Discussion paper issued without formal editing

FOR PARTICIPANTS ONLY
19 October 2016
ENGLISH ONLY

UNITED NATIONS
CENTRE FOR REGIONAL DEVELOPMENT

In collaboration with

Australian Government,
Office of Green Industries SA on behalf of the Government of South Australia,
Commonwealth Scientific and Industrial Research Organisation, and
Ministry of the Environment, Government of Japan

SEVENTH REGIONAL 3R FORUM IN ASIA AND THE PACIFIC,
2-4 NOVEMBER, 2016, ADELAIDE, SA, AUSTRALIA

Shifting Sands: The circular economy and its implications for natural resource supply and demand

(Background Paper for Plenary Session 6 of the Programme)

Final Draft

This background paper has been prepared by Dr. Anna Littleboy, for the Seventh Regional 3R Forum in Asia and the Pacific. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

Seventh Regional 3R Forum in Asia and the Pacific,

November 2-4, 2016, Adelaide, SA, Australia

Background paper

on

Shifting Sands: The circular economy and its implications for natural resource supply and demand

Authors: Anna Littleboy, Mark Cooksey and Kathie McGregor

CSIRO Mineral Resources, Queensland Centre for Advanced Technologies, 1 Technology Court, Pullenvale QLD 4069, Australia

Abstract

Australia as a nation is a mature producer and exporter of various minerals and energy commodities. Over the past two decades, and most notably since the Mining, Minerals and Sustainable Development Initiative in the early 2000s, significant progress has been made in practices and policies for improved environmental and social outcomes as well as enhanced economic productivity and efficiency. Generally, these developments drive towards *either* economic, social *or* environmental outcomes and are implemented at *either* operational, national *or* global scales through institutions that tend to inhibit integration between all these dimensions. The circular economy is a highly integrative concept and this paper will examine its implications for resource supply and demand, for the management of the resource value chain from exploration through to product and for global resource governance. The presentation will consider whether these trends are sufficient as a contribution from the resources sector to the UN sustainable development goals and, if not, why not.

Acknowledgements:

The concepts in this paper draw on research developed by the CSIRO Wealth from Waste Collaboration Cluster. This collaboration involved the following institutions: University of Technology Sydney (Institute for Sustainable Futures), University of Queensland (Sustainable Minerals Institute), Swinburne University of Technology, Monash University and Yale University.

1. Introduction

Potential cumulative investment in oil, gas and mining infrastructure is estimated at $19 trillion dollars by 2030. This is huge. At the same time, the recognition that we no longer live in a world of limitless resources is emerging into the public domain. In a "circular economy", these two points need not be incommensurate. The mine of the future may be increasingly concerned with materials that lie above, rather than below, the earth's surface.

The 20th century saw massive improvements in living standards for billions of people, underpinned by a dramatic increase in the utilisation of water, energy and mineral resources. As a nation richly endowed with mineral resources. Australia benefitted from the resulting global market for mineral and energy resources. A decade into the 21st century and the geopolitical landscape of mineral supply and demand is shifting markedly, affecting the norms and business models of those involved in the supply of, and demand for, mineral resources. Increasing interest is shown in the concept of a "circular economy" in which materials are designed for reuse and one man's waste is another man's wealth.

Drawing on the work of the Wealth from Waste cluster in Australia – a collaboration between the University of Technology, Sydney, the University of Queensland, Monash University, Swinburne University and Yale University – this paper examines the implications of a circular economy on resource supply.

2. Challenging the norm: the concept of a "Circular Economy"

The **circular economy** describes an industrial economy designed to produce no waste or pollution. In such an economy, biological nutrients are used and then re-enter the biosphere safely, and inorganic materials circulate with high levels of productivity and use through the biosphere and are both restorative and regenerative by design. The circular economy is one of organic and inorganic recycling and reuse and reduced (to zero) emissions.

Globally, there is already growing capacity and innovation in recycling. New forms of manufacturing and business models are being developed that integrate secondary manufacturing and product stewardship. In Australia, where rich stocks of in-ground mineral resources have founded national wealth based on mining and mineral extraction, extensive recycling activity is already taking place.

