making and business operations
Technological	
• Intensified rate of technological change	• Accelerated transformation of processes and operations
Societal	
• Higher demand for fairness	• Equitable distribution of benefits, costs and risks
• Increased "democratization"	• Decision-making and access to information more representative
• Abrupt generational change	• New ideas and values shape leadership profiles
• Rising concerns about artisanal mining	• Social and environmental challenges become priority
Geopolitical	
• Potential resource nationalization	• States take on sole ownership of minerals to be extracted
Geographical	
• Mining in remote, undeveloped regions	• Depleting sources drive exploration of new frontiers
• Declining grades	• Declining quality of ores render existing sites less economical

Figure 3: Mining and metals value chain and transition to a sustainable world



Access to resources stands at the beginning of the value chain. Primary resources (material being mined) and supporting resources (such as water and power) are essential to mining and metals value creation. The mining and metals activities – extracting ore and rock, processing and refining material, and creating metal products – then enable commodity production to meet end-industry and user demand.[19] Individual companies' operating models drive these processes in partnership with others. These elements of the value chain are presented here as the areas along which transition is required and where opportunity for action can be defined.

Taking into account the findings of the World Economic Forum's report, *The Future Availability of Natural Resources*, the areas of transition also reflect an integrated view[20] of resource availability. This means looking beyond the perspectives of material exhaustion, rising costs or social injustice. The integrated view also pays special attention to the role that strategy, technology, policies, preferences and various stakeholders will play in the future availability of primary and secondary resources.

The transition areas are:

Resource base

– *Virgin resources and new frontiers*
Mining companies will face the challenge of maintaining resource security well into the future. Companies already face diminishing reserves and grade decline in established locations, while virgin explorations come with increasing costs and concerns over environmental impact.[21] In the transition to 2050, it will be increasingly important to understand where and how new frontiers will be accessed and what resources will be economically available. Technology will be a vital determinant for this theme, from exploration to extraction, from seabed to asteroids.[22]

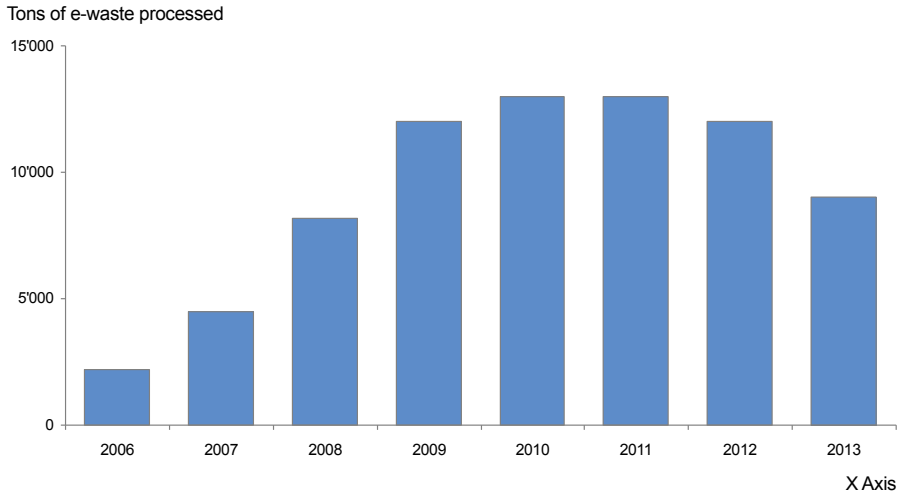
– *Reuse and recycle commodities and metals*
Resources are lasting longer, and recycling is creating new resources from old. Understanding and leveraging this shift – and how the supply chains of commodities and metals will change – into business models is key.[23] For example, will it become more profitable and sustainable to reposition a business as "providers of metals" or "providers of materials" derived from recycling or reuse rather than as a pure mining or metals company.

– *Enabling resources – Access and efficiency (e.g. water, power, land)*
Using less water, power and land will help companies reduce costs, improve their sustainability footprint and maintain support to operate.[24] Innovation in use and reuse of supporting resources will be significant drivers of success. In some regions, power and water shortages can be crippling constraints to investment and operations while land availability and use can require political leverage, sensitivity and good relationships.

Case study 1: Adapting the business model (Teck Resources)

E-Waste, a global challenge

From tube TVs to flat screens, paperbacks to Kindles, Betamax to Blu-Ray players, the pace of technological change is accelerating. With it comes an increasing amount of electronic waste, also known as e-waste. According to the United Nations Environment Programme, global e-waste production is estimated at around 40 million tonnes per year.



Embrace recycling

The mining company Teck operates its own smelter and refinery in Trail, Canada. It developed an e-waste recycling process which maximizes metal recovery. Metals are recovered from cathode ray tube (CRT) glass, computer parts and circuit boards through separation, segregation and smelting. Teck became the first metal supplier in Olympic history to include metals recovered from e-waste in the Olympic medals. Over 77,000 tonnes have been processed since 2006.

Securing metal supply while pursuing sustainability

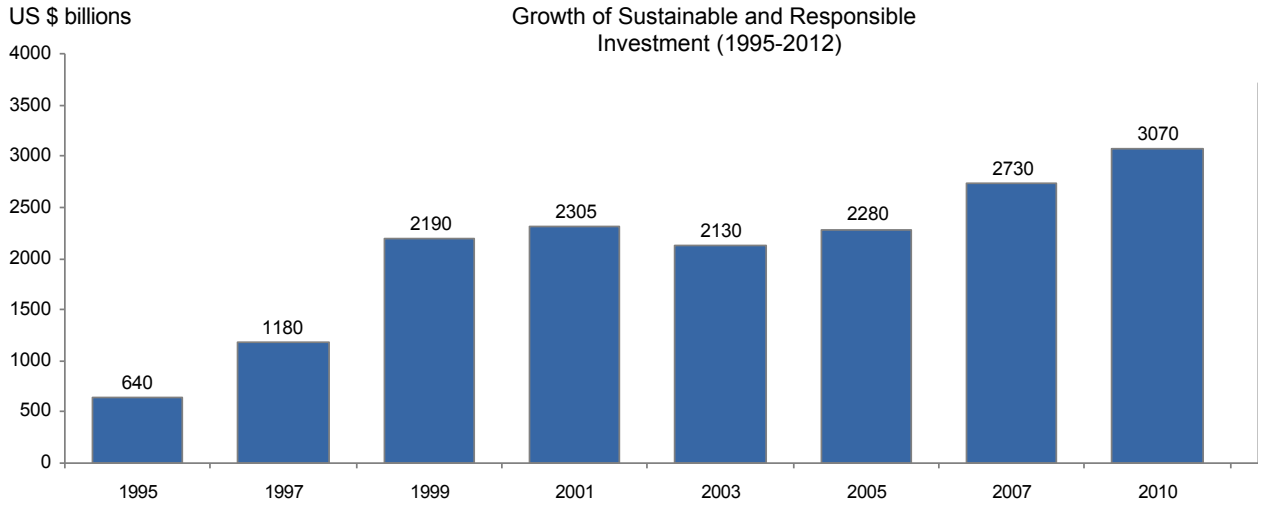
E-waste constitutes a reliable and rapidly increasing source of metals ensuring the long-term sustainability of Teck's operations. Moreover, the use of e-waste as a source of scrap enables the saving of energy that would have otherwise been used to generate mined resources.

Strategy and operating models

- *Strategy, leadership and embedding change*
  Embedding sustainability in a company culture, so that it is automatically considered alongside financial and operational imperatives, requires strong leadership and long-term vision within companies. At the same time, sustainability implies open and multistakeholder discussion, and mining and metals companies have the opportunity to be leaders in the wider societal debate on sustainability. Thinking about how and to what extent sustainability should shape corporate cultures and strategies, and what role can be taken in the broader debate, will be an important task for mining and metals companies.
- *Partnership models as part of business model*
  Working with partners such as service providers is already embedded in business models. What is changing is the role that sustainability will play in the choice and type of partners and partnership models, and the value of collaboration across the value chain.
- *Investment models*
  In investment, long-term thinking and a broad conception of value will be needed. For example, the transition to a more circular economy requires upfront investment before serious returns are generated. Sustainability will also continue to grow in importance in investment decisions, and potentially challenge investors to react to changing definitions of value.

Case study 2: Increase in sustainable investments (PFZW)

Global increase in sustainable investments
Worldwide sustainable investments have increased significantly and sustainability is becoming an essential investment criterion. These types of investments accounted for $3.74 trillion in total assets under management at the end of 2011. This represents a 22% increase compared to 2009.



PFZW example
Many market players have started using sustainable, responsible and impact-based strategies for investing in assets. PFZW, the Dutch giant healthcare pension fund, has announced that it intends to quadruple its sustainable investments to a value of $16 billion before 2020. The pension fund will also aim to halve the CO_2 footprint of its investments before 2020 by comparing companies in each sector and picking the best performers.

Technology and innovation

– *Process improvements and innovation*
In a sustainable world, technological advances such as big data and more sophisticated modelling will enable more efficient planning and more accurate, less intrusive mining operations. Business could also make greater use of metrics and increase its emphasis on environmental management processes.

– *Equipment technologies*
In mining and metals, the long term tying up of large amounts of capital in particular forms of technology could drive exponential change in future major technological advances. New equipment, such as 3D printing, is likely to reduce energy use and emissions while enabling greater automation in production processes. Investment in new equipment may require great caution and foresight to ensure adoption of new technologies without rendering the existing infrastructure obsolete or unusable.

– *Supporting infrastructure*
Infrastructure is essential to enabling the mining and metals sector; to access and operate in often remote locations and transport goods across the supply chain. As new supply chain patterns, new technologies and operations in more remote regions emerge, rethinking the future supply chain network and partnerships for shared use will be required.

People and workforce

– *Skills and attracting future labour*
With technological innovations, the future workforce is likely to be smaller, increasingly flexible and more highly skilled, especially in information technology. Creating opportunities for non-traditional sectors such as female workers will grow. Understanding the implications of these shifts will be important for employers as well as employees and communities. Potential implications such as fewer jobs, different working models to attract and retain workers and outsourcing will change opportunities for sharing sustainable value.

– *Labour relations*
Labour relations disputes can have a negative effect on the growth prospects of a company, an industry and the country as a whole. Participation and partnership models in response to emerging sustainability challenges will present opportunities as well as challenge business norms. Traditionally, a heavy reliance on union-driven collective processes in the mining and metals industry has eclipsed direct communication with employees. Building trust, communication and a shared vision of the future will be critical to propel this relationship in a sustainable world.

External relationships

– *External governance and regulations*
The transition to a more sustainable world will lead to more global standards and worldwide regulatory and governance bodies. Rules and regulations are likely to cover the full breadth of industrial impacts, including measures of the environmental impact of all stages of a product's life cycle. Mining and metals companies will be expected to play a vital role in reducing industrial impact. Understanding how regulation changes, how to comply with changing requirements, and how the industry can be part of the dialogue about future rules and regulations will grow in importance.

– *Government engagement and relations*
Governments will continue to be critical partners of mining and metal companies, both in terms of "hard" rules and regulation, and of softer modes of interaction like facilitating, partnering and endorsing sustainability-focused initiatives. Governments are likely to keep an active role in the development and operation of the industry, enhancing their capabilities to take on various roles, especially in developing and underdeveloped economies. The nationalization of resources debate is likely to continue, with focus on fair taxation and value sharing. Companies will have to think about the important relationships with local, regional and national levels of government and assess if they have the right measures in place. This can encompass close dialogue on local and regional level, relationship building on national level and efforts to extend international rules and standards.

– *Civil society and community engagement*
Gaining trust from surrounding communities and civil society is essential to maintaining a right to explore and operate. Participatory dialogue and interdisciplinary multistakeholder resource management[25] will be key to develop this trust and relationships. Open and genuine communication and transparency will be the new normal. Innovative and new models of partnership and ownership, especially with indigenous communities, will lead to business success.

– *Development goals and infrastructure*
A sustainable world is one of fairness and access to benefits, including those created by the sector – long-term job creation, local employment, social development and the creation of infrastructure, which can be a key driver of regional economic development. Some governments in particular are likely to seek these as conditions and agreements for granting licenses.

