The social and environmental harms of sourcing minerals for information technology have been widely covered. More recently, a series of much needed analyses have applied these critiques to renewable technologies in the context of the **Green New Deal**. These pieces add another dimension to an already complicated and uncertain landscape which is largely focused on the economic and political viability of renewable energy transition, and less so on its collateral effects on those excluded from these discussions. Responses to these analyses, when not dismissing them outright, often point to a wider set of options—different kinds of mining (as exotic as asteroid mining), for example, or technological advancements that can "green" mining—that presumably lessen these harmful effects. These solutions miss the deep relationship between extractivism, expansion, and these harms.

Renewable energy infrastructure does reduce **fossil fuel** usage and its extractive impacts, and while it is absolutely necessary to mitigate the worst effects of climate change, it comes with significant costs. Expanding this infrastructure is likely to increase demand for both "critical" metals like rare earths and cobalt, and less exotic metals like copper and steel. These changes in the market for minerals are likely to have lasting impacts on the politics and economy of regions from which they are mined. Conversations around a renewable energy transition can't take for granted that these harms are necessary for "the greater good". As we enter a world increasingly ravaged by floods, food shortages, and pandemics, we must continue to collectively fight for a green future. But in doing so, we must adopt an internationalist perspective which actively involves those who would bear the material costs of the transition.

Earth's Prospects

The transition to renewable energy will increase our reliance on metals. The proliferation of electric vehicles and batteries, for example, are expected to significantly increase lithium, cobalt, and nickel demand; various **solar PV** technologies rely on cadmium, indium, gallium, selenium, silver, and tellurium; wind power and electric vehicles rely on neodymium and dysprosium (both rare earths) for permanent magnets, and more copper and aluminum are required for electrification. These technical needs have caused some worry about supply—are there enough of these metals to sustain the necessary renewable energy transition?

Predicting future demand is difficult. With metals related to renewable and low-carbon energy infrastructure, the uncertainty is due to the aggregate demand for energy, the quantity of energy produced by renewable technologies, the combination of technologies (e.g. how much solar, how much wind, etc), the actual implementations of each technology (e.g. direct-drive wind turbines or permanent magnet turbines), and the specific material requirements for each implementation (e.g. magnet composition for permanent magnet wind turbines). Technological and economic changes, such as increases in material efficiency and the substitution of expensive metals with cheaper ones, also need to be anticipated. These effects may interact with one another: the dominance of one particular technology can drive up the demand and price for one particular metal, which might suddenly make substitutions more cost-effective, driving up the demand for those metals, and so on. For example, over a decade ago palladium was introduced as a substitute for platinum in autocatalysts to avoid platinum's high price. There is now talk of substituting palladium with platinum—to avoid palladium's high price, driven by its use in autocatalysts. Similarly, increased demand for metal increases mining, which further increases energy demand.

Anticipating future supply of a natural resource is similarly inexact. Estimates can change drastically almost overnight. Lithium estimates for Argentina's Salar del Rincon brine lake jumped from 253,000 tons in 2005 to 1.4 million tons in 2007. Peak oil notoriously has not materialized along predicted timelines due to the development of the North American unconventional oil industry, i.e. fracking—oil production is higher than ever.

The rough consensus is that there is cause for supply concern for the near term (30-100 years) under renewable energy transition scenarios, necessitating accelerated extraction. For some metals, such as cobalt, nickel, cadmium, and tellurium, current reserves may be insufficient through 2050 to 2060, depending on the specific transition scenario (e.g. cadmium and tellurium are particularly important for a specific type of photovoltaic solar technology), but for other metals reserves are sufficient to last until then and/or demand from renewable energy infrastructure makes up only a small portion of demand, e.g. for tin, iron, zinc, and rare earths. Some analyses find that lithium demand may overshoot current reserves, while others expect them to last a while. In all of these cases, the issue is increasing production to meet anticipated demand.

In general supply concerns are based on reserves, which can be economically produced in the present, rather than resources, which is the total quantity available in the planet. As technology improves and demand increases, pushing up prices, more resources are likely to become reserves. Accounting for resources slightly improves projections: most metals can last for at least a century given current projected demand. There nevertheless remain some outliers: copper supply may reach a deficit as soon as 2021, or outright exhaustion by 2100. The discovery of new deposits, potentially in the deep sea, are the primary hope for sustaining supply.