This activity in recycling and reuse is incentivised by many different schemes and institutions such as National Product Stewardship frameworks, greenhouse gas emissions targets, and the sustainable development goals. At the end of 2015, nations convened in Paris for the United Nations Conference on Climate Change to discuss the decarbonisation of the global economy as a response to climate change. This momentum for transitioning to a low-carbon society will require vast amounts of metals and minerals (Vidal et al. 2013). The notion of using "stuff" more than once is immediately appealing and, at face value, makes a lot of sense in terms of extracting most value out of every tonne of material taken from the ground.

However, we still lose significant amounts of valuable and recyclable materials into landfill and park valuable metals in tailings and spoil heaps. In Australia alone, around 14 million phones sit unused in drawers or cupboards, equivalent to more than one unused phone for every two people in the country (Clean Up Australia, 2009). In 2009–10, there were 21.6 million tonnes of waste received at landfills around Australia, which is one of the highest waste producing nations in the world (on a per capita basis). Australia has many of the characteristics of a linear economy (sometimes described as “take-make-and-dispose”) and a long way to go before it becomes a circular economy.

Why is this? Recycling and reuse have the undeniable potential to inject added value into an economy. For example, in Australia, e-waste has emerged as one of our fastest growing waste streams and we have been discarding increasing amounts of valuable metals such as copper, silver, gold, palladium and rare earths into landfill. In the period up to 2008, some 17 million televisions and 37 million computers were sent to landfill. According to the Australian Bureau of Statistics, if 75% of the 1.5 million televisions discarded annually were recycled there would be savings of 23,000 tonnes of CO_2 equivalent, 520 megalitres of water, 400,000 gigajoules of energy and 160,000 cubic metres of landfill space.

A key challenge to the full implementation of a circular economy at scale anywhere in the world is that it requires a new paradigm for relating to each other. Since the industrial revolution, Keynesian market economics have driven growth in linear economies by optimising supply chains for the delivery of a material, technology or service to an end user (or consumer). In a circular economy, there is both a life after that end user (i.e. an extended supply chain) and an intent to reduce emissions and waste. Both of these represent additional costs which, in a linear economy, are not equated to added value since they occur beyond the primary end user.

In a time when global attention has focused on the struggling finance sector and the booming service sector (internet and communication, tourism) it is easy to forget that the physical basis of our economic activities is raw materials (Klein 2012). The circular economy requires a much more integrated understanding of how these raw materials can be used most effectively in support of a multiple stages of production and consumption. Waste products need to be viewed as valuable inputs. A circular economy requires:

- a culture and a set of institutions that consider material life in a way that extends beyond the product life – “*stewarding”* materials from mineral to metal to product to metal (to product to metal to product to ...);
- transformation of our relationship with waste products to see them as a resource rather than a liability

This is a new paradigm and challenges the norms by which the resource sector has been operating (at least in Australia) for more than a century. The transformation is already driving niche changes in the way we design products, use materials and manage wastes. In the resources sector, its implementation will bring in new technology for raw mineral extraction to reduce wastage, the processing of these minerals into metals, the extraction of value from waste streams, the use of metals in product development, the life cycle of products in use, and finally, the recovery of those metals from end-of-life products through recycling.

3. So what? The potential impacts of the circular economy on resource supply and demand

The impact of these changes on resource supply and demand is difficult to gauge. Rate of change is even harder to determine – particularly given the immense geopolitical power of the highly competitive multinational players who dominate today's world markets. Below, three global trends' association with the notion of a circular economy are summarised. Each has an independent impact on what resources we develop and the way we develop them. Together, the interdependencies between these trends represent foreshadow significant evolution in the nature of resource demand, and the manner in which resources are supplied. The trends considered are:

- the concept of urban mining and its potential contribution to meeting demand
- carbon emission reduction and its implications for metal demand – both high volume, low value metals (e.g. iron and steel) for infrastructure and low volume, high value metals (e.g. rare earth elements, lithium, cobalt) for renewable energy generation and storage
- waste reduction and its implications for the use of mine wastes and the process of mining