Demand (value chains)

– Alongside supply, end-industry and user demand are crucial. How end-consumer demand and behaviour changes in the transition to a sustainable future will determine what industries can sell and how. Different value chains are relevant for different commodities and metals. Priority value chains can be identified by considering the current value of the commodities and metals used (Figure 4), along with potential future transformations to respective value chains, as mapped out by the World Economic Forum.[26]

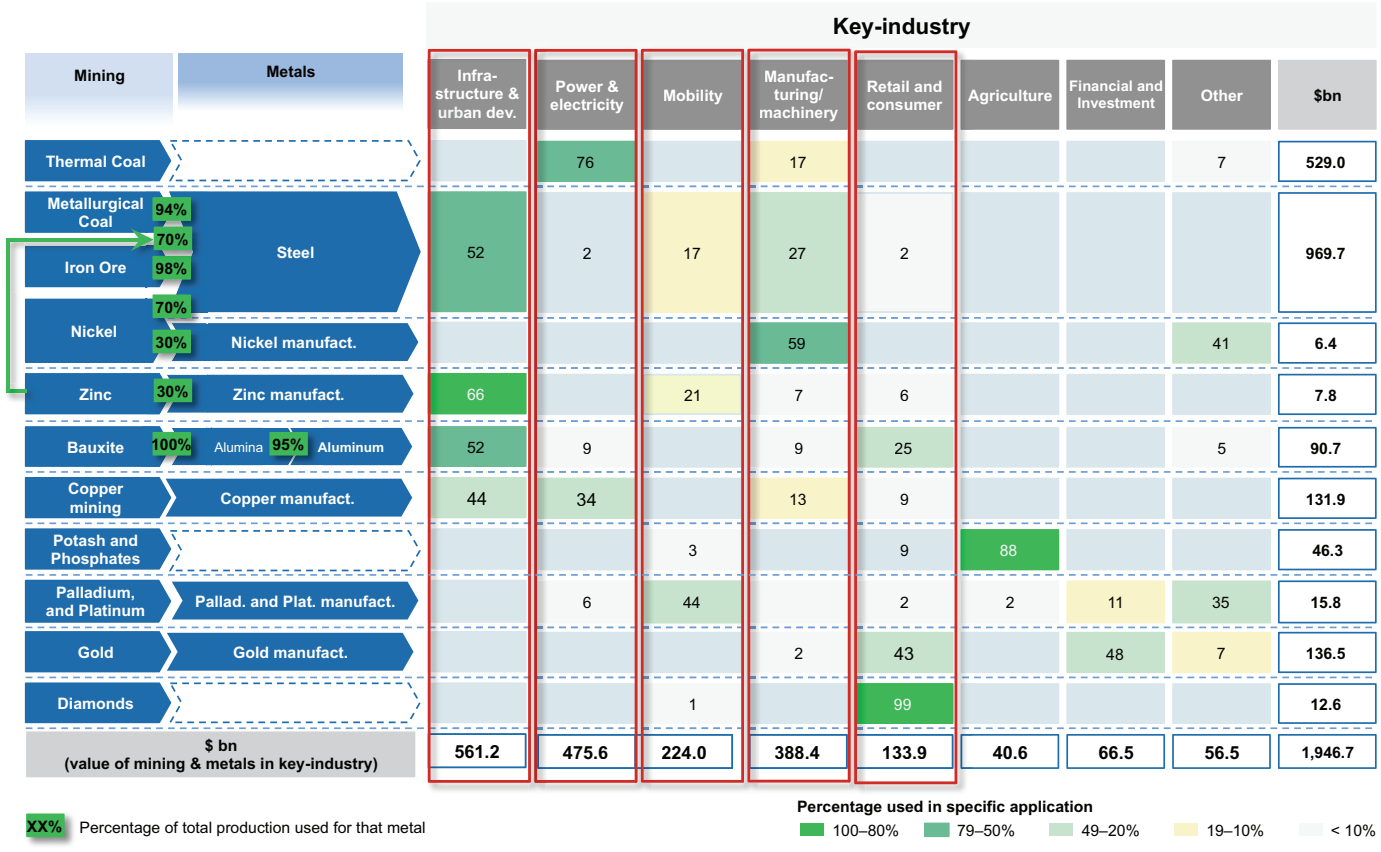
Based on these criteria, current priority value chains are:

– Infrastructure and urban development
– Power and electricity
– Mobility
– Manufacturing/machinery
– Retail and consumer
– IT/Telecommunication

Understanding end-industry and user demand and behaviour alongside transformations in other sectors and across value chains will be a key success factor for mining and metals companies in the future. The companies which grasp the changes and especially the opportunities will have a clear edge in preparing for the transition to a more sustainable world in 2050.

The case study presented in part 2 of this report offers a significant first step towards such an understanding by addressing questions around the circular use of commodities and metals.

Figure 4: Value of mining and metals in US$ billions along key industries[27]



Scenarios on the Future of Resources

The pathway to sustainability is unlikely to be simple or straightforward. Disruptions will inevitably occur. As such, the Mining & Metals in a Sustainable World framework considers various disruptions and diversions through a set of natural resource scenarios to help think through different potential contexts and test ideas under different conditions. These scenarios were developed drawing inputs from World Economic Forum's previous work, *The Future Availability of Natural Resources*[28] and *Mining and Metals Scenarios to 2030*,[29] supplemented with expert interviews and consultations. Testing the areas of transition in different scenarios starts to help identify and build a set of roadmaps for action. The scenarios are applicable across different potential case studies or deep dives and can be adjusted or refined in order to reflect the specificities of a region or a commodity.

A set of industry scenarios (Figure 5) has been developed to explore alternate trajectories as the mining and metals industry transitions into a sustainable world. It is not suggested any of these are probable outcomes, only that they provide valuable tests of the capability of the industry players and other stakeholders to meet a range of possible future needs.

A set of three different scenarios was developed to represent alternate pathways to the desired end state. The key dimensions, around which the scenarios were constructed, are geopolitical dynamics, technological developments, regulatory and legal environment, impact of circular approaches and sustainability-focused practices, frontier mining and trade flows. Each scenario required a number of assumptions to define the operating environment and evaluate the actions required by various stakeholders. These assumptions have been deliberately chosen to present a wider spectrum of the possible outcomes.

The scenarios are:
1. A world of two speeds
2. Resource abundance
3. Global fragmentation

Figure 5: Scenarios to capture multiple end states

Using potential disruptions of the path to the desired end state, three general scenarios were developed:

Desired end state

E.g.
- Improved energy efficiency and recycling through technological advances
- Broad multilateral cooperation
- Supranational **LCA**-based regulation
- Sustainability-oriented consumers
- Mining less invasive
- Lower amounts of waste
- Low environmental impact

1. A world of two speeds

- Two (or more) groups of countries moving towards sustainability at two different speeds :
  - "Sustainable forerunners"
  - "Mineral dependents"
- Customers from "sustainable forerunners" rejecting metals from invasive mining
- "Mineral Dependents" concerned with growth and employment
- Trade and political intercourse mostly within blocs
- Technology advancing faster in the "Sustainable Forerunners"
- Environmental damages in mineral dependent countries

2. Resource abundance

- New techniques to cheaply produce versatile metals or metal substitutes
- *Alternatively:* New sources tapped through frontier mining
- Strong global trade and open markets
- Lower incentive to recycle
- Metal substitutes rebound effect: Abundance and additional consumption lead to more waste and more primary extraction
- Sustainability and decrease of waste not primary driver

3. Global fragmentation

- All resources depleting faster than expected
- Higher population growth can be coupled with slower growth
- Growing commodities and metals demand
- Protectionism and international resource conflicts
- Clashing national interests lead to global fragmentation
- Companies slow to switch to sustainability due to missing global legislation
- No environmental focus
- Less penetration of technological advances

Roadmaps and Actions

The final step in the framework is identifying the actions required for a successful transition. Using the themes to explore in depth an area of transition, the outcomes and needs can be captured in the form of a roadmap across the value chain.

This process involves a clear upfront understanding of the specific topic to be investigated. A set of key questions are framed to help define the scope and focus of the analysis. The overarching principles of sustainability are then applied to the topic to frame the desired end state and identify prevailing baseline. Gaps are identified and specific milestones in the transition to sustainable world are then determined using a backcasting technique. Considering that there are likely to be deviations from this path, a set of scenarios help capture the impact of potential disruptions relevant to the topic. Finally, a roadmap can be created, which lays out the actions required by different stakeholders under various scenarios. This is an iterative process which will require review and updating as we learn and transitions manifest.

The steps below summarize the approach taken in the pilot case study to construct a roadmap of actions and is presented in detail in Part 2.

- **Step 1. Defining the scope and focus**
  - Outline the scope and focus of the deep dive and apply a set of questions to help frame
  - Agree on definitions and descriptions of relevant drivers of change
- **Step 2. Developing the desired end state and the baseline**
  - Apply the four principles of a sustainable end state to the context, define a desired end state and develop an ambition level
  - The baseline, against which the end-state ambition needs to be measured, is developed across these principles
- **Step 3. Identifying gaps**
  - Backcast from the desired end state to today to identify gaps and opportunities
  - The gaps allow a first view of areas which need to be addressed in the future
  - Interim milestones are indicated to highlight the short-term targets and long-term objectives
- **Step 4. Identifying key disruptions**
  - Identify specific disruptions which could occur on the way towards the desired end state
  - Analyse disruptions across each of the six areas of transition and evaluate their expected level of impact
  - Apply major disruptions in the creation of scenarios to capture the potential deviations in the path to a sustainable 2050
- **Step 5. Applying scenarios and outlining the roadmaps**
  - The scenarios describe alternative paths which require specific actions in order to ensure a Sustainable World 2050
  - Adjust scenarios depending on context (e.g. region, commodity, business model) to help test the proposed roadmaps and actions
  - Develop different roadmaps for each scenario describing the actions needed in different circumstances to move towards a Sustainable World 2050
  - Specific actions related to the deep dives will lead into holistic roadmaps across the whole mining and metals value chain

Applying the Framework – Circular Use of Commodities and Metals

The example of the circular use of commodities and metals offers a blueprint for future applications of the framework. It shows outcomes at each step, along with the actions needed to develop the model and an outline of actions.

The circular use of commodities and metals was chosen as the pilot example because of its wide range of implications for both the mining and metals industry and for the wider society. Reuse and recycling have the potential to reshape the sector by impacting the whole value chain – from extraction through conversion and application of business models, to demand patterns. It also highlights the latent value that lies at the intersections of these value chains.

A circular economy is one that is restorative by design, aiming to keep products, components and materials at their highest utility and value at all times. For the purpose of this work, we have focused mostly on scenarios of increased recycling and better enabled reuse of minerals and metals, as steps towards increased circularity. The deep dive was based on discussions with the Mining & Metal's Governors, the initiative's advisory board and experts at the World Economic Forum.

Three types of resources which play a role in the mining and metals value chain: primary (or virgin) resources are commodities and metals which are extracted directly from the rock; secondary resources means commodities and metals which are reused or recycled and thus not extracted; and enabling resources are those like water and power which are required as an input factor, but are not the source of the original material.

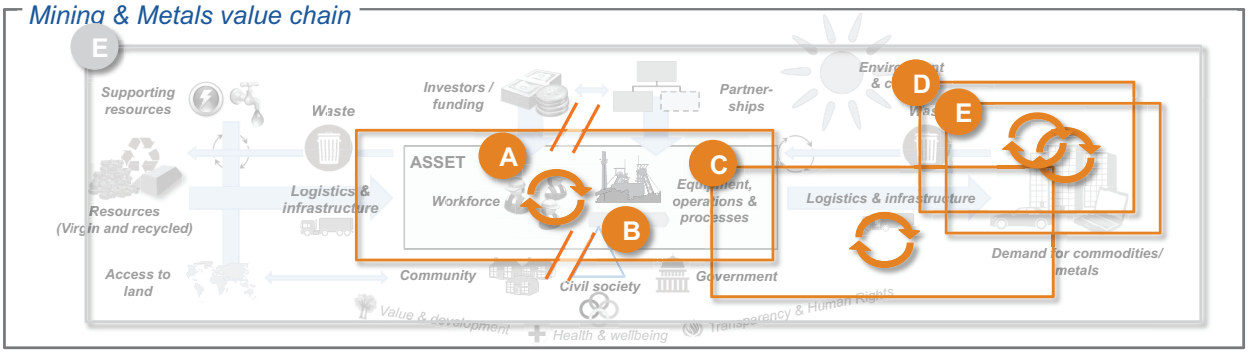
The deep dive focuses on the switch from primary to secondary resources, but does not focus on enabling resources (like water and power) where circularity also plays a role. However, the choice of energy sources for future metal production – circular or not – will have an environmental impact. A topic like circular use of commodities and metals has linkages across different sub-themes. The linkages will be reflected in the gaps and disruptions, which will be discussed along the key areas of transition.

While the following analysis provides valuable insights, it should also be remembered that it cannot explore all angles. The future of circularity and circular economy is likely to be affected by numerous factors within and beyond the mining industry, while this report focuses on selected key aspects relevant to the industry on a strategic level.

Scope and Focus: Five Aspects of the Circular Use of Commodities and Metals

As a first step, the scope and focus of the deep dive example is identified. Workshops and expert discussions helped identify five areas where the opportunity exists for the circular use of commodities and metals.

Figure 6: Aspects of the circular use of commodities and metals



A	**Waste retreatment** *"Tailings on mine"*	How will waste be optimized and reused within mine processing
B	**Scrap treatment** *"Home / new scrap in metals production"*	How will scrap be collected and reused in metal (component and end-product) production
C	**Recycling (from downstream)** *"Old scrap"*	Recycling of materials used in end-industry / final products
D	**Reuse through redesign**[1] *(within downstream)*	Design for reuse of components after end of life of product (instead of recycling); reuse could be within or outside same industry
E	**Different ownership models** *(within downstream and x-value chain)*	Increase of life through different ownership – shared economy, leasing, for-use renting or cross-value chain ownership

Waste retreatment and by-products

The different aspects of circularity are described along the mining and metals value chain starting furthest upstream, retreatment of waste/tailings, including slag. Tailings (waste from mining operations, excluding overburden) can be treated again, enabling reuse within mine processing and a corresponding saving in primary resources.[30] The same holds true for parts of slag. Some tailings are not available for retreatment as they are for instance used as backfill in underground mines.

In some commodities, retreatment of this sort is already well developed, since high commodity prices have made it cost-effective. While the extent and techniques differs, waste retreatment and (re)processing can be found across multiple commodities – ferrous and non-ferrous metals as well as coal or diamonds.

Scrap treatment

Scrap treatment describes the mechanism of reintroducing metal "leftovers" in the metal production process. In this context, scrap comes in two forms: it can be either home scrap (generated by the metal production process, such as in the milling process) or new scrap (from plants which manufacture metal products, such as automotive OEMs).