Deepening Impacts

While there are eventual limits to non-renewable resources, there appears to be enough of the necessary metals on Earth for the near-term. Beyond the question of supply, there remain concerns regarding the efficiency of mineral extraction. Already, 7-8% of energy use is by the metal sector, and digging deeper will only increase this. This is not to say the cure is worse than the disease: renewable energy infrastructure is expected to have a lower carbon footprint than existing fossil fuel systems, even when accounting for their full production life-cycle. However, as noted in a recent paper: "shifting from a fossil-based to a [renewable energy]-based system does not alleviate the problem of resource depletion, it merely shifts it from fuel to metal."

Renewable energy, while alleviating fossil fuel's extraordinary carbon emissions, does not depart from fossil fuel's fundamentally extractivist nature. Discussion around climate change too often focuses on the former while forgetting the myriad harm also caused by the latter, which renewable energy leaves mostly untouched. When this is taken into consideration, it's clear that the problem of metal supply is not about how much of a particular resource is left in the ground, but the increasing marginal costs—environmental and human—of extracting that resource. The key question about metal supply is not one of scarcity, but a political one of who bears that burden.

Moving Earth

The **environmental impacts of mining** include habitat loss, widespread land use, deforestation, increased water usage and contamination, erosion and soil contamination, and aerosolized metals and other toxic compounds. In the US, metal mining is the greatest producer of toxic pollutants, some 2 billion pounds per year. Mining is also energy intensive, contributing some 10% of greenhouse gas emissions. These can all arise from typical operation of the mine, but are exacerbated when the infrastructure meant to minimize these impacts fails, which occurs fairly often. Tailings dams, which hold in waste slurry leftover from processing, spill all the time, even in countries with relatively strong environmental regulations.

In 2000, a tailings spill at the Baia Mare gold mine in Romania resulted in 100,000 cubic meters of cyanide-laced tailings flowing into the Danube River, "the worst environmental disaster since…Chernobyl". In 2015, the Fundão tailings dam outside of Belo Horizonte in Brazil collapsed, killing 20, displacing 700, destroying the village of Bento Rodrigues, and poisoning the Doce River and the Atlantic Ocean—at the time, "Brazil's worst ever environmental disaster". In January of last year, the Córrego do Feijão tailings dam in Brumadinho collapsed, a mere 90km away from the Fundão tailings dam and owned by the same company (Vale), killing over 200 and also causing widespread damage and poisoning the Paraopeba river.

Unsurprisingly, seismic activity increases the risk of these failures, but hasn't deterred new mining operations—more than half of active mines in the Philippines, and two thirds of exploration, are in areas of high seismic risk. Outside of these spectacular catastrophes are leakages; the Mountain Pass mine in California, once the world's major producer of rare earths, regularly leaked radioactive waste during repairs of its wastewater pipeline. Even inactive mines carry risks: leakages can continue a century after their closure. This soil contamination can prohibit the rehabilitation of the land for future uses, scarring the natural world.

Rare earth production is especially harmful. In general, its water and energy intensity are much higher than other metals. The mining process kicks up clouds of radioactive dust which is dangerous for workers. Most of the impact in rare earth production is from the processing phase, requiring harsh chemicals and also resulting in radioactive waste which is expensive and difficult to properly handle. Rare earth tailings continuously generate radon gas, which, since it is radioactive, is especially carcinogenic, and easily spreads as far as 1000 km.

Rehabilitation of post-mine land is hampered by extraordinary costs. If clean-up happens at all, the cost is borne by the public. The EPA has estimates ranging from $20 to $54 billion in cleanup costs for hardrock mines alone. China's Ministry of Industry and Information Technology estimated a cost of RMB38 billion (roughly $5.5 billion USD at time of writing) for one mining area in Ganzhou, which is equivalent to 25% the combined market capitalization of the five major Chinese rare earth companies that encompass some 75% of Chinese production. More disturbingly, this one mining area is responsible for only 8.6% of Chinese rare earth production quota. Roughly scaling that cost up to cover all of Chinese production gives an estimated cost of about $64 billion USD.

These harms may seem less worrying if they are isolated far from life, but they rarely are. Mining concessions often conflict with protected areas. Over one quarter of mining activity (exploration and operation) is within 10km of a protected area. In Peru, gold mining operations cut into reforestation concessions, Indigenous land, and the buffer zones of national reserves. Even "small-scale" mining is damaging. Small-scale gold mining in Peru still involves deforestation and the use of mercury for extraction.

