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Critical Raw Materials and the Challenge of Climate Crisis in the New Millennium

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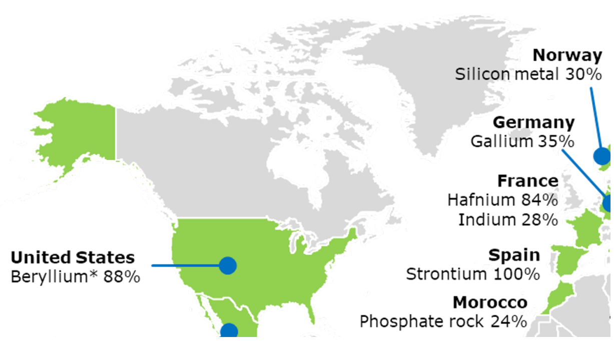
Abstract: *The green and the digital revolutions are intimately linked. Mastery of one technology will likely lead to leadership in the other. Both depend on ample supplies of critical materials, rare earth elements and other vital resources. Unfortunately, many are in short supply and demand for them will explode as those two revolutions unfold. Governments have awakened to vulnerabilities created by their need for these materials and are making efforts, with limited success, to ensure continued access to them. Given the consequences of leadership in both the green and digital arenas, it is not surprising that access to critical raw materials has become a geopolitical battleground.*

Keywords: *climate change, critical raw materials, rare earths, geopolitical competition, green revolution, digital revolution.*

The world is beginning two foundational transitions: the Green and the Digital revolutions. While distinct, they are linked. Mastery of either set of technologies – and because of the linkages, success in one will likely mean success in the other – will have geopolitical consequences, as leadership in those fields will determine global status and standing, bestowing power along with economic benefits.

Increasing attention is being paid to those geopolitical consequences, but much of the analysis has focused either on the military applications of digital technologies – how, for example, artificial intelligence sharpens warfighting capabilities – or how the embrace of sustainable and "greener" energy models will reduce the influence of oil-producing countries. This article examines a less visible dimension of those transitions, but one with equally powerful potential impacts: the role of critical materials. Digital technologies will be central to the functioning of the Green economy -- they are essential components of the infrastructure that will control how green tech is deployed and used -- which means that many of the resources needed to power one will be needed for the other as well. Control of those resources will shape the competition to lead in those fields as access to them will also determine which – and whose-- technologies dominate those transformations.



Global Sources of Critical Raw Materials (Please click to expand)

The Importance of Technology Leadership

Whether we refer to Industry 4.0, Society 5.0 or the Fourth Industrial Revolution, the meaning is the same: The world has entered a digital age in which ubiquitous instantaneous connectivity defines and enables daily life. Mastering the technologies that create those connections, and make sense of, sort and distribute the data that flows through them will bestow great wealth and power. Technology has long been seen as an important component of national strength but today governments around the world define critical technologies in a more expansive fashion and recognize that the very nature of digital technologies, in particular the importance of standards in guiding their proliferation and use, is different from previous "revolutions." The European Commission noted that "those who control digital technologies are increasingly able to influence economic, societal and political outcomes."[1] The technologies that the EU identified as being of strategic importance include advanced materials, advanced manufacturing, artificial intelligence, big data, cloud, industrial biotechnology, the Internet of Things, micro-and nanoelectronics (including semiconductors), IT for mobility, nanotechnology, photonics, and robotics (among others).[2] The US has a similar list of emerging technologies that it deems "essential to national security."[3] Among its 14 categories are: artificial intelligence (AI); biotechnology; microprocessor technology; advanced computing technology; data analytics; quantum information and sensing technology; robotics; additive manufacturing; and advanced materials.[4] These are the "keys to the kingdom," control of which is essential to leadership in a digital world.

These resources are needed for the production of all forms of digital electronics, from consumer devices to robotics, along with the infrastructure that girds modern society. It is predicted that the global datasphere will grow from 33 Zettabytes (ZB) in 2018 to 175 ZB by 2025, which will explode demand for data storage and all the materials required for memory production. If the forecast is accurate, in 2025 the datasphere will need 80 kilotons of neodymium, about 120 times current yearly European demand for this material. A shift to other technologies such as ferroelectric RAM would require up to 40 kilotons of platinum, or 600 times the EU's current annual demand.[5] The role played by these resources in the prospects of the world's most developed economies has prompted talk of a "new age for metals and minerals."[6]

Those technologies have many applications, but their use in green energy technologies is especially vital. Advanced materials and manufacturing are central to the creation of new energy generation, storage and distribution technologies. Computing technologies – AI, big data, cloud computing – are essential to energy distribution. No wonder then that "leaders in technological innovation are positioned to gain the most from the global energy transformation."[7] Those companies will profit financially and the network and first mover advantages will generate even higher revenues as consumers are locked in to particular technology ecosystems.