3.1. Urban mining: the new kid on the block

With projections of further population growth to about 9 billion people by 2050, resource demand continues to grow. Some commentators are now discussing materials scarcity as a bigger issue than energy scarcity (Valero, Valero, & Martínez, 2010) and conclude "*there is no energy scarcity, but mineral's scarcity".* Despite additional new supply sources in developing countries, declining exploration success, lengthened and more costly discovery-to-production timelines, and increasing tension about resource development means that, for several commodities, there are insufficient known resources to meet projected demand.

There are significant stocks of metals entrained into materials and products already in circulation. As an example, compare gold yielded from an open pit mine (between 1 and 5 grams of gold for every one tonne of ore body extracted) with 350 grams of gold yielded by one tonne of discarded mobile phones and 250 grams of gold yielded by one tonne of computer circuit boards. In a world increasingly addressing issues of sustainability, it is no wonder that such end-of-life products are now being seen as urban mines – valuable sources of above-ground metals which can be recycled and reused. Increasingly, studies are looking at above-ground stocks as assets and seeking to quantify the reserves available for secondary metal production (Figure 1).

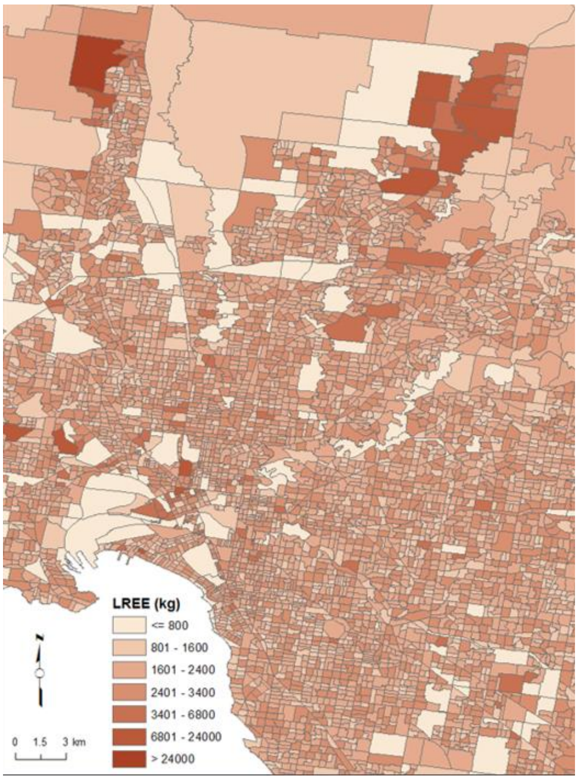

Figure 1: The distribution of light rare earth elements in north and eastern Melbourne. *This is taken from an atlas of urban metal stocks in Australia currently being developed at Monash University. The atlas is delivered in two forms: online atlas and geodatabase. An online version of the atlas is developed using ESRI Thematic Atlas software and served through ESRI map cloud service. The geodatabase is a spatially enabled database, containing all the map data layers, which allows users to design their own maps, perform advanced data analysis, and interrogate the database using ArcGIS software.*

Concerns regarding resource scarcity are already driving innovation for accessing these above-ground resources through new supply chains involved in recycling. Under current supply and demand conditions, and with current legislation, urban mining is unlikely be anything other than a supplement to primary metal production (mining and mineral processing). However, as the implications of the sustainable development goals permeate into international and national legislation and as nascent markets for recycled metals emerge, urban mining will become a stronger competitor in the metal supply market challenging the ascendancy of the major multinationals.

Figure 2 compares the results of modelling current and future production of copper from two sources, primary (mined) production and recycling. This modelling suggests that, for some commodities, the supply of metals available for recycling, combined with encouragement from governments to move towards a circular economy will eventually displace primary production. (Gregson et al. 2015).