Home scrap is "leftover" material that can be reused for the process which generated it. Much is of high quality and it is usually reused within a year. Large amounts of home scrap are often a sign of inefficiency in the metal production process. It is reused extensively since the limited need for rehandling makes it an easy source of additional metal.[31] New scrap is more similar to downstream recycling as it is further removed from the original metal production process and requires some similar logistics elements.

Downstream recycling

Downstream recycling (old scrap) reclaims metal from products which have reached their end of life or end of use. There are four prerequisites for downstream recycling to be sustainable and efficient:

1. Adequate collection and pre-processing infrastructures
2. Enough old scrap available for the process (volumes depend on the lifespan of metal currently in use)
3. Competitive production costs, since recycling competes with primary metal production
4. Possibility of recycling (including upcycling[32]) or reuse in different applications (recycled materials cannot always be reused in high quality applications due to alloying or impurities)

Reuse through redesign

A product's – or a component's – life cycle can be prolonged by reuse. For this to be possible products need to be redesigned by manufacturers so that components can be extracted for reuse easily and at reasonable cost. For instance, it should be possible to design the steel rods and beams used in construction so that instead of being destroyed during demolition they can easily be disassembled, collected, reconditioned and certified for reuse in new buildings. Modular construction is another possibility.

The prerequisites for this to work well are standardization of component design and specifications, close collaboration and cooperation along the value chain as well as commercial benefits for metals companies.[33]

Reuse can also be ensured through remanufacturing and refurbishing – the disassembly, cleaning, repair and reassembly of a product – restoring it to like-new condition. Remanufacturing/refurbishing fully restores a product while repair is limited to making it operational. Remanufacturing/refurbishing is an environmentally friendly and energy-efficient way to make domestic appliances, machine tools and especially engines and turbines reusable. Reusing a remanufactured/refurbished engine rather than producing a new one can for example consume up to 83 % less energy and save up to 87 % of emissions, so designs which make remanufacturing/refurbishing easier and cheaper should be encouraged.[34]

Alternate ownership models

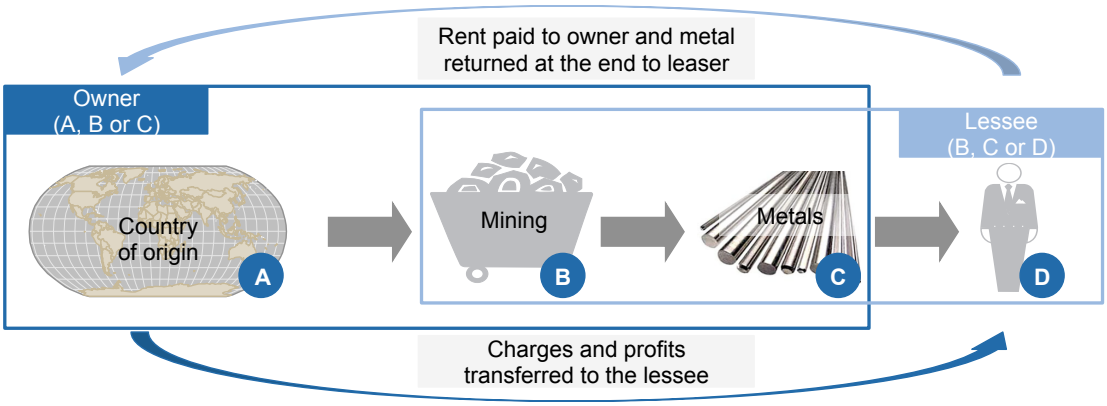
Ownership has traditionally taken the form of a product being bought and owned permanently by a single user and then thrown away or recycled. This model remains predominant, but others which are coming into use can either extend product life or decrease demand. Alternatives can be differentiated according to the degree of ownership:

– *Sharing economy*
  This model is based on sharing underutilized assets – spanning from spaces and things, to skills and services. One product is owned and shared by many users. Heavy usage means this will not extend its lifetime, but demand can be reduced. An example is several tenants sharing one vacuum cleaner. As more owners use a single appliance it will likely have to be replaced more often because of higher usage. Another variant of shared economy could be the concept of "for use renting". An example is where, instead of sharing a vacuum cleaner, customers rent one when needed from a nearby rental service. This shift between ownership and access to devices should mean reduced need for replacements, since the rental service has an incentive to minimize the need for new machines by ensuring regular maintenance.

– *Leasing*
  Consumers lease appliances, which are maintained by the manufacturer. A leased washing machine, for instance, is permanently located on the customer's premises but still owned by the manufacturer, who takes responsibility for maintenance and ensuring it a longer life. However, the reduced financial commitment involved in leasing means the customer is likely to want to switch sooner to newer models, increasing the overall demand for washing machines.

– *Metals leasing as a cross-value chain enabler*
  Metals leasing is driven by fundamental ownership considerations on the upstream side of the value chain. One party retains ownership of the metals which are transferred to the lessee, who enjoys both charges and profits[35] (see Figure 7). In exchange, rent is paid to the owner and the metal returned at the end of the lease. The complicated nature of maintaining ownership through continuous use phases – with changing value – of the metal means that to date there are limited successful examples of this approach. Nevertheless, it creates powerful incentives in favour of recovery of material at end of life.
  One potential issue is that nationalization could be required if the owner is the country of origin. It could also create new business opportunities, notably in resource management and monitoring.

Figure 7: Metals leasing: Ownership structure



A Desired End State for 2050

As a second step, the desired end state related to the deep dive (here circular use of commodities and metals) is identified based on the general principles of Mining & Metals in a Sustainable World – identifying what the principles will mean for the specific deep dive. The end state is usually expressed as an ambition range towards which mining and metals need to transition rather than a specific target.[36] *A baseline is then established to enable backcasting from the end state to today. The baselines should also be established along the four principles of sustainability, and spelled out via metrics and indicators.*

The desired end state for 2050 was defined in collaboration with the advisory board of the World Economic Forum's Mining & Metals in a Sustainable World 2050 project and the Global Agenda Council on the Future of Mining & Metals. While all principles need to be reflected, the environment and climate conservation principle served as lead for the deep dive around circular use of commodities and metals.

The desired end state under this principle included greater reuse of material and an increase in end of use recycling to 80-100%, all of it achieved while taking energy efficiency and emissions across the life cycle of products into account. Further aspirations were a fair distribution of value – either though greater beneficiation or production down the value chain or by shared ownership structures – transparent reporting at both the national and company level and a reduction in global fatalities and injuries to the levels currently found in the most developed mining and metals environments.

Figure 8: Baseline for circular use commodities and metals

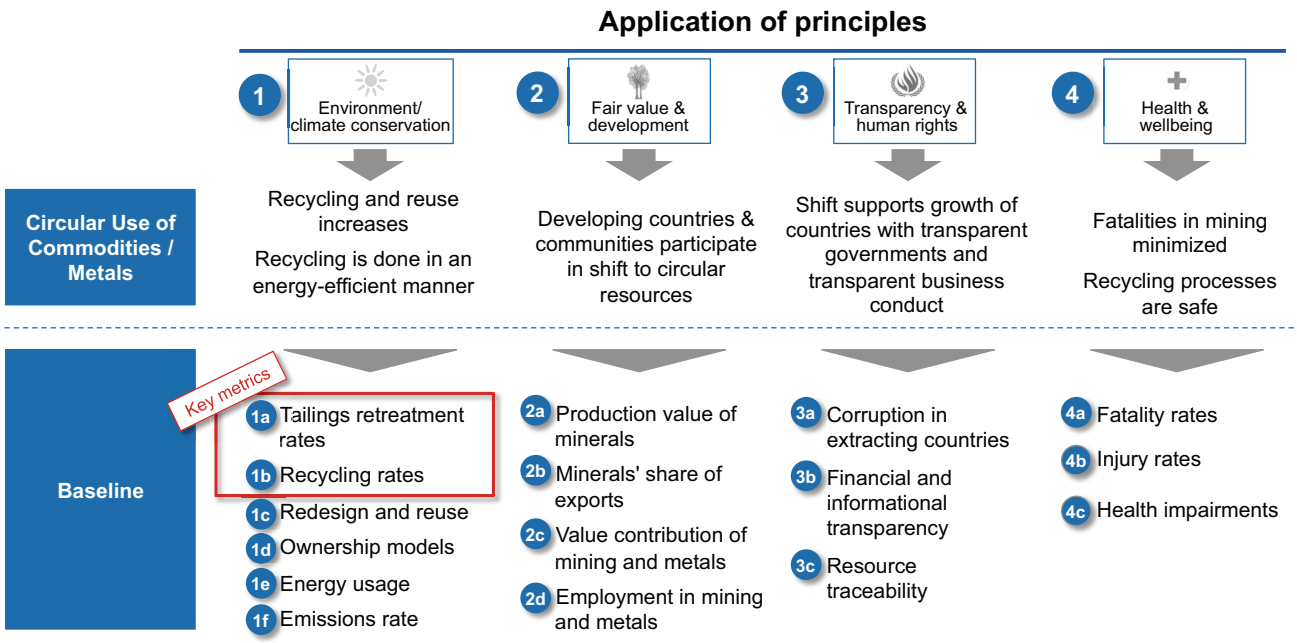
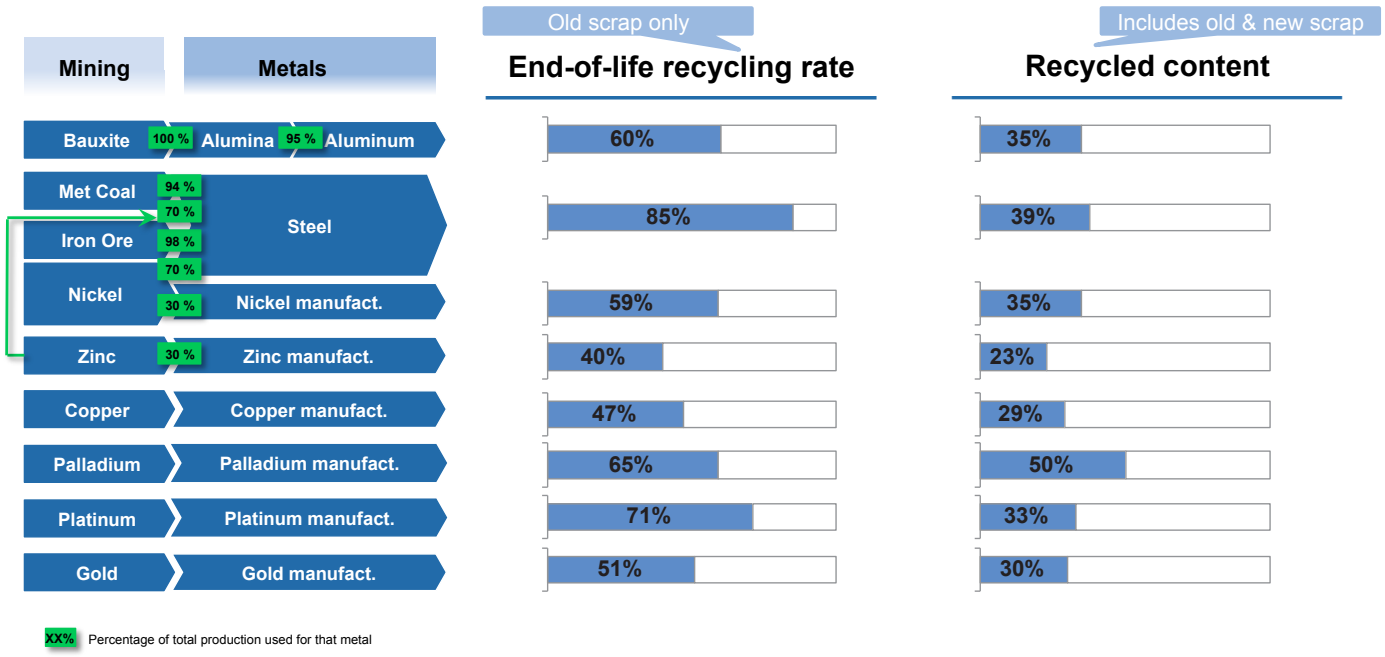


Figure 9: End-of-use recycling and recycled content rates[44]



Environment/climate conservation – Increase reuse and recycling

Applying the principle of environment and climate conservation to the deep dive translates into an increase in recycling and reuse while ensuring energy efficient and environmentally friendly production. Energy usage and emissions decrease and new ownership models extend the lifetime of products or reduce demand; redesigned production methods enable greater reuse of components.[37] Improving the collection and reuse of scrap as well as reducing the amount of scrap in metal production would also be a significant step towards circularity. Reducing the resources that are needed for a given product will further support this effort.[38]

One ambition for 2050 could be, for example, a reduction of more than 50% in the permanent waste generated by the metals and mining industry.[39] The baseline shows that mining and metals are among the world's great generators of waste, accounting for around 10 billion tonnes[40] a year, around 40-55% of the global total,[41] and about a tenth of global mining and metals production.[42] Tailings, the waste from extractive processes excluding overburden, can hold large potential value. Current estimates suggest that with the right technology for treating bauxite waste, aluminium production could be increased by 20%, a potentially huge capture of value from tailings.[43] This is more complex in other metals – namely base and precious metals – where increasingly small amounts of material need to be recovered from large amounts of waste but retreatment will be an important factor in the future.