Even when mining concessions don't outright overlap with protected areas, the environmental impacts of a mining operation can spill well beyond its lease boundaries, especially when considering the additional infrastructure such as roads which are built to accommodate the mining operation and the urban expansion that results from laborers moving to the area. In the Brazilian Amazon, mining increased forest loss up to 70km beyond the mine boundaries—this additional loss represents 9% of the total Amazon deforestation over 2005 to 2015. The prevention of further deforestation is an uphill battle: foreign investment into a region's extractive industries can eclipse funding for forest conservation for that same region. Protected area status means very little — in 2013, 7% of operational mines for copper, zinc, aluminum, and iron had some presence in protected areas. The situation is no better for World Heritage Sites, which in 2015 had an overall 30% overlap with extractive operations.

Deforestation and forest degradation already contribute between 14 and 21% of global carbon emissions. The increased metals demand from renewable energy infrastructure will presumably increase these emissions further as new operations open and existing ones expand. Mining concessions already cover 21% of the Amazon basin, one of the most important carbon sinks in the world.

As demand for these metals accelerate, we are likely to see these environmental costs intensify. The logic of extractivism is that first the most profitable deposits are mined: profitable because they are easily accessible, or in high concentrations, or because their extraction can be subsidized in some way, e.g. by discounting environmental costs or by exploiting cheap labor conditions. As these deposits run dry, anxiety around near-term scarcity causes the price to go up, thereby making once uneconomical deposits financially viable to mine. Aside from the impact of new mines—clearing forests for infrastructure, for example, this generally means lower-quality ores, which require more energy, water, and occasionally more toxic, extraction and processing steps. The environmental impacts of mining copper, for example, could double or triple by 2050 as a result of this dynamic—the global energy use of copper mining alone could rise to 2.4%, from 0.3% in 2016. Canadian metal production decreased from 1990 to 2008, but the mining industry's share of energy increased from 25% to 36%.

We will also see escalating encroachment of Indigenous lands as mines expand and new mines are established. We already see a tremendous amount of this encroachment; comparing mining concessions against protected areas (which include Indigenous lands) for Cameroon, Cambodia, Canada, Colombia, Gabon, the Republic of the Congo, the Democratic Republic of the Congo, Peru, Brazil and Mexico (countries for which there is available data) shows that about 25% of protected areas in these countries overlap with or are within 1km over at least one mining concession.

Sacrifice Zones, Sacrifice Peoples

Many of the environmental and health effects of mining—especially the most damaging ones—are relatively localized. The history of extractivism is one of pushing these externalities to the margins, and we can expect this pattern to intensify as mining increases. This is not inconsistent with the increases in domestic exploitation of resources due to supply concerns. The Australia company Lynas Corporation operates the Mount Weld rare earth mine in Australia, but the actual processing of the ore—the most toxic part of rare earth production—is sent off-site to a processing plant in Malaysia, under much resistance from locals who saw the plant as a way to shift health harms away from the Australian public to elsewhere, and also because the weaker environmental regulations there lower costs.

Prevailing narratives around **China's dominance** in rare earth production (around 71% in 2018, down from 97% in 2010) conflate production with resources, implying that China's overwhelming production is due to a disproportionate share of the planet's rare earth deposits. In fact, the largest deposits of rare earths are in Russia and Vietnam, and the two richest (i.e. highest ore grade) rare earth deposits are in Australia (Mount Weld) and in California (Mountain Pass). As detailed in Julie Klinger's Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes, the truth behind this "geological determinism" narrative around China is more complicated. Prior to Chinese rare earth production, the US's Mountain Pass mine was responsible for 70% of global rare earth production—until, as described previously, it was shuttered due to radioactive leakages and increasing domestic environmental concern.

Cheap rare earths, however, were still necessary, and the Chinese government, prioritizing economic growth, was willing to bear the environmental and health costs necessary to keep prices low. Thus the rare earth status quo as we know it was established. In 2010, however, priorities changed: the Chinese government tightened rare earth export quotas by almost half, stating environmental, health, and conservation reasons. These reasons seem plausible; the rare earth industry in China has resulted in huge environmental and health impacts including contaminated water, radioactive dust, decreased crop yields, and increased rates of cancer (it's important to note that the Chinese government has long been aware of these effects; these were seen as necessary sacrifices for economic growth). In response to the tightened quotas, the US, Japan, and the EU brought complaints to the World Trade Organization claiming it was manipulative to increase domestic downstream production of rare earth based products. The WTO upheld the complaints, ruling against the quotas.