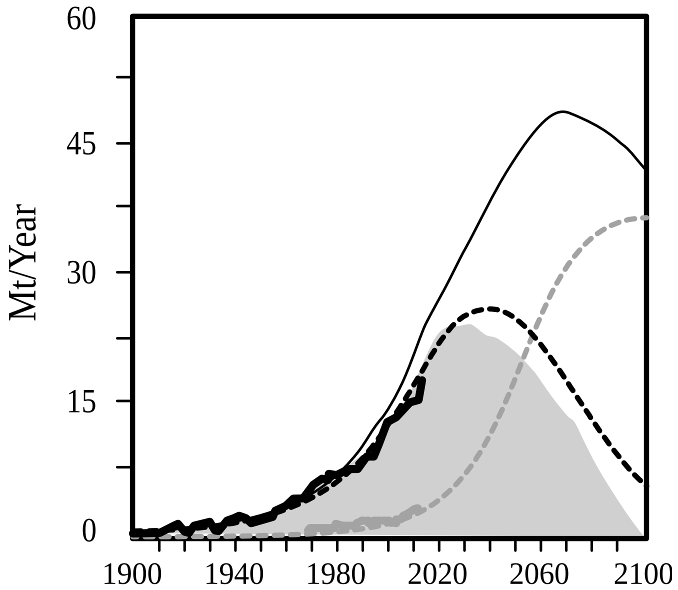

Figure 2: Modelled primary (dashed black line) and secondary (dashed grey line) copper production. *The black and grey continuous lines show the historical data of primary and recycled copper production (1966-2010), respectively (Prior et al. 2014)[i]. The continuous black line is the sum of the modelled primary and secondary production. The grey area provides a comparative analysis from Northey et al. (2014).*

3.2. Emissions reduction in a growing energy market: the minerals-energy nexus

Even though there has been much discussion about the imminent shortages of key commodities and the concept of "peak" metals, the most recent models (Northey et al. 2014) suggest such peaks lie beyond the middle of the century. However, global evaluations identify some specific metals for which an earlier supply risk exists (IRP 2007, EU 2014). These evaluations suggest that as we work towards lower emission energy production over the next two to three decades production will struggle to meet demand for several metals for which substitutes are not readily available.

Raw materials provide 97% of our current energy through fossil fuels, uranium and biomass (IEA 2010). These energy carrier materials need to be complemented by the use of metals and minerals, in particular (1) steel for ships, pipelines, mining equipment, power plants, refineries and exploration activities, (2) copper for the grid, generators, electric motors, (3) aluminium, primarily for the grid, and a host of other metals and minerals. The remainder of the energy is produced through hydropower, wind and sunlight – in order to produce this 3% we need significant amounts of concrete, steel and specialty metals. Under a scenario where we sought to decarbonise our economy and reduce global emissions of CO_2, these renewable energy sources would undergo significant expansion.

There are fundamental differences in a renewable energy based energy system, in particular in terms of metal requirements (Klein 2012). Wind turbines require REEs for magnets, copper for the generator, and steel and cement for the tower and base. PV solar cells require silver for silicon based cells, and, cadmium, telluride, indium, gallium and others (Ge, Ru) in other types of cells, energy crops require steel for agricultural machines and mineral inputs for fertilisers. Copper and steel are required for power lines and pipelines, and platinum and other speciality metals are needed for catalysts and storage. Rare earth elements are required in magnets, copper for motors, lithium, cobalt, nickel, lanthanum for batteries and platinum for fuel cells. Even without a switch to renewable energy, a transition to a lower carbon fossil fuel based energy system would still require new materials. Carbon Capture and Sequestration (CCS) would require 30 to 60% extra steel, highly efficient turbines in jet engines and power plants require rhenium for special temperature resistant alloys, and REEs are needed for the turbines, as well as efficient car engines, and LED and fluorescent lighting (Klein 2012).

Given this dependency of energy on metals, metal demand is dependent on energy mix.