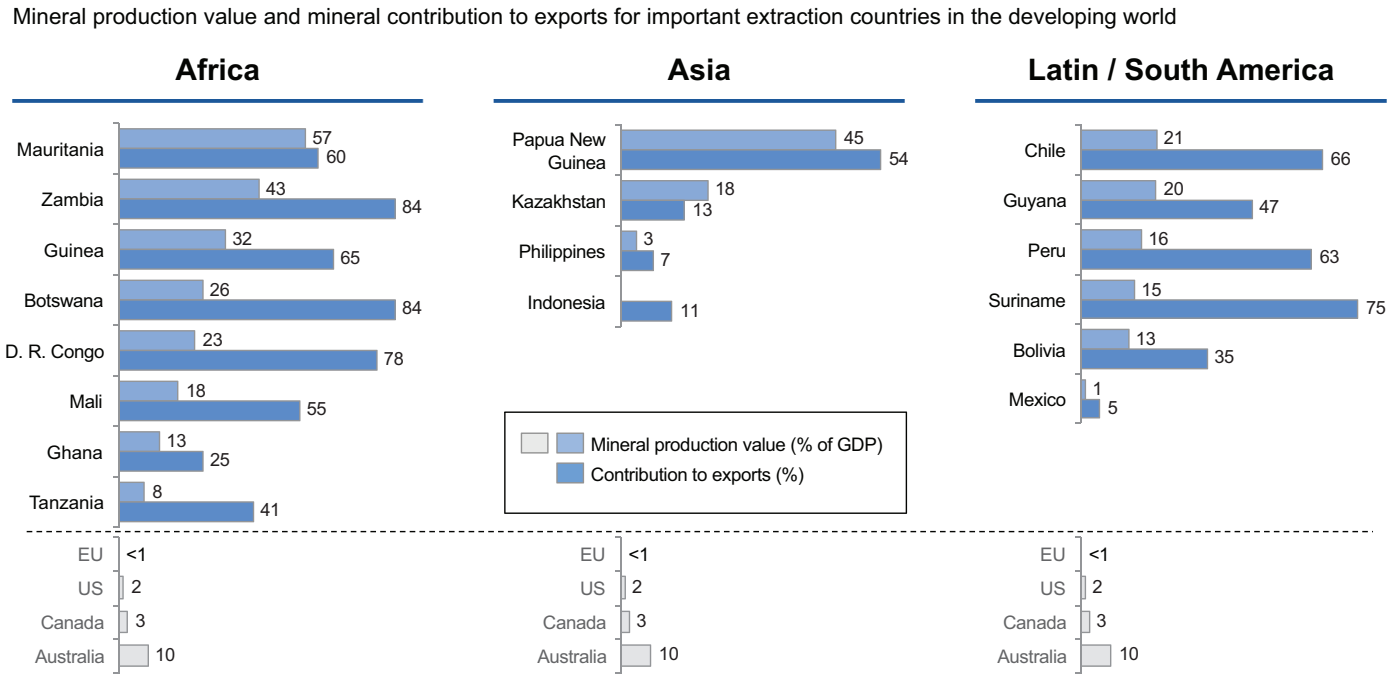
A further ambition could be to raise the percentage of energy-efficient end of use recycling to 80-100% across the range of commodities, adding more recycled content to production (The report's analysis of steel shows how the share of recycled content will have changed in 2050).

As Figure 9 shows, recycling rates today vary across the range of commodities while recycled content rates (percentages of recycled scrap as a proportion of inputs in metal production) lag well behind end-of use recycling rates. The greatest gap is in steel where 85% of discarded metal gets recycled, but only 39% of production input is recycled scrap. Growing demand, based largely on the infrastructure requirements in emerging economies, is the main reason, along with the long life cycles of metal products. There is also some efficiency loss in recycling, and limits to its use for some high quality applications.

Recycled content of close to 100 % is unlikely for decades to come, but changes in the production and manufacturing of metal components could make reuse – such as reusing steel beams used in building frames in new buildings – possible provided companies standardize design and specifications, cooperate along the value chain and share value.

Energy use and emissions must also be considered. The baseline shows that the top five mining companies are big energy users responsible for considerable emissions of CO^2 or CO_2 equivalents.[45] Recycling uses less energy, as shown by the case of aluminium and steel. Recycling aluminium only takes 5-10 % of the energy needed to produce primary aluminium, depending on technology, sorting effort and geographical location.[46] Steel production with 100 % scrap inputs uses 60 % less thermal, electric and upstream energy than steel production via the integrated route which relies on primary ore.[47] To ensure a holistic picture across the whole value chain, from mining to product use, energy use and emissions for the whole life cycle should be taken into consideration, for example, by aiming for carbon neutrality across the value chain.

Figure 10: Mineral contribution to GPD and exports[49]



Fair value and development – Developing mining countries participate in the shift

Mining-dependent countries will have to adjust their economies to ensure fair participation in a shift towards a more circular economy. This could mean adding a significant share of downstream value creation to their mining and metals sectors. Their ambition could be to reduce mineral production's share of their GDP to a maximum of 10%, roughly the share of mineral production in Australian GDP during the commodity boom. A growing recycling industry would also have to provide employment opportunities.

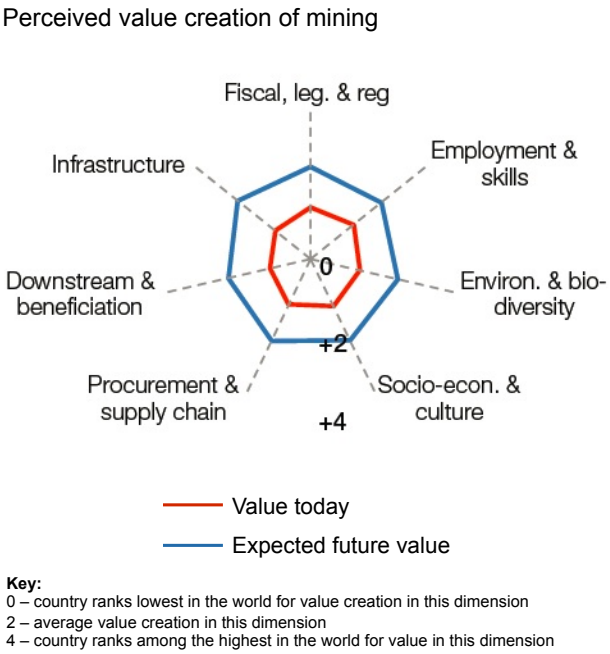
Such switches would require significant changes. Mineral production currently accounts for 57% of Mauritania's GDP and 43% of Zambia's.[48] Figure 10 shows how other developing countries rely on mineral extraction. Extraction usually accounts for a much smaller share in industrialized economies like the US, Australia or the EU countries.

Adding downstream capacity in geographies focusing on mineral extraction will not be easy. Limitations in skills and capital plus lack of access to trade and recycled material can slow down such a process. Nor will today's manufacturing centres readily reduce their share of global production. An alternative ambition might be the introduction of more shared ownership structures of commodities and metals across the value chain.

On the flip side, these countries represent the opportunity to leapfrog and avoid implementing wasteful systems such as seen in many Western economies. Designing scenarios for circularity in such economies might turn out to be easier than for countries in which systems are already well established.

Any shift will need to be significant. Today, extraction remains an important value driver for these countries. Production value is, as the World Economic Forum's *Responsible Mineral Development Initiative* has shown, only one dimension of value. Value is also realized through the form of government revenue (taxes), employment, infrastructure, procurement and supply chain, and environmental and cultural impacts.[50] (See Figure 11)

Figure 11: Perceived value of mining and metals[51]



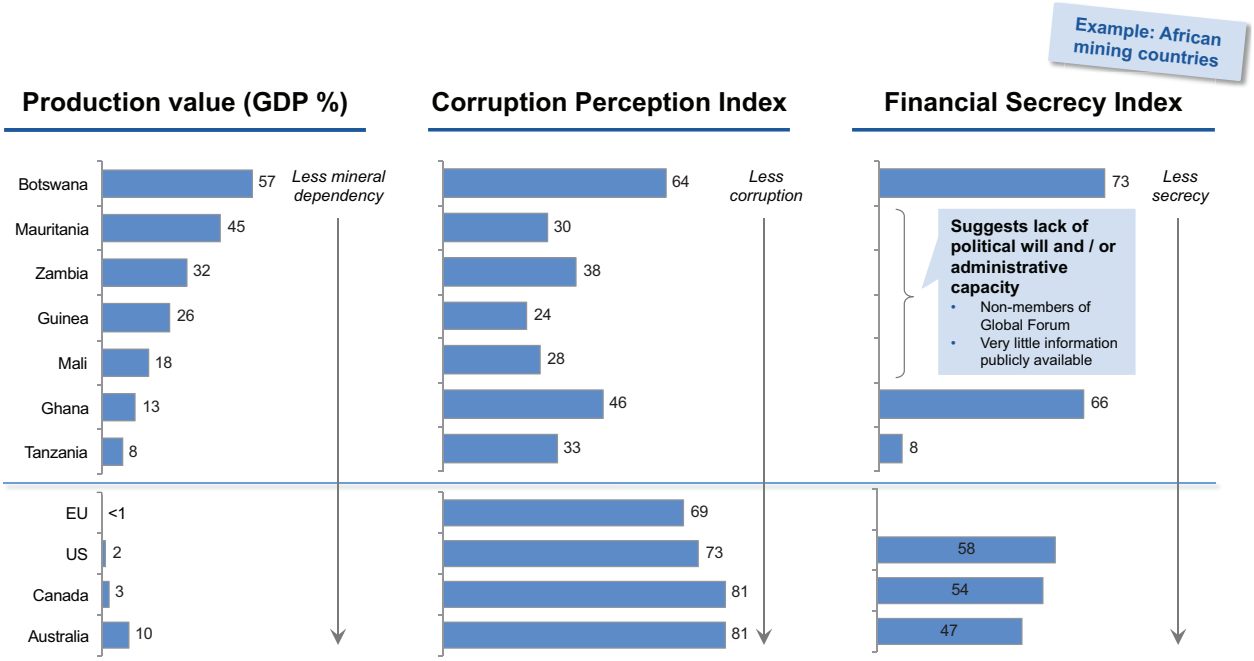
Key:
0 – country ranks lowest in the world for value creation in this dimension
2 – average value creation in this dimension
4 – country ranks among the highest in the world for value in this dimension

Transparency and human rights – Growth in countries with transparent governments and business conduct

Applying the principle of transparency and human rights means that a shift to circularity would go along with more transparency in the affected businesses and regions. An emphasis on transparency could, if it created a shift away from developing nations towards more transparent industrialized economies, lead to conflict around fair value and development.

Country scores on Transparency International's Corruption Perception Index, which is also a proxy for acceptable business conduct, were used to define the transparency baseline. Several African countries with high mineral production score low on this index (see Figure 12) and also have poor scores, or are unable to supply data, under the Tax Justice Network's Financial Secrecy Index.[52]

Figure 12: Perceived transparency



Case study 3: Transparent supply chains - example: Food traceability

What is food traceability?

Ability to track food through all stages of production, processing and distribution

- Originated in the context of food safety
- Risk management tool for businesses and authorities
- Laws specifying traceability standards, for instance in the European Union

A successful example – CLEARthru

CLEARthru traceability software for food products

- Coded label applied to a case or individual item at production level
- Product information linked to specific grower, manufacturer and/or processing facility
- Product information detail level customizable
- Consumers trace the item via web or mobile-enabled device

Although commodities are more complex, learnings from food value chain traceability are translatable

1. The EU General Food Law requires all food and feed operators to be able to identify where their products have come from and where they are going to
Source: European Commission Factsheet Food Traceability 2007, http://www.junctionsolutions.com/

A shift towards more circular practices, including formalized recycling for example, is important as an informal unregulated recycling sector can exacerbate human rights issues. An example is the use of child labour in the unskilled manual treatment of e-waste imported from wealthier countries, found for instance in Ghana and Nigeria.[53]

The ambition for 2050 could be the establishment of a tracing system that increases the value chain transparency and could allow to better capture the value of minerals at end-of-use.[54] Today, traceability of resources is not common place, with the exception of diamonds.[55] A model is offered by food and agricultural value chains, where software such as CLEARthru or HarvestMark is ensuring the traceability of fresh produce back to farm level.[56] While mining value chains are more complex, agricultural products are also reused and remanufactured and offer similarities to other commodities. Besides providing transparency, traceability can also help enable new ownership models around metals leasing.

Health and well-being – Harm to humans minimized

Circular use of commodities and metals should enhance health and well-being through safer processes and the minimization of harmful waste and tailings. Reductions in hazardous waste treatment and dangerous recycling should decrease work-related injury, fatality and disease rates[57] along the lines already seen in mining in developed countries.

Health assessments should take injuries and the general health of employees and communities into consideration. While a shift away from mining would help create safer working environments in some regions, the industry is already making its own contribution through automation and upskilling, making this a principle under which there is a potential conflict between the objectives of safety at work and high employment rates.