China's decision to sacrifice people for economic growth is not at all unusual—mining is frequently framed as a boon to the host country or local community, both by foreign mining companies and local governments. Latin American and African metal deposits have already been identified by the World Bank as particularly promising for a renewable energy transition and an asset for their economies.

Extractive industries do often form the financial bedrock for states. But, as Thea Riofrancos notes, this income is inevitably contingent on "violent forms of dispossession", i.e. the theft of land, displacement, and intense policing. The promised local economic benefits seldom materialize: extraction-dependent states tend to have higher proportions of their population in poverty and higher inequality. What does materialize is conflict. The Observatory for Mining Conflicts in Latin America (OCMAL) found that foreign investment in mining predicts conflicts throughout Latin America as locals resist the expansion of mining operations and their myriad impacts on health. The social and environmental effects of the Panguna copper mine in Bougainville, Papua New Guinea sparked a 10-year civil war that left about 20,000 dead.

The heavy water demands of mining competes with community uses of water, which is especially damaging in more arid regions. In the "Lithium Triangle", for example, which is the lithium-rich area encompassing Argentina, Bolivia, and Chile representing more than half the world's supply, lithium-rich brine must be pumped up deep from underneath expansive salt flats, requiring tremendous amounts of water—as much as 500,000 gallons per tonne lithium. In Chile's Salar de Atacama, located in "the world's driest desert" and responsible for one-third of global lithium supply, lithium production uses as much as 65% of the region's water, thereby absorbing the resources required by locals for living.

Cobalt mining in the Democratic Republic of Congo (DRC) is widely reported on—half of cobalt production is from the DRC, some of which is extracted under dangerous conditions and with child labor. Many of the mining concessions in the DRC were signed over to foreign companies under desperation following the devastating war—the deadliest since World War II. These mines are major social and economic disruptions, driving locals to dangerous and meager artisanal mining in the first place. The Tenke Fungurume copper and cobalt mine, one of the world's largest, itself is a result of foreign powers (in this case, the US government) pressuring the Congolese government into signing so-called "sweetheart deals" which are extremely asymmetric in their benefits. In June of this year, the DRC army deployed soldiers to forcibly remove the some 10,000 artisanal miners in the (now Chinese-owned, formerly owned by US-based Freeport-McMoRan) Tenke Fungurume concession who have torched homes and reportedly injured at least two children.

When locals try to engage in small-scale mining of their own resources as a supplemental income, they are subject to these same violent dispossessions. In a gold and rare-earth rich region of the Brazilian Amazon, Cabeça do Cachorro, Indigenous land rights extend to only the top 40cm of the land—the federal government owns anything deeper. These rights are sold to mining companies, who then develop infrastructure that facilitates both private and government control over the area. Here, the discovery of rare earths serves to advance an existing agenda to "conquer the northwestern Amazonian frontier", and no doubt the increasing need to secure domestic rare earth supply will serve to further rationalize this agenda. This too echoes a common pattern: weakening protections for Indigenous territories, if not outright undermining them, for mining. As new supply needs to be secured and new mines established, this is likely to accelerate.

Growing concerns over supply security are beginning to precipitate similar human sacrifices in the United States. Rare earths, it is often noted, are not rare (though they are rarely found in concentrations worth mining; usually they are mined as byproducts of other minerals). Most countries have enough within their borders to supply their own needs. Growing panic over tightening Chinese rare earth export quotas in 2010, from 50,000 tonnes to 30,000 tonnes compelled the US DOE to prioritize developing substitutes and increasing the recycling of "critical" metals, which include rare earths but also metals such as lithium. Recent trade war concerns have seen further legislation, such as the bipartisan American Mineral Security Act, meant to develop domestic production capacity of these critical minerals. Last year Senator Marco Rubio introduced a bill which would establish a "rare earth cooperative" to facilitate domestic end-to-end rare earth production, explicitly to reduce dependency from China out of national security concerns.

Like China, the **US** is increasingly prioritizing resource extraction over communities. This is reminiscent of the US's recent energy independence with respect to oil. Fracking has considerable health, environment, and social costs, but the continued expansion of that industry demonstrates that energy security concerns and profitability supersede those costs. Indeed, the US's dominance in oil production has strengthened its geopolitical position by allowing it to gain independence from OPEC and Russia. A similar trade-off will become standard with mining, continuing established practices of relegating the harms to marginalized communities.