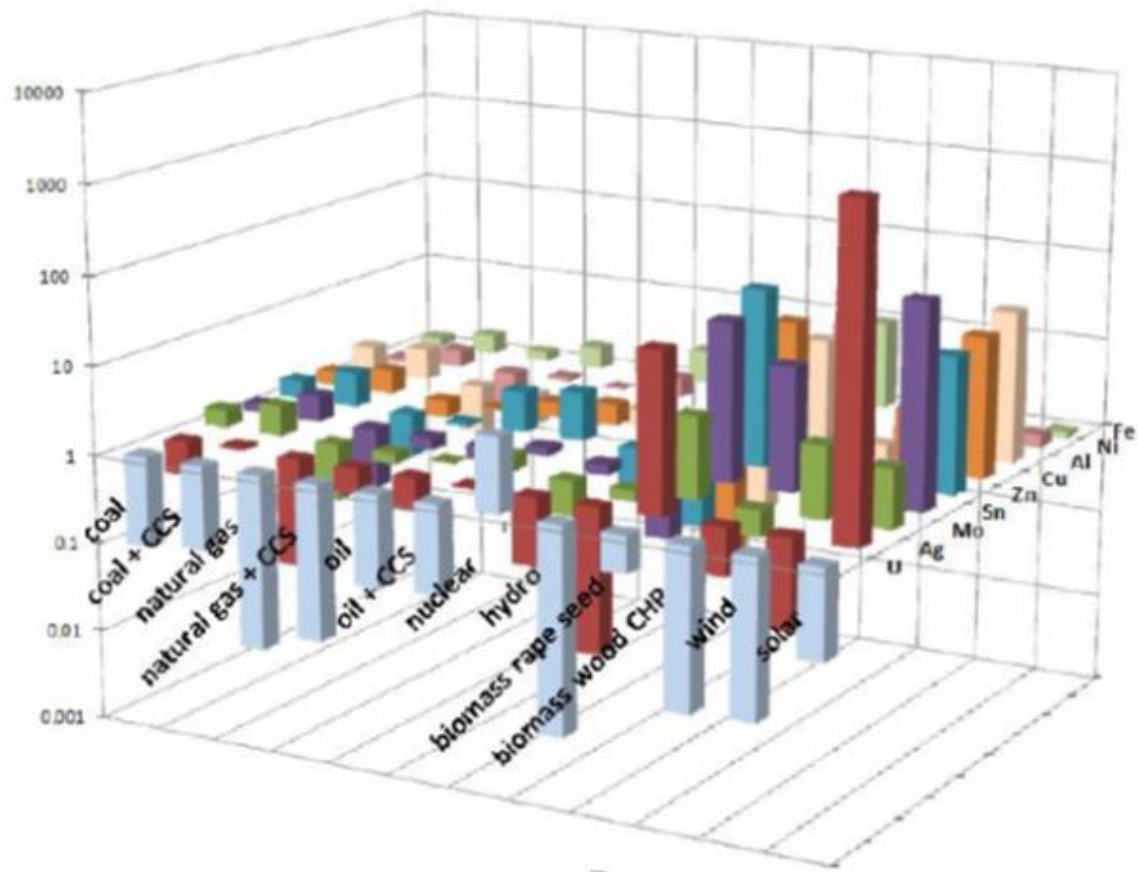

Figure 3: The dependency of metal demand on energy mix (after Klein 2012*). Figures are presented in grams of metal/kilowatt hour compared to the current energy mix.*

With these variations in mind, studies examining metal requirements for a transition to a low emission energy future (involving a large range of low-carbon technologies including fuel cells, electricity storage, electric vehicles and lighting) found that eight metals are "critical" (Moss et al. 2011, Moss et al. 2013). These are the six rare earth elements (dysprosium, europium, terbium, yttrium, praseodymium and neodymium), and the two metals gallium and tellurium.

Four metals (graphite, rhenium, indium and platinum) are found to have a medium-to-high rating and are classified as "near critical". Critical and near critical metals act as hot spots which can in times of crisis perturb the resource commodity markets.