Success in the development of those technologies will require both innovation and the raw materials necessary to realize those visions. As the European Commission has acknowledged, "access to resources is fundamental for the entire EU industry and central to Europe's ambition to deliver the Green Deal and ensure the digital transformation of the EU economy. These ambitions will need to continue to be anchored in diversified and undistorted access to global markets for raw materials."[8] The US calls them "critical materials," and defines them as a "non-fuel mineral or mineral material essential to the economic and national security of the United States, (ii) the supply chain of which is vulnerable to disruption, and (iii) that serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for our national security."[9] There is no single universal list of "critical materials" but they are "of existential importance for modern, technology-intensive societies," writes Jeffrey Wilson, an Australian researcher. Their role in scientific and industrial applications, digital and renewable energy technologies, and defense equipment means that "they pose unique risks to the security and sustainability of an economy."[10] Every government competing for leadership in the digital economy has a list of resources it considers critical. There are 24 on China's list, and 24 on Australia's (although items are different); Europe has 30, Japan has 34 and the US has 35. (The lists are periodically updated, so names and numbers may differ.) They are needed in industries ranging from aerospace to petrochemicals to digital sectors.

For over a decade, this discussion has focused on rare earth elements (REEs), a catchily but misnamed group of 17 heavy metals essential to the manufacture of many high-tech products. They aren't actually rare, but economically exploitable deposits are hard to find since they are dirty (ecologically speaking) and expensive to mine and process. It's estimated that more than half of all manufactured products imported into the US contain rare earths in one form or another.[11] The US once dominated production of rare earth elements, but the environmental impact of mining, along with rising costs, prompted the shutdown of those operations. China filled the gap and became the world's leading producer by the late 1990s. Rare earths were in the headlines in 2010, when China shut off REE exports to Japan after the arrest of a Chinese fishing boat captain who rammed and then ran from Japanese Coast Guard vessels after he was caught fishing in waters near the Senkaku Islands. That incident exposed the reliance on Chinese supplies and the vulnerability that resulted; a 2014 World Trade Organization ruling subsequently limited Beijing's ability to repeat that coercion. Consumers of those minerals have since tried to diversify their sources, with some success. For the most part, however, China continues to dominate the rare earth industry, from production to processing and magnet manufacturing; more worrisome still, as will be discussed below, China is increasingly consuming those rare earths and other critical minerals itself.

Green is Good – and a Drain

That continuing dependence is troubling but it becomes even more alarming as demand for critical minerals will skyrocket during the transition to a green, carbon-free, economy. The prospect of global climate change that threatens the lives and livelihoods of billions of people prompted more than 200 governments to sign the Paris Agreement to cut emissions of greenhouse gases and hold global warming at or below 1.5°C–2°C. Success in this effort depends on the shift to a low carbon economy and the adoption of "clean energy," which are critical to any hope of limiting greenhouse gas emissions. But, as Andrew DeWit, professor at Rikkyo University who has done considerable work on energy economics, explained, "Greening requires prodigious amounts of very tangible critical raw materials whose environmental costs and geopolitical implications are increasingly huge."[12]

A recent report by the International Energy Agency (IEA) provides worrying numbers. A typical electric car requires six times the mineral inputs of a conventional car. An onshore wind plant requires nine times more mineral resources than a gas-fired power plant.[13] At the same time, power generation requires more minerals: the IEA estimates that over the last decade, the average amount of minerals needed for a new unit of power generation capacity has increased by 50% as the share of renewables has risen.[14] In fact, mineral input intensity increases with the level of decarbonization. Meeting the goals of the Paris Agreement -- climate stabilization at “well below 2°C global temperature rise” – requires a quadrupling of mineral requirements for clean energy technologies by 2040. If the goal was net-zero globally by 2050, then mineral inputs would be six times greater in 2040 than they are today.[15] The World Bank agrees. Its analysis concludes that over 3 billion tons of minerals and metals will be needed to deploy wind, solar and geothermal power, as well as energy storage, required for achieving a below 2°C future.[16]