Bounty of the Sea

The anxiety around metal supply and its human toll overlooks 70% of the Earth's surface: the oceans. When we consider how oceans provide abundant food, medicine, and industrial compounds, and are already drilled for oil (16% of US crude oil production is offshore), it's reasonable to expect that they may also provide metals. The deep seafloor, holding deposits formed by hydrothermal vents pumping heat from deep within the planet, potato-sized polymetallic nodules buried in abyssal plains, volcanic ferromanganese crusts, and less glamorous muds, is rich with metals of all varieties: nickel, cobalt, platinum, gold, silver, lithium, rare earths, among others.

Though terrestrial supplies are likely sufficient to sustain demand for several decades, deep sea mining is increasingly proposed as an alternative to terrestrial exploitation, often framed as an unspoilt backup frontier should terrestrial reserves actually run dry. Deep sea exploitation is especially alluring to countries such as Japan, where its development could mean less reliance on China. As demand for critical metals increases, higher prices will make the technical challenges and logistic complexities of deep sea mining a more feasible investment. There is already plenty of movement, Since 2001, the International Seabed Authority (ISA), which manages exploration and mining leases for the seabed outside of national jurisdictions, has recognized 29 claims over deep sea minerals encompassing some 1 million sq km outside of national jurisdictions, which are all in exploratory stages. Paradoxically, the ISA was established to distribute exclusive national rights in the area that is recognized in the United Nations Convention on the Law of the Sea (UNCLOS) as the "common heritage of mankind" as opposed to protecting it from such claims.

One analysis found that one square kilometer of Pacific deep sea mud contained enough rare earths to satisfy one-fifth of the world's annual demand, such that one area near Japan's Minamitorishima Island can meet supply for decades. Cobalt concentrations in deep sea crusts may be three to ten times the amount of terrestrial deposits. Even less exotic metals, like copper and zinc, have already been found in Papua New Guinea's waters in concentrations higher than terrestrial deposits, though the overall size of the deposits may be overstated.

While there are minor benefits to deep sea mining (e.g. less radioactive elements in deep sea rare earth deposits), the overall effect is no less damaging than its terrestrial counterparts. Biodiversity loss is unavoidable—an "impossible aim", especially given that as much as half of the local life is directly dependent on the deposits that would be mined. Recovery of damaged habitats and populations are practically irreversible on reasonable timescales, potentially taking centuries if happening at all. The full extent of the damage can't really be appreciated given that still so little is known about deep sea life. What is clear is that the biodiversity loss from deep sea mining negates other benefits of the ocean, including food, medicine, and useful enzymes. Many of these useful enzymes—some of which have applications in sustainable technologies—are sourced from the very hydrothermal vents around which deposits are located. They can also be sustainably harvested; the total economic value of marine-derived enzymes is estimated at over $50B per year. The ISA is working on environmental regulations to accompany its leases, but this is recognized as an “unattainable goal” under all existing mitigation schemes, save for establishing protected areas.

More alarmingly, the ocean’s crucial functioning as a natural, massive carbon sink — absorbing about 40% of CO2 emissions since the Industrial Revolution—could be disrupted by mining, as could other important ecological processes the ocean is a key part of. The weakening of a negative feedback loop like ocean emissions absorption is potentially devastating.

Deep sea mining does not mitigate the human costs of mineral extraction, as it has the potential to harm ocean reliant communities. Mining explorations have already impacted Pacific Islander communities, and will likely continue disproportionately impacting them, by polluting the area and threatening fishing supply and other customary uses of the ocean. When applied to the sea, typical programs which seek to remediate the local impacts of extractivist projects may serve only to redistribute environmental health and biodiversity away to regions already safe from mining—in wealthier jurisdictions. We are already seeing this pattern emerge—more protection of deep sea resources in the Northern Hemisphere, and more prospecting of those in the Southern Hemisphere, where biodiversity is potentially the greatest. When considering terrestrial extractivist dynamics, deep sea mining is nothing new. Like all other “frontiers”, the deep sea is always and already deeply integrated into ecological systems and human communities that will fall apart with increased extraction.

Far Out: The “Outer Spatial” Fix?