Today's baseline shows that mining still carries occupational hazards. It ranks fifth in industrial fatalities. At the same time, safety has improved steadily in developed economies like Australia.[58] Processing and metals recycling industries can be safer, but will have to be formalized and regulated for a shift downstream to lead to improved safety and fewer injuries.[59]

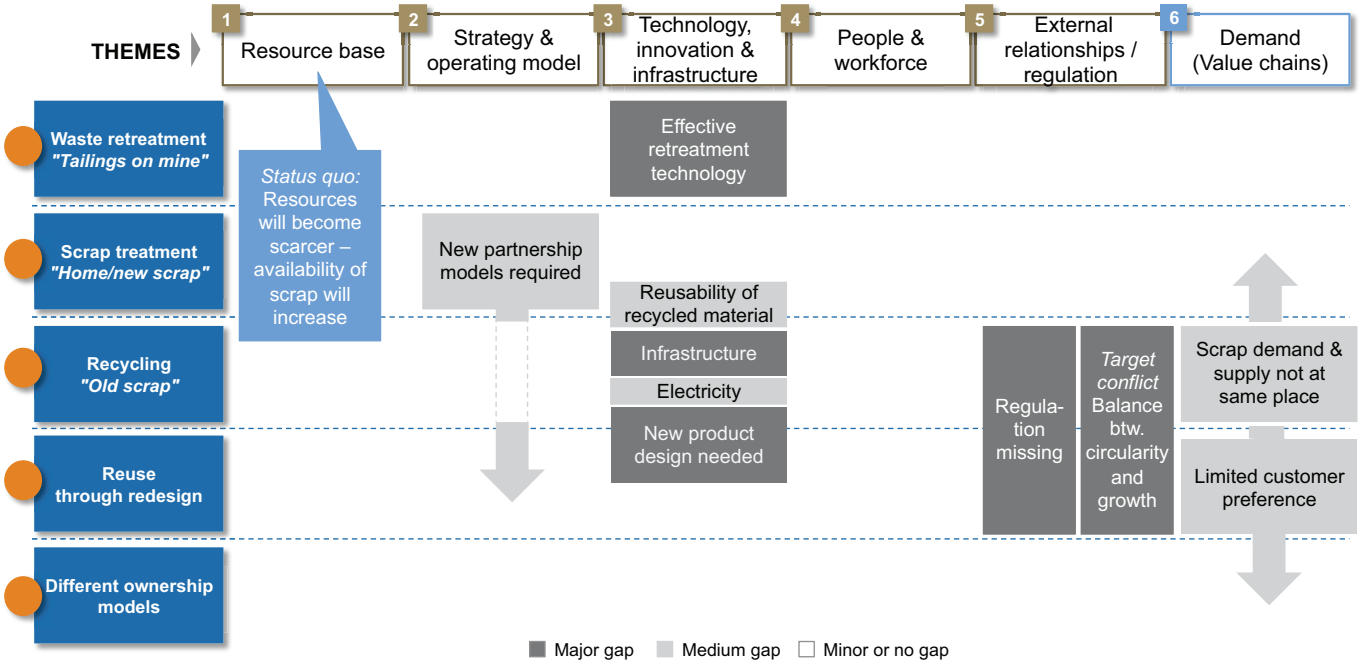
Identifying Gaps

As a third step, every deep dive/focus areas would be backcast from the end state to today, identifying gaps between tomorrow and the baseline. Multiple linkages between different areas mean that gaps are clustered along the different areas of transition in order to make them transparent. The gaps were identified via a three-step process which can be adjusted and applied to other deep dives.

1. An initial view was created by research and brainstorming, including input from the World Economic Forum's Industry partners and experts from The Boston Consulting Group.
2. The framework of gaps was then established through stakeholder consultation with advisory board experts of the Mining & Metals in a Sustainable World project and industry partners, the project team, experts from the World Economic Forum and The Boston Consulting Group and other topic experts.
3. Final refinements followed interviews with key experts.

For the deep dive on circular use of commodities and metals, gaps were identified across the full scope of the topic (i.e. the five relevant aspects). The guiding principles remained that recycling and reuse should increase with resource production and is achieved in an energy-efficient and environmentally friendly manner, as outlined in Figure 8. The exercise also accounted for the other three principles of sustainability. Figure 13 presents an overview.

Figure 13: Gaps towards 2050



The increased scarcity of resources serves as a starting point for the analysis of gaps. The supply-demand ratio and resulting price remains a key underlying driver, beyond any environmental concerns, of the transition to more circular use of resources. As resources become more difficult to access and grades decline, increasing global demand creates a natural economic rationale behind a shift towards recycling and reuse, and in particularly as recycling becomes cheaper relative to the rising costs of primary extraction.

Gaps provide guidance to the community on both for actions it will have to consider, and the changes for which it must be ready. The impact on the stakeholders within the mining and metals community – from mining companies to investors – will vary, with each stakeholder facing different challenges. Among these challenges is the possibility that the role of mining and metals companies could change in the transition to greater circularity in the use of resources. Yet primary extraction will continue even in a world of a circular use of commodities and metals. Mining companies will want to ensure they are competitive and technologically cutting edge, while working towards being perceived by other stakeholders – especially indigenous, local mining communities – as "development partners".

Metals companies whose operations are primarily based in developed and urban areas are subject to different forms of community relationships. They could play a role as a provider of the link between commodities and end consumers and as an enabler of new technologies. They are usually part of "Western" jurisdictions, as are investors. Investors may also accelerate the switch to circularity, either through increased emphasis on compliance by large funds or a drive for sustainable investment by government funds or well-funded foundations. A brief summary of the roles that stakeholders in mining and metals could play in a 2050 sustainable world is shown in Figure 14.

Extensive consultation inevitably captures a range of opinions. Different perspectives and priorities were consolidated into a list of top 10 gaps:

1. Effective retreatment technology

Unless technology enabling, efficient and economical waste retreatment is developed, it will be impossible to significantly reduce the amount of permanent waste produced by the mining and metals sector. Efforts to close this gap could involve mining or metals companies driving cross-industry research and development on tailings or slag reduction. Other research opportunities will involve finding alternate uses for tailings, for example being modified as new cements or fertilizers.

Figure 14: Gaps towards 2050

Mining companies	• **Be competitive and technologically cutting edge, while becoming a development partner** → E.g. focus on scale and costs, develop innovative processes → E.g. engage in value dialogue with local communities → Assess areas where they can move on to the metals space
Metals companies	• **Provide link between commodities and end-consumer and enable new technologies** → E.g. expand and invest in closed loop system → E.g. work with end-manufacturers on design to ensure cross-value chain collaboration → Redefine parts of business as "materials provider" (e.g., non-metals, metals leasing,...)
Governments	• **Drive shift to more circularity, reuse and remanufacturing and ensure development** → E.g. ensure recycling regulation and work towards a level regulatory playing field globally → E.g. define economic benefits applicable to recycling sector → E.g. ensure holistic environmental assessment across life cycle including use phase
Local communities	• **Be a partner to mining and metals (largely different communities for each)** → E.g. use local meetings to engage with mining companies shaping esp. rural, less developed areas → E.g. as "urban communities", address metals companies and develop engagement strategies
Civil society / NGOs	• **Be the link between communities, government and industry to ensure inclusive economy** → E.g. establish working groups (NGO space more diverse with various development goals) → E.g. counterbalance nationally focused government assessments of recycling and reuse benefits
Investors	• **Provide funding for changing business models and new technologies** → E.g. venture capital for clean tech and companies moving into recycling and reuse → Government funds and global foundations could play a role as "sustainable" investors

2. Infrastructure

Recycling, for example, requires three types of infrastructure: the collection and transportation of recyclable material, separating and sorting facilities to isolate components, and reprocessing facilities, such as smelters and refining, to make new metals from scrap. Solid municipal waste data shows that the greatest gaps, particularly in sorting and reprocessing, are in developing countries. While sorting and reprocessing infrastructure are generally in place in most industrialized countries, some have scope for more intensive metal collection – 30% of aluminium scrap is for instance not collected in the US. Facilitating the return of e-waste, for example by setting up easily accessible e-waste containers, is the key to raising scrap return rates in countries where customers have limited monetary or regulatory incentive to recycle. Education about recycling opportunities needs to go hand-in-hand with developing the infrastructure.

3. New product design needed

Product design can be changed to make the reuse of components easier and increase recycling. Modular buildings could for instance decrease waste from construction. Smaller changes will also have an impact. Mechanisms which fix the floor to steel beams in buildings can be redesigned so that the beams are not bent or twisted during demolition. Most electronic products could be redesigned for the easier extraction of metals from scrapped devices, such as disassembling smartphones to reuse displays or other functioning components.[60] Metal companies could collaborate with end industries in creating redesigned, standardized, durable products which enable reuse. In this case, the two parties will need to share benefits, whether as a license to operate, increased profits or increased market shares.

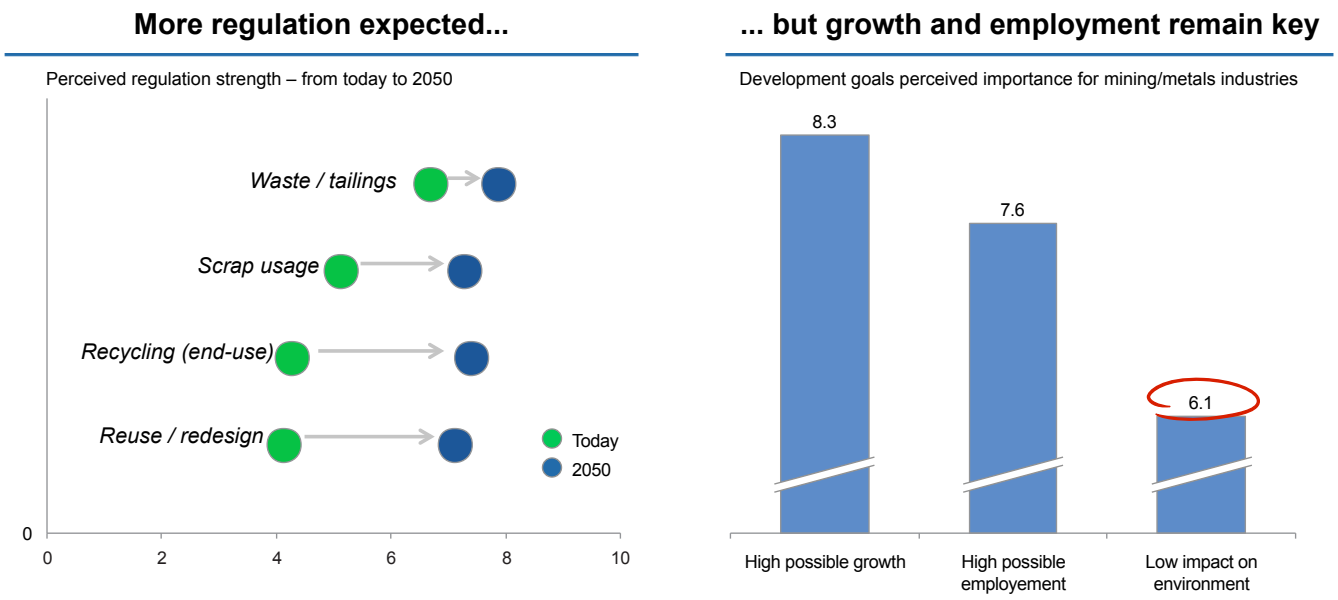
4. Regulation

Regulation has a major role in closing gaps between 2050 and today. Recycling and reuse need to be regulated more effectively. Recycling could be made mandatory for private and commercial consumers, while rules should demand product design that enables easy dismantling and metals extraction, e.g. from computer case. To close the gap, governments would need to legislate for reduced production of waste and tailings and higher scrap usage in the production and manufacture of new products. Life cycle assessments, which measure the true environmental impact of a product, could help governments determine recycling regulation. Regulation will be complex as it needs to take several aspects, from life cycle energy use to global scrap availability, into consideration.

5. Target conflict

A World Economic Forum survey found that while government regulation is expected to rise across the topics of waste, scrap usage, recycling and redesign, these rules may not drive more circular use of resources as long as high possible growth and employment remain key development goals (see Figure 15).[61] A balance needs to be created to resolve the conflict of targets. Workers, communities and government will not champion the shift to recycling unless the jobs, social insurance and skills lost as mining declines are replaced by the recycling and metals sector. While this is clearly not the only factor which will affect the future of mining and metals this conflict needs to be addressed by those involved.

Figure 15: Regulation without harming growth



Case study 4: China and recycling regulation – Steel and beyond

Industry overview

The serious environmental and resource issues facing China have prompted government initiatives intended to close the gap with other countries by promoting a more efficient and pollution-free use of energy. Chinese demand for steel has fallen for the first time in 14 years, creating an uncertain environment for the promotion of recycling and other sustainable initiatives.

Regulation

China has in recent years taken a series of environment and resource initiatives:

Law promoting circular economy (2008): Focused on energy saving and reducing pollution discharges by monitoring high-consumption and high-emission industries; companies were given incentives, such as tax breaks, to innovate in recycling technologies.

Law setting new requirements for producers and importers of waste electrical and electric equipment (2011): Included new labelling and management rules and an obligation to take on part of the costs of disposal and recycling.

"Operation Green Face" (2013): A 10-month campaign of random inspections aimed at preventing the importation of contaminated solid waste which diverted thousands of tonnes of scrap to other markets.

Recycling

There have been strong efforts to curb pollution through recycling. Some steel producers are moving along the value chain, and integrating recycling into their current business. At the same time there is a push for consolidation within the recycling industry aimed at promoting efficiency and new technologies

Infrastructure

China's metal production infrastructure is unlikely to evolve in the short run. This is in part because of the heavy investment in blast furnaces in the last decade, making a rapid switch to EAF unlikely in China. These furnaces do, though, have capacity for greater use of scrap and collection capacity is capable of growth.

So governments, especially those in developing countries which are heavily reliant on mineral extraction, need to ask whether they understand the implications of more recycling for their economies, and if they have a long-term plan for shifting value creation downstream; plans that exist in countries like Indonesia or Botswana. Governments also need to consider incentivizing growth in the recycling sector and to drive the shift to more beneficiation, while informal recycling must be kept at a minimum.

