Please cite the original document, available at: 10.1016/j.oneear.2019.11.009

"Dark" materials for a brighter energy future

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Summary

Clean energy requires increasing quantities of minerals to provide for global greenhouse gas mitigation targets. Social, political and environmental issues may impact on potential supply, making these targets more difficult to achieve. Local environmental issues and global emissions reductions present a trade-off that could prove pivotal for mineral supply.

Introduction

The global transition towards cleaner energy systems has been accelerating in recent decades, as nations and companies commit to mitigation of climate change as well as reducing local pollutant emissions. This acceleration has led to a direct increase in the requirement for resources to manufacture the infrastructure to deliver this transition. The confluence of government support (e.g. Feed-in-Tariffs), dramatic cost reductions (e.g. photovoltaics (PV)) due to economic scale effects, rapid technology improvement (e.g. Li-ion batteries, notably for electric vehicles (EV)) and the falling-out-of-favour of conventional fossil fuel technologies due to the local pollutant emissions and their adverse impacts on health and quality of life (e.g. concentrations of pollutants in cities in China) has been driving much of this acceleration. But upstream in the minerals sector providing for these technologies there have been causes for concern that supply may struggle to meet demand, which has led to a rapid development in the field of "material criticality" studies, primarily focusing on non-fuel minerals [1].

A selection of some of the technologies and minerals that have been the focus of many of the criticality studies are shown in Table 1. It is widely acknowledged that the number of elements being used in energy and other high-technology sectors has expanded dramatically over the last century, in seeking for efficiency and other performance improvements. It is notable that these minerals vary widely in the scale of production and the make-up of producing nations and competing sectors of consumption.

Table 1: Technologies for the clean energy transition and potential critical minerals

Clean Energy Technologies	Materials of concern	Uses in the technology
Electric vehicles (EV)	Co	Lithium-ion batteries (electrodes)
	Li	Lithium-ion batteries (electrolyte)
	Dy, Nd	Magnets in electric motors
Solar photovoltaics (PV)	Ag	Electrical interconnects
	Ga, Ge, In, Te, Se,	Various thin-film PV layers
Fuel cells / Fuel cell vehicles (FCV)	La	Solid-oxide fuel cells (SOFC) electrodes and electrolytes
	Pt	Polymer electrolyte membrane fuel cells (PEMFC) electrodes
Wind turbines	Dy, Nd	Permanent magnets in generators

In the mining sector, the current concern about mineral supply is not new, as there have been periodic episodes, often in the wake of global socio-economic disturbances (such as the world wars) or when conflict or political disputes (armed or diplomatic) have put supply chains at risk [2]. Moreover, this focus on critical minerals has come as somewhat of a “second wave” of scrutiny, following-on from the broad re-envisaging of the role of the minerals sector within sustainable development that occurred around the turn of the millennium [3]. In the interim, with concern that the mining sector in particular needed to deal with its environmental footprint as well as the prominent social issues causing direct conflict in and around mining areas, in addition to the greater consciousness with regards to “conflict minerals” that were being used to support ongoing civil wars leading to legislation in Europe and the USA to push for better transparency and supply chain management from companies utilizing these minerals [4], there has been an improved atmosphere for addressing these issues. Mineral criticality then, integrates many of these issues into semi-quantitative frameworks to try to identify how these multiple influences can affect supply risk, and what the consequences might be to a nation, company, the world or an economic sector. But there are certain risks or potential shocks that are still very difficult to incorporate in a generalized framework with confidence.

Environmental Risks

Supplying the metals for clean energy transitions has already had a significant impact on the environment, but the expectations of expanded demand driving increased supply from lower grade, deeper, more complex ores in more sensitive environments is a key concern [56]. On the global scale, these mining trends portend a general decline in the overall environmental performance of the sector, in turn implying that the energy sector`s embodied impacts will increase – and dramatically, if the trends in technology roll-out continue as anticipated [7]. Already, the global supply of rare earths vital for so many of the new energy technologies was restricted ostensibly due to environmental concerns in China, and the USA`s Mountain Pass mine was closed for similar reasons [8].

But rather than considering the global-scale generalized impacts, it is perhaps more important to consider the mine-by-mine impacts that could stop significant proportions of supply. Water use and pollution are already an issue for many mines, and this is likely to remain prominent or be exacerbated with clean energy minerals. In the production of lithium from brines in Chile notably, there are already signs of discontent due to the utilization of water in arid areas. If water issues are exacerbated with climate change, with drier periods and extreme wet periods, then the issue of mine water containment will also potentially be exacerbated – particularly as the low grade of many minerals will expand the need for tailings storage, and the recent collapse of a number of large tailings dams globally has prompted both social backlash and global industrial review.