If both terrestrial and deep sea mining are too harmful and politically fraught, then perhaps we should look elsewhere—outside of these limits. Moving mining and other dirty industries off-world is a suggestion that has gained more attention over the past decade, which envisions space as an expanse of infinite resources and an endless trash bin (the “perfect vacuum”), sparing the Earth the continued cost of our ceaseless expansion. Certainly, several of the world’s billionaires have used the space industry as an outlet for their excess capital—Eric Schmidt and Larry Page have specifically funded space mining endeavors, while others like Elon Musk and Jeff Bezos invest in the required launch infrastructure. Jeff Bezos recently summarized the vision:

We send things up into space, but they are all made on Earth. Eventually it will be much cheaper and simpler to make really complicated things, like microprocessors and everything, in space and then send those highly complex manufactured objects back down to earth, so that we don’t have the big factories and pollution generating industries that make those things now on Earth…And Earth can be zoned residential.

Under the assumption of infinite material, space mining has even been described as the key prerequisite for a post-scarcity utopia. Indeed, one concern around space mining is that it would cause a sudden spike in resource supply, destabilizing the global economy. One business strategy therefore involves sequestering space-metal orbs into orbit so they can be sold slowly to maintain planetary scarcity.

Surveying celestial objects is not cheap or reliable, but there are indeed a lot of metals in space. Rare earth elements have been found on the moon in higher concentrations than on Earth, and so far analyses of near earth asteroids (NEAs) estimate massive supply of platinum group metals (PGMs). Terrestrial PGM ore concentration is in the range of 0.5-3g/ton; LL chondrites, which are formed from asteroids, are estimated to have concentrations of over 50g/ton. One 200m LL chondrite could supply double the 2000 annual primary production of platinum.

There are no doubt advantages to mining in space. Many of the complicating aspects of terrestrial operation are just gone. For example, there is no rain or atmosphere to corrode materials. Higher ore grades mean less energy-intensive processing. Even considering carbon emissions from transportation (i.e. launch and reentry), space mining could have lower impact—according to one analysis, 150kg CO_2 eq/kg platinum (depending on payload size as a percent of launch mass) compared to ~40,000kg CO_2 eq/kg platinum for mining and ~1,800kg CO_2 eq/kg platinum for recycling—though there are other impacts such as ozone layer depletion that may be worse. The earthbound environmental impacts of space mining are largely contingent on the impacts of launch and reentry, so improvements to that process, such as renewable and zero-emission fuels, can go a long way. Minimizing transit between Earth and space would of course also improve the footprint. Production that requires the metals can also be relocated to orbit such that only finished products are brought down, for example.

The exact cost of a complete space mining operation can only be speculative at this point, but one analysis estimates that for the same investment that went into the Prudhoe Bay Oil Field, which produces ~0.3% of the world's daily oil consumption, the global supply of PGMs could be increased by about 50%. The biggest operational cost is transit. Launch prices are decreasing—over 90% to low earth orbit in a decade—but are still risky enough that valuable payloads are avoided. Of course, costs also vary depending on the particular mining approach. In the case of asteroids, a mining operation can meet the asteroid in its orbit or it can capture the asteroid and bring it closer to Earth. One report suggests that for the latter case the captured asteroids would need to be 20m or less in diameter, so that were something to go wrong it would disintegrate in our atmosphere, avoiding impact. Yet impact is not the only way an asteroid can inflict damage. The Chelyabinsk meteor in 2013 was 20m in diameter and damaged over 7,000 buildings with its shock wave (at least 15,000 people were injured in the ensuing panic).

Perhaps the biggest complication is a chicken-and-egg problem: the infrastructure for space industry simply doesn’t exist, but the most economical development of that infrastructure requires operational space mining projects. Given that transit has the biggest cost and footprint, transporting raw ore to Earth for processing would undermine the profitability of these mining endeavors, and also contradict their environmental justifications. Establishing the processing infrastructure in space would similarly require heavy transit: launching the necessary facilities, equipment, and resources. Over time, launch costs may go down such that this problem is more tractable, but for now, even the world’s richest billionaires can’t afford this gambit.