6. Reusability of recycled material

The production of metals based on scrap inputs, especially high quality alloys, needs to be improved. Much depends on how well specific metals can be isolated from other metals and non-metals during the recycling process. This begins with mechanical sorting, but some complex metal materials such as Indium in LCD screens need to be further concentrated through chemical pre-processing in order to be recovered.[62] These processes need to become more cost-efficient towards 2050, while metallurgical and chemical processes which prevent the removal of other metals once one has been isolated need to be improved. Technology is the major enabling factor for these improvements.[63]

7. Electricity

Unstable electrical grids are a potential gap in particular for steel recycling. Making steel from recycled materials takes more than three times more electric energy than BOF[64] steel production (based on primary coal and iron ore).[65] This makes a stable and reliable electric energy grid key for the recycling of steel. From a sustainability perspective, it is also important to consider the source of energy and related emissions for future metal production. The cost of the electrical power provided also plays an important role as it influences efficiency and the feasibility of specific routes.

8. New partnership models required

New partnership models, such as downstream companies and manufacturers working together with metals producers who take scrap back from them, are essential in the company-driven sector of scrap treatment. Scrap treatment and particularly end-of-use recycling could be enabled by expanded closed- loop systems in which the producer, or an alliance of players along the value chain, is responsible for production, collection, recycling and re-production.[66] Such partnerships – for instance between a metal producer, a manufacturer and a mail company – would allow appliances and products, such as old kitchen goods, to be reinserted into the production cycle.

Collaboration between metals companies and end industries would help create redesigned, standardized, durable products which enable reuse. In this case, the two parties will need to share benefits, whether as a license to operate, increased profits or increased market shares. Mining also has a role to play in assisting reuse, via collaboration with metals companies over redesign specifications.

9. Scrap demand and supply not in the same place

The geographic mismatch between places where recyclable material is available and those where it is most needed is a gap on the way to a 2050 sustainable world. Most of the recyclable metal waste is created in industrialized and high income countries, while the countries which will need sufficient scrap to make the transition from mining to a circular use of resources are mostly low-income and have immature recycling sectors.[67] States could help solve this problem by providing recycling infrastructure. This would also allow developing economies to absorb existing scrap, for instance from old cars which are imported from Western Europe, extending their lifetime.

10. Limited customer preference

Consumers also play a role. Steady demand is needed to promote reusable products, those manufactured with little processing waste (home and new scrap) and the new ownership models provided by companies. Consumers are not currently opposed to more circularity, but will need to become more enthusiastic for alternate ownership models to work. Together with the private sector, governments in industrialized countries should therefore promote sustainable consumer behaviour, including a preference for recycled products, reusing products and alternative ownership models. Consumer preferences are linked to pricing structures – the cheaper repaired or used products are compared to new products, the more likely a change in behaviour.

Case study 5: New partnership models in recycling

Players	• Korea Zinc: A major integrated zinc and lead producer • $5.7bn market cap & $4.9bn annual revenue • ZincOx Resources: A Zinc recycling specialist • £20m market cap & £21m annual revenue
Actions	• ZincOx Resources (Zinc recycling specialist) teamed up with Korea Zinc to build a major Zinc recycling plant • In 2010 Korea Zinc provided loans amounting to $50m for the production of the "Korean Recycling Plant" • Korea Zinc agreed to an off-take agreement for the entire zinc concentrate production
Results	• ZincOx will overall supply more than 840,000 tons of Zinc to Korea Zinc • The plant will generate enough cash to repay the development loan fully from internal resources • The plant has an internal rate of return of 30% and annual EBITDA of ~$29m

Sources: ZincOx press releases; Company annual reports; proactiveinvestors.co.uk; FT markets data

Impact of the transition from primary to secondary metal production: The example of steel

Closing the gaps and moving towards the 2050 ambition can have significant impact on the industry. The following section discusses this potential impact and practical limitations to the transition from primary to secondary metal production.

Introducing the model: Steel as proxy

The shift to more recycling between now and 2050 is being quantified via the example of global steel production. Steel has been chosen as a proxy for the sector because it is an important commodity, which is used in key value chains. These chains are also relevant for other commodities, so conclusions for steel may apply elsewhere

Scenario approach

The analysis relies on modelling the fundamental demand for steel, and has been conducted through several steps. To create a comprehensive view of potential change for steel between now and 2050, two scenarios were used: “Keeping a green line” and “True change”. Keeping a green line assumes that current assumptions for the steel market will still hold, where true change assumes a more sustainable world geared towards more circular use of resources and, therefore, more recycling. The two models generate differing results offering sharp insights into the directions the steel market, and to some extent other metals markets, can take in the future.

The model also incorporates assumptions. One of the most critical assumes that steel intensity will drop slowly in most developed regions, while Chinese intensity falls closer to European levels, and India and Africa show steady growth as new steel consumers. Both scenarios are based on the same underlying steel demand assumptions.

Scenarios overview

Keeping a green line

This scenario assumes that significant elements underpinning current production will remain constant: the regional split between the two main types of steel processing infrastructures (basic oxygen furnaces and electric arc furnaces); the share of scrap basic oxygen furnaces and current regional collection rates. Yet even this scenario assumes that scrap will play a more important part in the steel-making process and that growth in demand for primary resources (iron ore and met coal) will slow.

True change

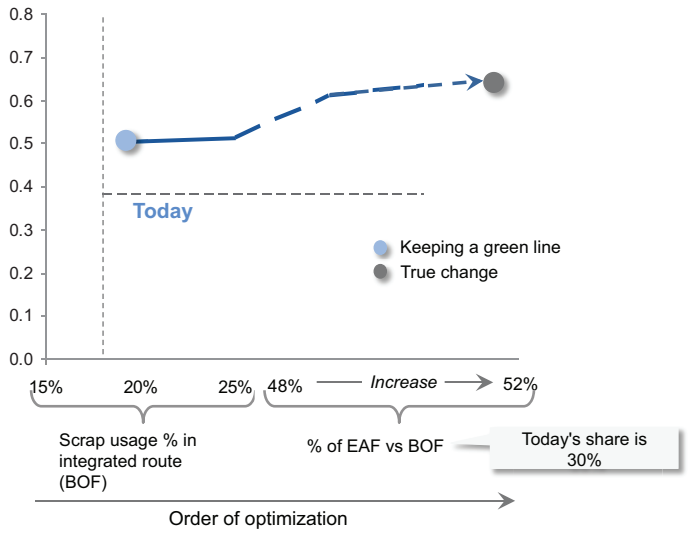
This scenario follows the very different assumption of a global shift between primary production and scrap recycling. This shift will be driven in part by increased regulation in Europe and the United States, but most of all by an increased emphasis on recycling in China. This will increasingly force steel producers to use scrap rather than other primary materials. Shifts in the relative prices of primary materials and scrap will drive such a switch even if the regulators are less active than anticipated.

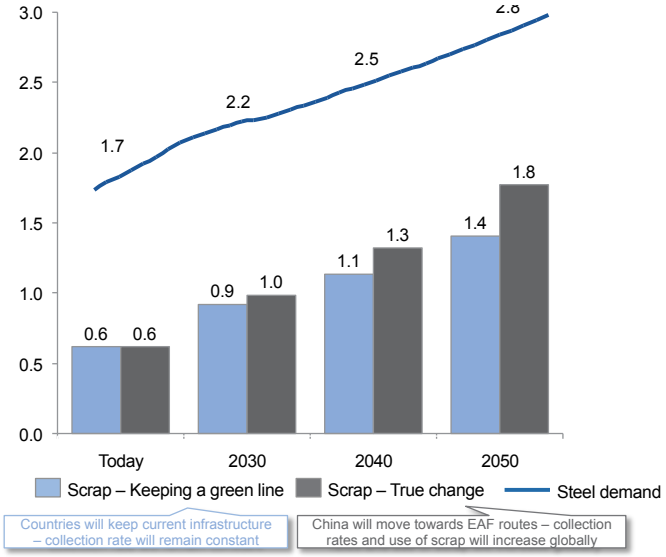
With the use of scrap increasing for both major production routes, each will absorb annual volumes equivalent to its maximum capacity. Demand for scrap will also be driven by China’s increasing adoption of electric arc furnaces, which can absorb a higher proportion of scrap in production. This increased demand will incentivize recycling and raise collection rates.

Results

1. Steep increase in demand for scrap in a world geared towards recycling

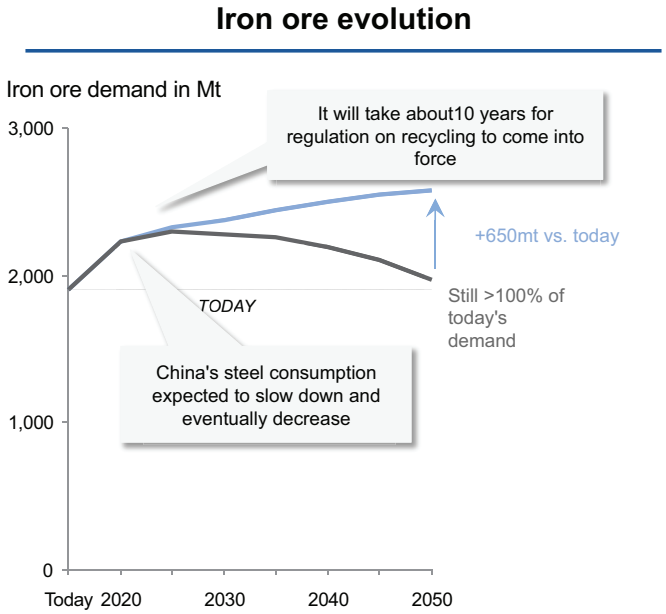
The first scenario predicts global steel production of around 2.8bt in 2050, with around half coming from scrap. Under the second scenario, scrap becomes predominant due to changes in the regulatory landscape. Electric infrastructure will more than double its share of Chinese production. Increased demand will drive rising collection rates, with further important volumes of scrap delivered by China's late industrialization. These phenomena will lead to 2050 primary steel production only marginally above today's level.

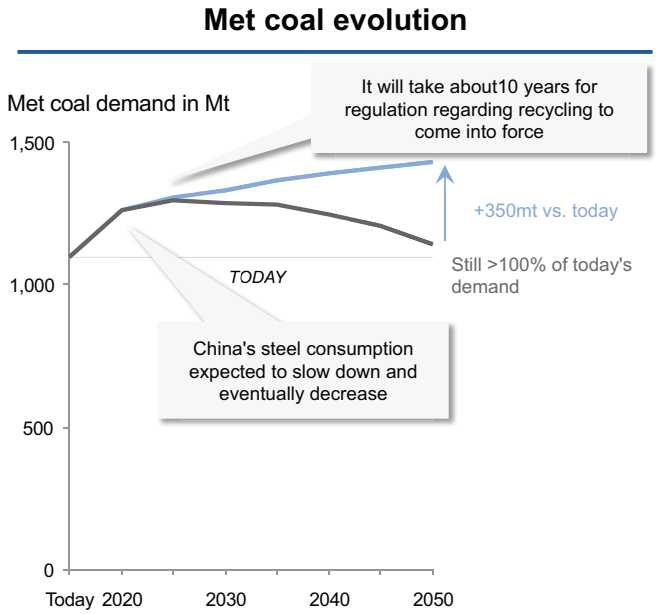




2. Demand for other primary materials remains

The exercise also enables projections for the future demand for primary materials, such as iron ore and metallurgical coal, used in steel production. Under "Keeping a green line", the demand for both commodities will continue increasing, although growth will slow. Recycling will grow in importance, slowly reducing the use of primary resources, even under this scenario. "True change" forecasts that because of the growth in recycling and consequent increase in scrap use, demand for both primary commodities will decline from 2020. Yet even by 2050 they will remain slightly above current levels.



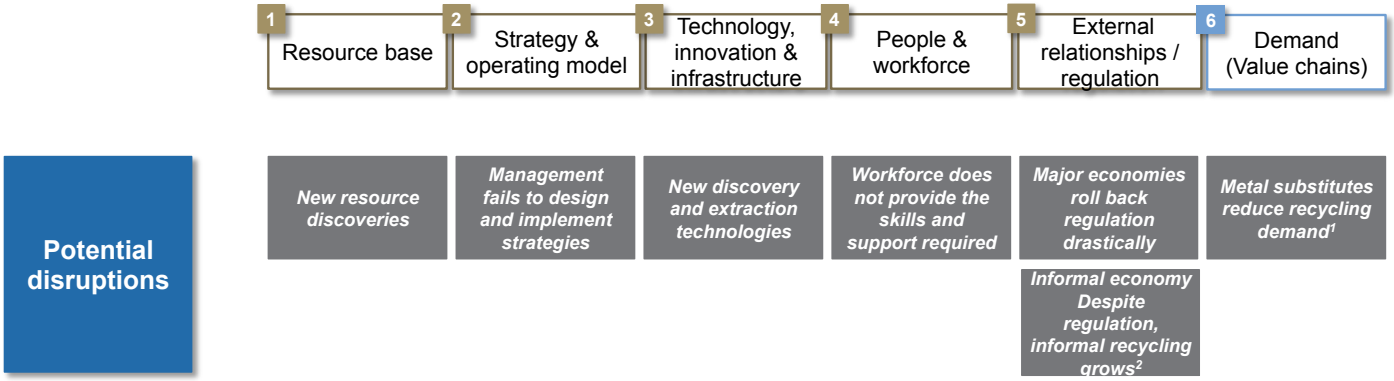


The shift towards true change requires concerted action between governments and industry to incentivize and operationalize the shift in infrastructure and recycling rates and ensure its financial feasibility. Even in this scenario, met coal and iron ore demand will remain at today's levels.