3.3. Mining mine wastes: new sources of value from mine operations

The mining industry currently operates as a linear process with each step increasing the value of the product by concentrating the material of interest and discarding as waste the material not of interest. Hence waste is produced at each stage of the mining process and mining is itself one of the largest producers of waste materials. Each waste stream mining produces has its own set of characteristics and associated concerns. One of the most significant waste streams is that produced on mine sites during the initial extraction and concentration stages.

A large number of mines close before the mineral resources are exhausted and many close without considering the value that can be obtained from mineralised mine wastes. And yet as grades decline, mine tailings can contain highly significant amounts of metal, albeit in a fine-grained form and entrained into tailings and/or waste rock (Edraki et al. 2014).

Significant attention is now going into the processing of mine wastes of all types. Along with the economic value that can be delivered from the extraction of metals from these there is also significant attendant benefit by reducing the environmental risks that can be associated with the wastes (Corder and Golev 2016).

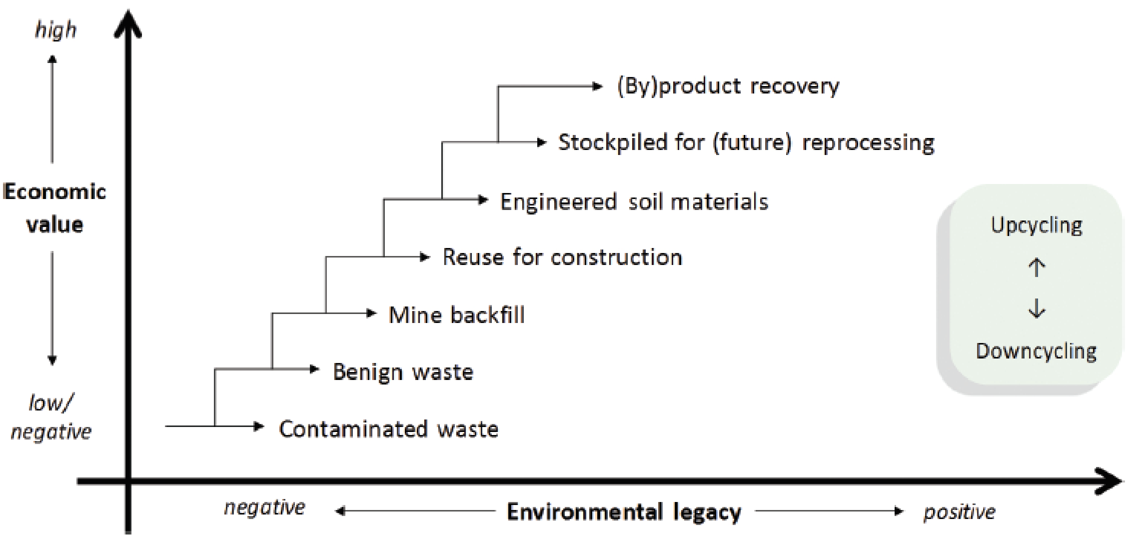

FIG 1 – Value chain options for mine waste.

Figure 4: Mine waste use in economic and environmental terms. *Presented in Corder and Golev 2014, compiled from (but not limited to) Edraki et al. 2014, Franks et al. 2011, McLellan et al. 2009.*

Technology evolution is a key enabler of the ability to reprocess these vast quantities of waste. Recent life cycle analyses of three separate sages of operation at Mount Morgan shows the substantial difference that can now be achieved in terms of reducing wastes and increasing efficiency.