The quantity of resources needed depends on which scenario materializes: demand is a function of both the trajectory of climate change and the specific pathway adopted to combat it. So, for example, in the REmap scenario (the Renewable Energy roadmap, used by the International Renewable Energy Agency, IRENA), demand for aluminum, indium, and silver are forecast to increase by more than 300% by 2050 from the base scenario, while demand for copper, iron, lead, neodymium, and zinc is expected to increase by more than 200%. In the most ambitious IEA scenario, B2DS, or beyond two degrees, the demand for more than five minerals is expected to double by 2050, from the base scenario.[17] Under 2DS, production of graphite, lithium, and cobalt will need to grow nearly 500% by 2050 —from 2018 levels — to meet demand from energy storage technologies. These projections do not include the associated infrastructure needed to support the deployment of these technologies (for example, transmission lines) or the physical parts (like the chassis of electric vehicles). Overall, global lithium demand is estimated to increase fourfold by 2035, and the World Bank projected in 2017 that this could double by 2050, increasing by more than 1,000%.[18]

The role that electric vehicles (EVs) will play in transportation – globally, they are expected to enjoy a compound annual growth rate of 29% over the next 10 years[19] -- will create substantial demand for critical materials. Demand for battery-grade nickel is expected to rise 10-to-20-fold by 2030 and could rise even more if it becomes a critical catalyst in the hydrogen economy.[20] Or consider copper: a combustion-engine-powered car contains 20 kg of copper, a hybrid electric car requires 40 kg, a plug-in hybrid 60 kg and an electric battery vehicle about 80 kg.[21] The batteries they use will become an especially important determinant of demand. If lithium-ion batteries become the preferred storage medium, then there will be additional demand for graphite and manganese; redox flow batteries will require more vanadium and zinc; if hydrogen fuel cells prevail, then demand for platinum will likely spike.[22] (This is in addition to skyrocketing demand for nickel, cobalt, lithium, heavy rare earths and copper, regardless.) The bottom line is simple: any lower-carbon pathway will increase overall demand of minerals. Perhaps more significant is this tradeoff: the more ambitious the climate targets, the more minerals and metals will be needed.

Steep increases in demand are likely to yield shortages. Take cobalt. An EV battery needs 10–11 kg of cobalt, and these batteries already account for 80% of the demand for refined cobalt. Global demand for cobalt to meet increasing demand for EVs is expected to rise from 46,000 tons in 2016 to 76,000 tons in 2020, to more than 90,000 tons by 2030.[23] Or consider copper. Various analyses from Citibank, Morgan Stanley, Goldman Sachs, and DBS Bank predict a copper supply deficit beginning sometime between 2019 and 2022, Supplies are already tight. In December 2018, total global copper stockpiles were reckoned to be able to meet less than two weeks of production.[24] One scenario anticipates copper prices rising from $5,600 (in October 2019) to $8,800 a ton – a 57% increase -- to meet the UK’s 2030 targets for decarbonization.[25]

Consistent with that market is the IEA conclusion that "Expected supply from existing mines and projects under construction is estimated to meet only half of projected lithium and cobalt requirements and 80% of copper needs by 2030."[26] Shortages of neodymium, praseodymium and dysprosium oxide alloy and powder are forecast to amount to 48,000 tons annually by 2030m or about the amount needed for 25 to 30 million electric vehicle traction motors; global shortages of dysprosium oxide (or oxide equivalent) will rise to 1,850 tons in 2030, an amount roughly equal to current global annual mine production.[27]

Nevertheless, the IEA also argues that "there are generally no signs of shortages."[28] This could reflect a conventional economic logic that reasons that demand will supercharge exploration and exploitation. That may be true, but it ignores rising prices and rising energy intensity, the implications of which we turn to now.