These scenarios offer an understanding of the impact of a switch to recycled material under specific pre-defined conditions. It must be remembered that other factors not taken into consideration could still influence steel demand, prices and development between today and 2050.

Potential Disruptions

In step four, potential disruptions relevant for the deep dive are identified in discussions and workshops with experts. Even if all gaps were remedied, disruptions – events or developments of a broader and more uncontrollable nature – could still divert the path towards a more circular use of commodities and metals in 2050.



Six key disruptions were identified along the areas of transition (see Figure 16):

1. Resource base

The discovery of large, new primary resources could have a negative effect since, by making increased recycling and reuse less attractive, it would reduce the incentive to shift to a more circular economy. Such discoveries would have a greater impact on scarce minerals and metals which are extracted in small quantities, for example rare earth elements. For commodities with large volume markets, extensive new low-grade resources would be as likely to hurt exiting high-cost primary producers as recyclers.

2. Strategy and operating model

The changes and transformation necessary to achieve the desired end state will require major adjustments in operating models and company strategy. This will only be possible if the management embraces the required changes and supports them with public commitment and potentially with comprehensive change management programs. Conflicting shareholders or management interests could prevent necessary changes to happen and cause companies to continue operating under their current operating models and strategy. A disruptive economic environment in which performance and profits are under pressure could also prevent management from implementing adequate measures. The incentive structures, governance and communication all have to support the changes needed to move towards more circularity.

3. Technology and innovation

New discovery, extraction and processing technologies increasing the supply of mineral resources (or making it cheaper to extract given resources) could hamper the shift to recycling and reuse, making processes much more efficient and even more economically viable. Here too, the impact varies. Technological disruption may be much quicker in small mines yielding low quantities of minerals than in huge operations where change takes longer and there is significant investment in existing machines and processing facilities. It is also possible that metal substitutes could be developed based on abundantly available material. There would be little incentive to recycle such cheap material, and this might not in any case be possible for a long time. It could thus cease to be economically viable to recycle some metals. If primary suppliers were equally impacted by substitutes, the percentage of overall recycled material could, however, remain similar for traditional materials.

4. People and workforce

The revised business models and technologies on which the 2050 desired end state is based require the workforce to adapt and evolve. Employees, as a key pillar of mining and metals industries, will need to acquire the necessary skills required by these changes but more fundamentally to support in the long term the process by which they will be enabled. Because of their role, employees have the power to disrupt this process. Increased automation and lack of transferability of their skills in a world geared towards recycling could incentivize them to oppose the changes paving the way to the desired end state.

5. External relationships and regulations

A significant producing country might provoke a major negative disruption by dismissing regulations promoting reuse and recycling. There is also the danger – without regulation or with regulation unenforced – of informal recycling continuing in many developing countries. This means that recycling is done very inefficiently, so the economic benefits from selling the extracted metals to secondary commodity markets do not help to build a sustainable recycling sector, keeping these countries from participating in the shift to a more recycling-based economy in 2050.

6. Demand

Customers could create a disruption through demand by misappropriating new ownership models. This could happen if new models are embraced with adverse effects, if, for instance, customers convinced by the face value of new models renew leased cars after short periods, so that the total number of vehicles increases. Another example would be if the rise of city car rental services saw them used in addition to, rather than as a replacement for, personal vehicles.

The introduction of new materials in end industries can also significantly impact the end state. They could replace currently recyclable materials, but not be recycled at the same rate for decades. An example is carbon fiber-reinforced plastic, which currently offers limited repair or recycling options. For reasons of cost (no economic incentive to recycle) and technology (no recycling rates) new material could mean less circularity. Nonetheless, the overall energy and emission footprint would have to be assessed to judge its impact on sustainability – the impact of metal substitutes might after all be positive if they contribute to reaching a goal like full carbon neutrality by 2050.[68] A new material will not invariably totally replace an older one, but will still affect sustainability if it reduces volumes or recycling scale.

Scenarios and Roadmap Building

As the last step to identify specific actions – be it on an industry or company level – scenarios based on possible geopolitical, societal or technological changes are applied along the given theme. The scenarios describe alternative futures which would warrant different actions. While scenarios are not predictions, they can point to important issues of which stakeholders need to be aware of, and possibly act upon, in the future. Based on this a roadmap of actions for stakeholders is derived corresponding to each scenario.

Three applicable scenarios have been identified and can be used for future deep dives. The World Economic Forum's *The Future Availability of Natural Resources* report provided the base for the scenarios. They were refined by integrating relevant elements from the report *Mining & Metals Scenarios to 2030* as well as reflecting potential disruptions previously mentioned, such as new resource discoveries and technologies, metal substitutes or major economies rolling back regulation.

A set of three diverse scenarios were created which represent distinct business landscapes that mining and metals companies may find themselves operating in:

- Scenario 1: A world of two speeds
- Scenario 2: Resource abundance
- Scenario 3: Global fragmentation

These three scenarios aim to serve as a base applicable across all future deep dives, even on a company or commodity-specific level. Despite their universal applicability, the scenarios should not be used blindly. In case of future application, it will be necessary to determine if they need to be adjusted or refined in order to reflect the specificities of the region or the commodity to be analysed as well as the business model of the organization using the framework. Refinement or even integration of new scenarios is encouraged and possible.

Scenario 1: A world of two speeds

A world of two speeds is characterized by the emergence of two (or more) groups of countries which are moving at widely differing speeds. One group, the "sustainable forerunners", is advancing rapidly towards a circular use of commodities and metals, while the other, the "mineral dependents" has deliberately chosen a slower pace.

The sustainable forerunners are countries with an environmentally concerned public and governments keen on regulation on recycling, waste reduction, etc. Private and business customers from this group reject metals based on invasive mining, while governments and consumers in the mineral dependents group are primarily concerned with securing growth and employment through traditional mining. In the latter bloc, the recycling sector is less developed.

The sustainable forerunners might still require certain primary materials to sustain high tech advances. In the world of two speeds, most political agreements will be between countries in the same bloc, so trade will be much more vibrant within than between blocs. Investment with a longer-term horizon will mean that the technology which enables more efficient recycling will advance much faster in the sustainable forerunners' bloc. Mineral dependents might be subject to greater environmental impact as heavy mining impacts are mitigated by technological advances.

Roadmap for mining and metals

- Mining companies must be a development partner for mineral dependents while transferring sustainable practices initially developed for sustainable forerunners
- They need to react to different customer needs in the respective bloc
- Multinational mining and metals companies have to be aware they could serve as a link connecting the two blocs
- Industry can follow "sustainable first movers" if regulation goes along

Specific actions for the mining and metals community

Mining companies

- Focus on cost effective extraction, e.g. by identifying best assets and focussing on commodities least impacted by recycling
- Implement clean technology in the mineral dependents bloc, e.g. by aligning on cross-industry standards for low impact technologies

Metals companies

- Increase recycling in the forerunners" bloc, e.g. by starting pilot recycling projects in regions with best infrastructure before roll-out
- Build up beneficiation presence in the mineral dependents bloc, e.g. by discussing concerted efforts with other metals players

Governments

- Foster international dialogue to promote global regulation, e.g. by identifying key stakeholders and aligning and commonalities

Local community and civil society

- Promote sustainable thinking among consumers in both blocs and educate accordingly, e.g. by wide scale collaboration between industry and different civil society organizations

Investors

- Invest in energy efficient and sustainable companies, especially in the "slower" countries, e.g. by earmarking a certain share of investment for this purpose

Scenario 2: Resource abundance

In the scenario, there is no scarcity of materials. This is due to technological changes that lead to increased metals production. Resource discoveries and processing innovations could increase the use of some materials – titanium would, for instance, have many more applications if it were more readily and cheaply available. The resource abundance scenario also sees metal substitutes becoming available cheaply. However, the recycling of these substitutes might not immediately be feasible.

Alternatively, resource abundance could result from frontier mining. This is mining in new, formerly unknown areas, including the deep sea and, in the long-term future, potentially asteroids. Resource abundance through process innovations, metals substitutes or increased frontier mining may reduce economic incentives to become more resource efficient.

With global economies moving towards more open markets and strong global trade, abundant metals or substitutes enable and create additional consumption in all regions of the world. So even if substitutes were fully recyclable, a rebound effect could kick in: higher demand creates still greater need to exploit primary sources to produce recyclable material. In the resource abundance scenario, there are few incentives to decrease waste production or to strengthen the recycling sector. Waste production becomes an increasingly important environmental problem.

Roadmap for the mining and metals community

- Mining companies need to make sure they have the capital, and also cutting-edge technology, to enable expanded and more energy-efficient minerals extraction
- Mining and metals have to be prepared to adapt their business model to the rise of metal substitutes
- Mining and metals will continue to think about the environmental impact of their operations

Specific actions for the mining and metals community

Mining companies

- Ensure energy efficiency and tailings reprocessing, e.g. by supporting cross-industry R&D programmes
- Focus on extraction of minerals not impacted by substitutes, e.g. by organizationally splitting commodities into an affected and a non-affected group

Metals companies

- Optimize metal processes as alternative to substitutes, e.g. by focusing on specific applications and metals
- Understand customer sentiments down the value chain, e.g. by partnering more closely with end-consumer industries

Governments

- Ensure environmental regulation of new frontier extraction, e.g. by setting up a global regulatory body
- Drive recycling of new materials, e.g. by building infrastructure and establishing rules

Local community and civil society

- Be a critical partner to industry, e.g. by focusing on key topics and “speaking in one voice”
- Promote consistent focus on responsible use of resources, e.g. by teaming up with industry on a global campaigns and discussions

Investors

- Favour low-impact companies, e.g. by analysing financial benefits of low-environmental impact

Scenario 3: Global fragmentation

This scenario assumes an increased competition for resources by inability to match supply and demand. Higher population growth can be coupled with slower growth. Resources, including minerals, water, food and others, deplete much faster than expected or are not traded sufficiently. At the same time, demand for commodities and metals cannot be fulfilled.

Countries all around the world are cutting back on exports of these products, fulfilling their domestic needs first. In some cases, this new protectionism leads to international resource conflicts with potential military confrontations between states in order to secure national resource supplies. This world is characterized by clashing national interests leading to global political and economical fragmentation, although sporadic strategic alliances persist. Due to a lack of internationally agreed legislation, major companies find it hard to switch to sustainability. In this fragmented world, environmental impacts vary considerably but are mostly significant. Similarly, the penetration of technological advances will vary by country, but with a general tendency to decrease.

Roadmap for the mining and metals community

- Mining and metals need to reconcile being multinational corporations with the need to produce and sell more locally
- Mining companies must find a way to deal with potential resource nationalization
- Companies must prepare for potential security issues

Specific actions for the mining and metals community

Mining companies

- Ensure efficient and low-impact mining despite low regulation, e.g. by driving global industry standards
- Engage against nationalization, e.g. by fostering government and community relations

Metals companies

- Focus on local sources of scrap, e.g. by supporting schemes to build collection infrastructure
- Together with mining, lobby for open trade and borders, e.g. by means of industry associations

Governments

- Facilitate recycling nonetheless, e.g. by developing recycling and collection infrastructure
- Engage in multilateral dialogue, e.g. by integrating mining and metals industry in key meetings

Local community and civil society

- Mitigate/negotiate conflicts over resources on a local level, e.g. by clearly mapping local needs and potential conflicts

Investors

- Invest in less protectionist countries with green agendas, e.g. by evaluating impact on shareholder value/returns

Next Steps

The drive towards more sustainable consumption will be a dominant theme in a more sustainable world. Resources will last longer while increased reuse and recycling drive a more circular economy. A strong move towards recycling and circularity is likely, but fundamental changes are required to support this transition, including appropriate infrastructure, regulation and legislation, and competitive cost economics. Irrespective of the range of possible scenarios, conclusions can be drawn for the industry.

Mining will not disappear; primary extraction will continue but volumes are unlikely to grow in line with GDP growth. This means that pressure to realize scale effects and cost efficiency will remain in the foreseeable future. Demands for cost-effectiveness will exist in parallel with demand for environmentally and socially responsible actions, leading to new partnership and operating models (see case study 6).

Metals will not disappear; metals companies will act as a liaison between commodity producers and end-industries. Opportunities will exist to adapt business model transformations and reposition as materials providers.

Technology will be key, and it will become increasingly important to better understand supply chains and consumer preferences. At the same time all stakeholders will have to work together to prevent unintended consequences from a shift towards more recycling and reuse.

The evolution of the circular economy will be governed by many external factors within and beyond the mining and metals industry. Nonetheless, the industry has a key role to play in shaping future circularity.