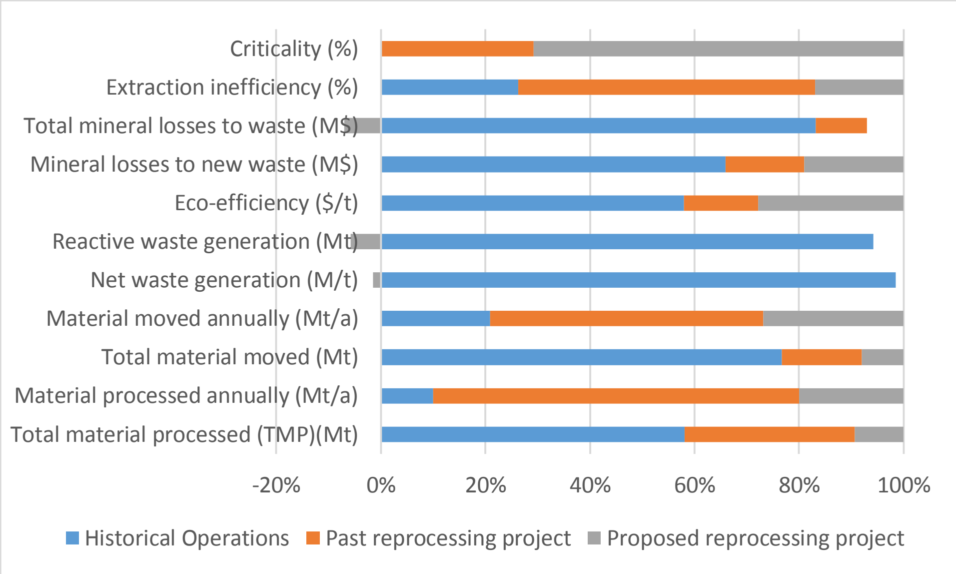

Figure 5: Comparison of material flow indicators for past and proposed operations at Mount Morgan (Queensland, Australia) (after Corder and Golev 2014).

However, although such efficiencies are possible, it is the economic landscape that determines whether they will be put into action. If it makes sense for a company to implement this type of operation, then they will. Currently, this means if it makes financial sense, which is determined by the complex geopolitical systems that determine commodity price and share value in the global markets.

In fact, for all three of the examples given above, the biggest barriers to change are social and political.

4: New social constructs and evolving institutions driving a circular economy

Under current global social constructs and market settings, primary metal production and a linear approach to resource use hold an economic advantage over secondary production and recycling. If settings change in any of the ways outlined above, the economic, environmental and social competition will change. This would, of necessity, drive adaptation in the business models of primary metal producers.

At a global level, one of the most significant social constructs ratified in recent years has been the 2030 Agenda for Sustainable Development and the associated Sustainable Development Goals. This represents civil society's plan of action for social inclusion, environmental sustainability and economic development. The notion of sustainable consumption and production underpins much of the agenda described in these goals, setting the scene for sustainable supply and efficient production to help address global poverty alleviation. This has a number of implications. A recent mapping by the Columbia Centre for Sustainable Investment for the World Economic Forum suggests that the mining industry can support all 17 of the sustainable development goals.

Figure 6: SDGs and mining (Sorensson 2016) Major issue areas for mining and the SDGs. Abbreviations (in order): NCDs = non-communicable diseases; TB = tuberculosis; OSH = occupational health and safety; EIDs = emerging infectious diseases; TVET = technical, vocational, and educational training; CCS = carbon capture and storage; IFFs = illicit financial flows; PPPs = public-private partnerships. SDG icons adapted from http://www.globalgoals.org/.

However, implementation of a global agenda for sustainability will only emerge from changes to institutions governing nation states, corporations, and individuals. The introduction of a circular economy and the sustainable consumption and production that underpins it will be dependent on behaviour change in political and community circles.

Australia's trading partnership facilitating the supply of resources to China, for example, will evolve as the Chinese actively explore the circular economy concept and it is unclear what direction that will take. At a Corporate level, seeing wastes as a valuable asset rather than a cost on business is the first step towards extracting the significant entrained metal in wastes from mine sites. And at a more local level, a circular economy requires consumer behaviour that enables collection and recycling and national infrastructure to turn these collected materials into their next life.

5: Conclusions

Although the concept of the Circular Economy is emerging into relatively common use amongst researchers and analysts, it is the components of the concept that are being implemented into practice. These components are waste/emissions reduction and product recycling/reuse which are already driving new technologies and new supply chains around urban mining, reducing carbon emissions and processing value from mine waste.