Dirty Little Secrets

The mining sector uses a lot of energy and generates considerable carbon emissions. Rising demand for critical minerals will worsen those tendencies. In 2012, the metal sector worldwide consumed 52 exajoules (EJ) of energy, about 10% of global primary energy consumption – for comparison, global home electricity demand that year was one-third that amount, about 18.4 EJ. The transition to a clean energy future, one that limits global warming to 1.5 degrees over pre-industrial levels, will require as much copper in the next 25 years as was produced in the last five millennia.[29] Yet increased demand will occur as the quality of deposits declines. High-grade mineral deposits will be depleted and the amount of energy needed to produce metal will increase exponentially.[30] According to one analysis, the average copper ore grade is expected to decline from 2%-4% at the beginning of the century to 0.2%–0.4% by mid-century and extracting 1 kg of copper concentrate from these resources will require seven times more energy than it does today. As a result, copper production could grow from 0.3% to 2.4% of global energy demand by 2050. This will be "a major obstacle to global decarbonization."[31]

The supply of critical raw materials is also hampered by the political conditions in many of the countries in which reserves are found. Half of CRMs are located in fragile states or politically unstable regions.[32] More than 60% of the world's cobalt is found in the Democratic Republic of Congo (DRC); some of the bloodiest fights in the country's history have been fought for control of mineral resources. The companies running its cobalt and copper mines have been cited for human rights violations.[33] Several would-be consumers of those minerals have refused to purchase cobalt from the DRC to avoid being tainted by those practices.[34] The higher demand for these mineral resources will also generate even more intense scrutiny of the environmental and social performance of mining companies and host governments, putting additional stress on supply chains.

Finally there are risks created by the very climate change that these minerals are supposed to help alleviate. The IEA report notes that copper and lithium, are "particularly vulnerable to water stress given their high water requirements."[35] Major producing areas are also subject to extreme heat or flooding, which also makes production inconsistent.

Shortages Looming

Ultimately, then, the prospect of shortages of supplies of critical minerals is real – and growing. Green technologies use considerably more critical materials than conventional technologies and both the production and the use of clean tech must grow exponentially if the world hopes to reach its climate goals. Honoring the Paris Agreement means that clean energy technologies would account for 40% of the demand for copper and rare earths, 60-70% for nickel and cobalt, and almost 90% for lithium.[36]

The prospect of shortages – whether natural or manmade – has motivated governments to explore other methods of ensuring supplies. Recycling is popular, both for its ability to generate supplies as well as its consistency with the broader concept of a circular, sustainable economy. For over a decade, Japanese magnet producers have been reprocessing industrial waste and recovering as much as 30% of rare earths used in the first production stage. The EU and North America have mandated recycling of older lead and nickel-based batteries, and the recycling rate is 99%.[37]

Results have been mixed, however. While 95% of cobalt can be recovered from battery recycling, rates are low for lithium and manganese.[38] In fact, no commercial recycling technologies are available yet for most CRMs.[39] Moreover, the consensus view is that even a 100 percent increase in recycling efforts for minerals like copper and aluminum would not be enough to meet demand for renewable energy technologies and energy storage.[40] Another option, the use of substitutes, has been frustrated by the fact that for some rare earth elements, the heavy ones in particular, no material replacement has been found.[41]

Governments are looking for alternative sources of supply. Japan has been especially aggressive, providing financial support for projects but has had limited success.[42] In April 2018, Tokyo announced that it had found 16 million tons of rare earth oxides on the sea bottom within its EEZ. The deposits are thought to be large enough to meet global demand for centuries: 780 years' worth of yttrium, 620 years of europium, 420 years of terbium and 730 years of dysprosium.[43] The accuracy of those assessments, and the ability to exploit them remain uncertain.

ASEAN is another option. Vietnam has an estimated 22 million metric tons of rare earth mineral reserves, 18.3% of the world total.[44] The Philippines has the world's fourth largest reserves of cobalt, 280,000 tons of an estimated total of 6.9 million tons.[45] Those prospects are dimmed by low production figures – single digits of world consumption – and the region's increasing dependence on China's refining capacity for those minerals.