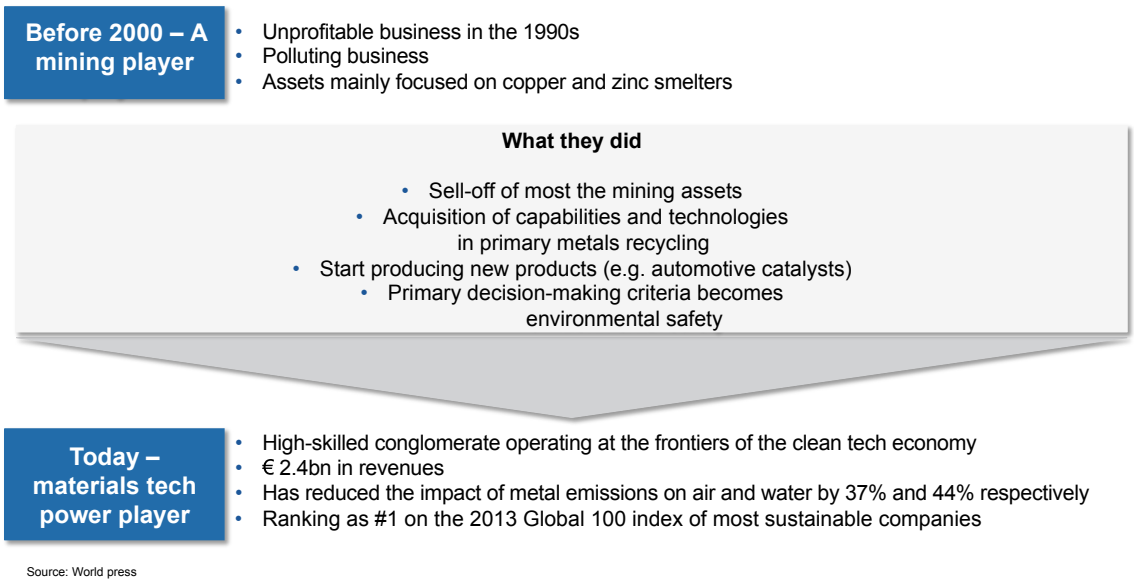
Rules are changing, social pressure to act more sustainably is growing, and increased circularity has the potential to disrupt the sector. Faced with a changing world, mining and metals companies need to identify the actions they need to take today to better prepare themselves to be the industry leaders in 30 years' time. Thinking about the right issues today will prepare the industry to successfully cope with a variety of future developments, without losing the ability to contribute to a more sustainable world.

The framework developed as a part of this initiatives provides the key checkpoints that mining and metals companies need to be thinking about to adapt to a progressively sustainable world. It also provides a scenario-based assessment of the diverse paths this journey may take and how the various stakeholders need to position themselves amid such future developments.

Using the framework, the pilot research work on the topic of the circular use of commodities and metals explains in detail the opportunities and challenges presented by emerging trends and potential disruptions in the area of recycling, reuse and redesign of mining and metals products in future. By applying the scenarios as filters, the report identifies what different stakeholders should do to prepare the industry for the expected changes while being able to contribute to a more sustainable world.

The report serves as a foundation for further explorations of the challenges and opportunities identified in last year's work. In a first step, companies and other stakeholders can apply the themes and sub-themes within this framework in order to identify any missing elements which are critical for the journey towards a sustainable world. This will help modify the proposed action plans or trigger new action plans that may be required for collaborative action by various stakeholders. Continuing on our efforts to help create industry-specific insights through focussed research work, one potential area for further exploration in 2015 will be technology and the identification of key technological disruptors.

Case study 6: Umicore - mining player to materials tech leader



Source: World press

Acknowledgments

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Endnotes

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15. World Economic Forum, *Scoping paper: Mining and Metals in a Sustainable World*, February 2014, p.9.
16. As for example described by Natural Step as "resources being used fairly and efficiently to meet human needs", http://www.naturalstep.org/en/the-system-conditions, accessed on October 18th, 2014.
17. For more details on value of extraction, cf The World Economic Forum, *Responsible Mineral Development Initiative*, 2013.
18. The value chain does not differentiate between mining and metals operations but illustrates the business combined.
19. Demand is shown in a simplified form – the end industries in themselves are in fact value chains (e.g. the automotive industry).
20. The report speaks of an "integrated paradigm" that rests on five insights into the global availability of food, water, energy and minerals. These insights are arrived at by analysing the assumptions behind typical fragmented paradigms that various interested parties are putting forward in the resource debate. Since this report is focused on mining and metals, the integrated view applied here is not identical to the "integrated paradigm". Cf. World Economic Forum, *The Future Availability of Natural Resources. A new Paradigm for Global Resource Availability*, 2014.

21. Ernst & Young, *Business risks facing mining and metals 2014–2015*, 2014.

22. "The robot is ready – so when will deep sea mining start?" Reuters, April 18, 2014, http://www.reuters.com/article/2014/04/18/us-mining-deepsea-idUSBREA3H06T20140418.

23. European Commission, *Towards a circular economy: A zero waste program*, July 2014.

24. James Wilson, "Water scarcity and rising energy costs threaten mining industry", Financial Times, July 27, 2014, http://www.ft.com/intl/cms/s/0/780e738a-13f0-11e4-8485-00144feabdc0.html#axzz3Lggekii0.

25. That resource management should also integrate governments, local communities and civil society, as well as the scientific community, was one of the six key strategies for understanding and mitigating risks related to future resource availability, according to the World Economic Forum's *The Future Availability of Natural Resources* report.

26. World Economic Forum, *Metals and Mining Transformations from the Summit on the Global Agenda 2013.*

27. IAI. USGS, WoodMacK, RBC, WGC, Morgan Stanley , Deutsche Bank, Ore Primer, Goldman Sachs , CRU, CIBC, MacQuarie, RMG, TD Securities, World Bank, Boston Consulting Group analysis.

28. World Economic Forum's World scenario series, "The Future Availability of Natural Resources - A New Paradigm for Global Resource Availability".

29. World Economic Forum, "Mining & Metals: Scenarios to 2030", http://www.weforum.org/reports/mining-metals-scenarios-2030.

30. Definitions of tailings differ. For instance extracted material with a specific iron content today could be considered tailings today, but might in the future be considered ore due to changes in price and technology.

31. United Nations Environment Programme (2013), *Metal Recycling: Opportunities, Limits, Infrastructure. A Report of the Working Group on the Global Metal Flows to the International Resource Panel,* Reuter, M. A.; Hudson, C.; van Schaik, A.; Heiskanen, K.; Meskers, C.; Hagelüken, C.

32. Reuse of material to create a higher quality or higher value product; for examples see Takamatsu, Nobuhiko, et. al., Steel Recycling Circuit in the World, Tetsu-to-Hagané Vol. 100 (2014) No. 6., p. 736-745.

33. Mining companies could be negatively impacted but have limited direct influence.

34. Vanessa M. Smith, Gregory A. Keoleian, "The Value of Remanufactured Engines: Life Cycle Environmental and Economic Perspectives", Journal of Industrial Ecology, Volume 8, Issue 1-2, pages 193–221, January 2004.

35. The most likely set up is that the lessee will only have the obligation to retransfer the same quantity and quality of metal. Other alternatives are possible but would significantly increase complexity and costs.

36. Different aspects of the end-state can be inherently conflictual, e.g. when full employment and development clashed with the idea of minimizing safety and health risks by automating labour.

37. It should be noted that one possible consequence of extending product lifetimes through new ownership models or increasing reuse is a reduction in the amount of metal available for recycling.

38. An example from the steel space are high strength steels and advanced high-strength steels which reduce the amount of steel needed for a given machine or car.

39. Note that what today is considered tailings might tomorrow be considered ore – when it becomes economically feasible to retrieve Fe (Iron) from waste that still contains 20% of it. The definition of waste and tailings in mining is a matter of economics.

40. Australian Centre for Geomechanics, *Making an Unsustainable World more Sustainable*, 2008.

41. "Generation of primary waste by sector", OECD.StatExtracts, http://stats.oecd.org/Index.aspx?DataSetCode=WSECTOR (accessed 31 Oct 2014).

42. IAI. USGS, WoodMacK, RBC, WGC, Morgan Stanley, Deutsche Bank, Ore Primer, Goldman Sachs , CRU, CIBC, MacQuarie, RMG, TD Securities, World Bank, Boston Consulting Group analysis.

43. Up to USD18billion in current market prices. Cf. Mishra et al. "Recovery of value-added products from red mud", in: MINERALS & METALLURGICAL PROCESSING, Vol. 19, No. 2, May 2002; "Recycling Red Mud" (Interview with Victor Mann), in: Mining Magazine (May 2013); www.onemine.org (accessed 31 October 2014).

44. UNEP International Resource Panel, *Metal Recycling: Opportunities, Limits, Infrastructure,* 2013*;* Simon Glöser, Marcel Soulier, and Luis A. Tercero Espinoza, "Dynamic Analysis of Global Copper Flows", in: Environmental, Science & Technology 2013, No. 47; IAI Global Mass Production Flow Model; Bureau of International Recycling Ferrous Division, 2012; Tata Steel Europe, 2013.

45. In 2013, the top three mining companies (based on their share of value of world mine production of all minerals) used more than 1bn gigajoules of energy and emitted far more than 100m tons of CO_2 or CO_2 equivalents. See Rio Tinto, BHP Billiton and Glencore annual reports 2013.

46. Gro Gilstad: "Life cycle assessment of secondary aluminum refining", Master Thesis, Norwegian University of Science and Technology Trondheim, 2013; Organisation of European Aluminium Refiners and Remelters, *Aluminum recycling in Europe*, 2006.

47. Expert interview Edwin Basson, World Steel Association; Standard Chartered: *Chinese metal recycling sector. Value in the scrap heap,* 2011.

48. SNL Metals & Mining database; World Bank GDP data.

49. ICMM, *Mining Contribution Index*, 2012; SNL Metals & Mining; World Bank GDP data, http://data.worldbank.org/indicator/NY.GDP.MKTP.CD, accessed 25 November 2014; National Mining Association (US); Australian Bureau of Statistics; Mining Association of Canada; Eurostat.

50. World Economic Forum, *Responsible Mineral Development Initiative*, 2013.

51. Chart shows "factor-driven" economies that mainly compete on the basis of their factor endowments, primarily low-skilled labor and natural resources; multi-stakeholder survey which included government officials, commodity producers and NGOs. Cf. World Economic Forum, *Responsible Mineral Development Initiative*, 2013, p.10.

52. Tax Justice Network Financial Secrecy Index (http://www.financialsecrecyindex.com/introduction/fsi-2013-results); Transparency International Corruption Perception Index (www.transparency.org) (accessed 31 October 2014).

53. Cf. Hamburger Stiftung für Wirtschaftsethik, *Elektro-recycling. Eine ethische Risikoanalyse*, 2012.

54. This would mean that consumers and regulators were able to trace a certain product's supply chain and learn, for instance, about its material composition (share of recycled material input, etc.).

55. The case of diamonds shows that there has been progress in making mineral value chains more transparent. Since for instance the Dodd Frank-Act was passed in 2010, companies listed on U.S. exchanges are required to audit their supply chains and report the usage of 'conflict minerals'.

56. Cf. http://www.junctionsolutions.com/; https://www.harvestmark.com/ (accessed 4 November 2014).

57. This also includes long term health such as the cancer rate in the next generation.

58. Safe Work Australia (http://www.safeworkaustralia.gov.au/); United States Department of Labor Bureau of Labor Statistics (http://www.bls.gov/), accessed 4 November 2014.

59. The number of fatal injuries per million hours worked was 0.14 and 0.11 for exploration and coal mining compared to zero for smelting and refining in 2008/2009. Cf. Minerals Council of Australia, *Safety Performance Report of the Australian Minerals Industry 2008-2009.*

60. Concepts as that of Phonebloks are currently being commercialized. Cf. "Phonebloks – the next step for a better phone", http://phoneblocks.com/ (accessed 25 November 2014).

61. Survey of 38 respondents during a panel discussion on Mining and Metals in a Sustainable World 2050 at the World Economic Forum's Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development, Geneva, October 2014.

62. Steven Art, Umicore presentation on Precious Metals Refining (http://www.stichtingrta.nl/upload/documents/ab18bb9099eb73c4022bb60af02d3d94-RTA 2014 Umicore.pdf) (accessed 25 November 2014).

63. It should be noted that the high quality metal sector represents only 10-20% of total.

64. Basic Oxygen Furnace with usually more than 80 % virgin material input.

65. Electric energy used in Electric Arc Furnaces: 5.10 GJ/ton of steel produced; integrated/BOF route: 1.55 GJ/ton. Cf. Expert interview Edwin Basson, World Steel Association.

66. Closed loop or ‘cradle-to-cradle’ systems require little or no ‘outside’ inputs because no material is lost to the system during the product’s life cycle. This unity of initial production, collection, separation and recycling is ensured by close collaboration between players along the value chain. The return of products to the production cycle can be ensured either by partnerships with logistics companies who provide consumers with convenient recycling infrastructure or by alternate ownership models that allow manufacturers to retain permanent ownership of the devices.

67. It should be noted though that trade data suggests considerable ‘flows’ to low income countries, for instance of used cars: Global trade in 2005 was 5.65m vehicles with Germany, USA and Japan accounting for 63% of exports and 54% of the total going to developing countries. Cf. Fuse et al.: “Estimation of world trade for used automobiles”, in: Journal of Material Cycles and Waste Management, Vol. 11, Issue 4, December 2009.

68. At the UN climate negotiations in Lima in December 2014, “carbon neutrality/net zero emissions by 2050” was drafted as a long-term goal for a new climate change agreement that is to be finalized at the 2015 UN Climate Change Conference. Cf. Graham Readfearn: “Goal to end fossil fuels by 2050 surfaces in Lima UN climate documents”, The Guardian, December 9, 2014, http://www.theguardian.com/environment/planet-oz/2014/dec/08/goal-to-end-fossil-fuels-by-2050-surfaces-in-lima-un-climate-documents (accessed December 16, 2014).

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