Delivering a circular economy will support action on sustainable development and move towards the sustainable development goals. However, the biggest challenges to delivering a circular economy are in the business models between markets and supply chains, between nation states and corporations and between consumers and producers. To fully unlock a circular economy, it is suggested (Florin et al. 2014) that suppliers substitute renewable material inputs, maximize material and energy productivity, adopt a stewardship role to deliver functionality rather than ownership, and view waste as wealth.

6: References

Corder, G. and Golev, A. (2014) Can mining be part of the Circular Economy or is it Squaring the Circle? In Proceedings of the Life of Mine Conference 2016. AusIMM.

Edraki, M., Baumgarti, T., Manalpig, E., Bradshaw, D., Franks, D. and Moran, C. (2014) Designing mine tailings for better environmental, social and economic outcomes: a review of alternative approaches. *Journal of Cleaner Production* 84, 411–420.

European Commission (2014) Report on Critical Raw Materials for the EU. Report of the Ad hoc Working Group on Defining Critical Raw Materials. European Commission, 2014.

Florin, N.H., Sharpe, S., Wright, S. & Giurco, D. (2014) Business models for a circular world the case of metals, in Part IV: Circular Economy and Decoupling Natural Resources Sustainable targets, Technologies, Lifestyles and Governance. Eds Ludwig, C., Matasci, C. & Edelmann, X.A. World Resources Production, Printed by Paul Scherrer Institute, Villigen PSI, Switzerland.

Graedel, T. E., Harper, E.M., Nassar, N.T. and Reck, B.K. (2013) On the materials basis of modern society. *Proceedings of the National Academy of Sciences of the United States of America*, doi: 10.1073/pnas.131275211.

Gregson, N., Crang, M., Fuller, S. and Holmes, H. (2015) Interrogating the circular economy: the moral economy of resource recovery in the EU. *Economy and Society* 44, 2, 218–243.
https://setis.ec.europa.eu/system/files/CriticalMetalsinStrategicEnergyTechnologies-def.pdf

Klein, R. (2012) Materials and energy: a story of linkages, material requirements of new energy technologies, resource scarcity and interconnected material flows. PhD Thesis, Leiden University, The Netherlands.

Lebre, E. and Corder, G. (2014) Utilising Mineralised Mining Waste – Contributions to the Circular Economy. In Proceedings of Life of Mine Conference 2016, AusIMM.

Moss et al. (2011) Critical Metals in Strategic Energy Technologies, Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies, JRC – Institute for Energy and Transport Oakdene Hollins Ltd, The Hague Centre for Strategic Studies.

Moss et al. (2013) Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector – Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies. https://setis.ec.europa.eu/system/files/Critical%20Metals%20Decarbonisation.pdf.

Moss, R.L., Tzimas, E., Kara, H., Willis, P. and Kooroshy, J. (2011) Critical Metals in Strategic Energy Technologies Assessing Rare Metals as Supply-Chain Bottlenecks in Low-Carbon Energy Technologies. JRC Scientific and Technical Report. EUR 24884 EN – 2011. European Union.

Northey, S., Mohr, S., Mudd, G. M., Weng, Z. and Giurco, D. (2014) Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining. *Resources, Conservation and Recycling* 83, 190–201.

Prior, T., Giurco, D., Mudd, G., Mason, L. and Behrisch, J. (2012) Resource depletion, peak minerals and the implications for sustainable resource management. *Global Environmental Change* 22(3), 577–587.

Sorensson C. (2016) Mapping Mining to the Sustainable Development Goals: A Preliminary Atlas 2016. Consultation Draft produced by the Columbia Centre for Sustainable Investment for the World Economic Forum.

Vidal, O., Goffé, B. and Arndt, N. (2013) Metals for a low-carbon society. *Nature Geoscience* 6, 894–896.

[i] Prior, T., Giurco, D., Mudd, G., Mason, L. and Behrisch, J., 2012. Resource depletion, peak minerals and the implications for sustainable resource management. *Global Environmental Change*, 22(3), 577–587.