The New Geopolitics

At times, geopolitics seems reducible to a simple equation: Power is a function of demand for critical resources x control over those supplies. That simple formula explains the influence that Middle Eastern states have exercised over global politics in the fossil-fuel era and is one component of Russia's ability to shape Europe's foreign policy decision making. (Its nuclear weapons also play a role). Governments around the world are now alert to the role played by critical minerals – the label is something of a giveaway – and stepping up efforts to secure supplies to ensure that they are not handicapped in the race to master digital and green technologies. The European Commission gets it. "The transition to climate neutrality could replace today's reliance on fossil fuels with one on raw materials, many of which we source from abroad and for which global competition is becoming more fierce."[46]

In 2009, the EU launched the Raw Materials Initiative, which calls for, among other things, the creation of a list of critical raw materials, which is regularly reviewed and updated.[47] In the most recent iteration, released last year, the EU identified 30 critical raw materials.[48] In the fall of 2020, the Commission adopted the Critical Raw Materials action plan that outlines concrete actions to tackle vulnerabilities in the raw materials supply chains. It launched the European Raw Materials Alliance (ERMA) which has started work on developing a resilient European value chain for rare earths.[49]

China gets it. Deng Xiaoping quipped in 1992 that "the Middle East has oil; China has rare earths."[50] In 2010, China showed those weren't empty words when it cut off REE exports to Japan. Then, in 2019, Chinese President Xi Jinping sent a not-so subtle signal with a high-profile visit to a rare earth processing facility as the trade spat with the US intensified. But China isn't interested in just playing the rare earths card. The mandarins in Beijing are eager to be global leaders in 21st century, fourth industrial revolution technologies and various national plans chart paths to do so. Consistent with those visions, China now uses more than 80% of the rare earths it produces and believes import dependence on raw materials "poses a great risk to China."[51] That explains China's increasing overseas investment in mining and processing of critical materials. Chinese state-owned companies control more than 70% of worldwide REE production, more than 90% of REE refining processes, around 80% of global refined cobalt production, and more than 60% of the worldwide lithium-ion manufacturing capacity.[52]

Zero-sum thinking is the product of intensifying competition for those minerals. One study identified 11 minerals that threaten to be the source of particularly acute competition between the US and China.[53] Production and processing of many critical minerals is highly concentrated in just a few countries, with the top three producers accounting for more than three-quarters of supplies– in many cases, one of the three is China.[54] China is the world's top supplier of 18 critical materials, and a near-monopolist (over 70% market share) in five.[55]

The US is waking up. Critical materials vulnerabilities were a core element of President Biden's 100-day supply chain review. Its recommendations included the creation of sustainability standards for strategic and critical mineral industries; expanding sustainable production and processing capacity; using federal authorities to stimulate investment and create capacity; strengthen stockpiles; and work with allies and partners to promote supply chain transparency.[56]

Japan has been most aggressive in finding and minimizing critical materials vulnerabilities. It has reduced its reliance on Chinese rare earths from 85% in 2009 to 58% a decade later, and the country looks set to reach its target of relying on a single supplier for no more than 50% of its consumption by 2025.[57] Japan is actively promoting recycling and stockpiling, along with the search for new sources.

But awareness doesn't seem to have blunted the emerging geopolitical competition. In fact, it seems to be accelerating it. Industrial consumers lack confidence that international markets will provide either reliable or cost-effective access to these essential inputs. There is fear of exposure to diplomatic coercion by monopoly suppliers. Not surprisingly, there are signs of a "worldwide scramble by governments, state entities, and original equipment manufacturers to lock in supply."[58] Jane Nakano, an energy expert at the Center for Strategic and International Studies, a US think tank, argues that "clean energy technology has become the latest frontier for the geoeconomic rivalries sparked by China's competitive economic sector."[59] That isn't surprising, given the stakes.

Climate change is an existential challenge and one that we'd like to think would force cooperation to prevail over competition. Unfortunately, too many governments frame that threat in ways that validate a zero-sum logic. For some of them, the costs of mitigating climate change are so high that they can upend a development process. (This is one factor behind the refusal of high greenhouse gas emitting developing countries to take action; they see mandates as a penalty for the indifference of a developed world that got to pollute consequence free.) Or, they recognize that technologies to combat this menace can be used as sources of influence. Standard-setting manufacturers will enjoy economies of scale and network effects that allow them to dominate these emerging industries. This will encourage suppliers of those minerals critical to green tech to be attuned to who they supply and on what terms.

We have at times decided that some technologies were so important that prevailing rules about intellectual property should be suspended; pharmaceuticals are the main example. We might want to consider a similar exemption for green technologies, not only to ensure that they are available to all, but to undercut the temptation to horde supplies and build power and influence as governments do so.

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