Another area of current resurging interest is the mining of the deep ocean floor – both within national exclusive economic zones and in the international "Area" managed by the United Nations as the common heritage of humanity. Deep sea mining has been contemplated since at least the 1970`s, but the economics and technology have not converged to make it viable yet. Many deep sea ore deposits contain target rare elements for clean energy systems [9] as well as base and precious metals. Estimates indicate large global potential, and many of the ore grades are very high compared to terrestrial mining cut-off grades. But deep sea mining environmental impacts are still far from clear, and the social opposition in the most progressed mine (Nautilus Minerals` Solwara I project in Papua New Guinea) has been a focus for both domestic and international opponents. Deep sea mining poses further problems of uncertainty around the appropriate stakeholders for consultation and the potential for impacts to surrounding non-mining industries.

One of the disadvantages of the current minerals of concern for energy is that many are co-products or by-products, making the prediction of reserves and the security of the supply chain more difficult. However, from the perspective of environmental impacts

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causing stoppages at the mine scale, this may be a significant advantage – the interruption of the larger volume target metals with which they are extracted is probably less risky, due to the broader distribution of deposits and more fundamental stability of demand (although increased recycling may counter this to some extent). But the question of whether sufficient refinery capacity to recover these metals will be in operation remains. Likewise, if the refinery operation is not well-managed, then the possibility of local pollutant emissions causing acute or long-term health impacts needs to be considered.

When it comes to planning of mines and mineral processing operations, it is apparent that the clean energy transition will move from fossil fuel mining to metals. Thus a decrease in coal mining may be replaced with an increase in metal mining. The fact that they are both types of mining will not appease the concerns of communities losing employment due to the closing of coal mines (unlikely to be in the same area as target metal mines) or communities with new mines opening nearby and producing environmental impacts.

International relations and political risks

Centralisation of supply – either at the mine or further along the supply chain – is one of the highest concerns with regards to metal availability. With high monopolization, the ability of a single country or a cartel to manipulate prices or restrict supply in response to diplomatic disputes is exacerbated. China`s restricted rare earth exports (2007 ~ 2013) sent a shock through global markets and made importers and manufacturers panic about the risk to ongoing supply. In more recent years, a combination of increased demand for electrode materials (such as cobalt) for lithium batteries, and increased speculation on metal markets, has led to heightened cobalt prices, putting the cobalt supply chain under further inspection. Cobalt production is highly centralized at both the mining side (Congo) and the production of metal (China). It is one of the key critical mineral examples in that the potential for conflicts at the point of extraction, environmental or political decisions at the mid-stream could easily be envisaged to interrupt the stability of supply. Other issues, such as trust and the role of foreign mining companies – e.g. the non-expansion of mining of lithium in Bolivia – are also likely to have some effect on the ability to rapidly expand supply.

Past international disputes have led to importing countries and companies on the demand side taking action to mitigate the impact of supply restrictions and the risk of

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them occurring. Typically for technology manufacturers this is reduction of material intensity or use of substitute materials, while for countries it is stock-pilling of required minerals, domestic production and diversification of supply routes where possible. China and Russia have large proportions of global reserves and production of many of the key energy metals, and both governments have shown a willingness to restrict exports in the past – so much relies on the ability of countries to deal well diplomatically with each other. A major issue with minerals is that they are geologically concentrated in specific geographic locations – mines cannot be relocated like the downstream elements of the supply chain. Recycling has also been seen as a potential solution, which obviously can access a domestic resource – but recycling rates of energy metals are generally still low, and the facilities, technology and economic incentives to promote recycling are not typically present.

Looking Ahead

Will the situation get worse or better? This is the critical question. It is certain that, in order to achieve global greenhouse gas emissions reduction and clean energy targets, that there will continue to be increasing demand for minerals. There are mixed predictions about whether global supply can keep-up –considering short-term supply-demand dynamics or in the long-run considering cumulative consumption and reserves. Some reduction of demand may come from substitution or material intensity reduction, while supply can be supplemented with recycling and shifting of consumption from other sectors. However, policy-makers and society more broadly will face trade-offs between the local environmental impacts of mineral supply with the global benefits of climate change mitigation. These decisions involve multiple stakeholders and competing perspective, making this a complex governance dilemma. If mines are developed “right” this should swing the balance in favor of secured supply – but the concern may be whether we can develop them “right enough” and fast enough.

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