The cost and technology barriers are compounded by legal ones, specifically around property rights. Space mining companies will be hesitant to invest billions into an endeavor they can’t claim the profits from. Outer space is legally recognized as a commons, though there is ambiguity about what exactly this means. The 1967 Outer Space Treaty states that no nation can claim sovereignty over a celestial body, though they can use them. While deep sea mining has the ISA, a governing authority that can parcel out extraction rights in what is otherwise a common territory, no analogous authority exists for space. That hasn’t stopped the US from trying. In 2015, Obama signed the Commercial Space Launch Competitiveness Act of 2015 into law (also known as Spurring Private Aerospace Competitiveness and Entrepreneurship or SPACE Act), which was in part driven by lobbying from Deep Space Industries and Planetary Resources. The SPACE Act recognizes private claims of US citizens over space resources and allows civil suits against entities that interfere with these rights, though without recognition from the international community it may not mean much. Legislation like this sets up space resources as a first-come-first-serve race, such that those resources become monopolized by only those countries wealthy enough to access them. Non-space-faring states—many of which were or are exploited by the space-faring ones—are shut out.

Beyond the legal and technical uncertainties lie obscene profits, estimated to reach as high as $35 billion for a single asteroid. Companies like Planetary Resources and Deep Space Industries (DSI) were formed to pursue these profits. Both companies were recently acquired and stripped for parts. DSI worked on a water-based propulsion system and pivoted to smallsats, a significantly more straightforward product, making it indistinguishable from most space companies. They were acquired this year by Bradford

Space for their propulsion system. Planetary Resources also pivoted to smallsats to improve asteroid prospecting technology and was also acquired this year, though rather confusingly by Consensys, a blockchain company. It's unclear what will come of the acquisition, other than some vague gesture at "opening up" space. Joseph Lubin, the founder of Consensys, described the acquisition as "reflect[ing] our belief in democratizing and decentralizing space endeavors to unite our species and unlock untapped human potential," which, when considering that the success of these space mining companies is contingent on the enclosure of space, is a dubious statement.

We also need to consider who provides the resources—labor and material—for producing the infrastructure and machinery that bootstraps this space industry. Again, we can expect regions and peoples to be used as a stepping ladder for space-faring countries and companies to monopolize outer space.

Space mining is distant enough that we should not organize society around its possibility. Even if it were achievable, there are many ways to do it wrong—just extending social and economic problems into space—and it's not clear that there is a way to do it "right". We should be hesitant to accept any solution that requires us to wait just a little bit longer with our accelerating extractivism. Nevertheless, the possibility of space mining and industry remains key to the fantasy of endless expansion. Viewing space exploitation in this way assumes that resource scarcity and environmental impacts are the only limits to growth, and that holding out for some vague space-faring future is something we can afford to wait for. While environmental impacts are especially urgent right now, organizing society around the growth-at-all-costs imperative also relies on exploitative and extractive social relations that outer space can't fix.

In the Loop

Most of the issues outlined so far are concerned with primary production: mining new ("virgin") materials and introducing them into circulation. One of the consistent proposals for mitigating the impacts of primary production and securing supply is to ramp up secondary production, i.e. recycling. Unlike fossil fuels, the metals in renewable energy infrastructure can theoretically be recycled infinitely. As one paper puts it, we should "minimize the seemingly bizarre situation of spending large amounts of technology, time, energy, and money to acquire scarce metals from the mines, and then throwing them away after a single use."

Recycling is promising, and ideally it can substitute all of primary production. Recycled aluminum and nickel have about 90% less CO_2 emissions than primary production; for copper the savings are 65% and for gold it can be 80% less. Energy use is also drastically

reduced, by two to ten times, as is water use, by more than ten times for many metals. The waste produced is also significantly less since recycling is typically dealing with higher concentrations of the material than found in nature. Smartphones have a concentration of gold 100 times than that in gold ore. An important exception to this trend is rare earth recycling, which can be as toxic and energy intensive as primary processing, though still better overall. Across all metals, recycling is greatly preferable to primary production.
There are, however, three limiting factors. One encompasses logistical and physical challenges—namely collection, separation, and thermodynamic limits, the second is the economics of recycling, and the final is growth.
For many metals, collection of end-of-life (EOL) products for recycling is well-established and relatively straightforward. Iron and steel are among the most recycled, with 70-90% EOL recycling rates. For aluminum and copper the rate is closer to 50%. These are metals that tend to make up the majority of the product they are a part of—an aluminum can, for example is basically entirely aluminum—so their distribution is relatively concentrated, making "mass recovery" possible.
Modern technologies complicate the picture in two ways. First, the concentration of metals are much smaller and more dispersed, making them more difficult to collect and producing a lower yield per item. This disincentivizes recycling—it's just not worth the money. For example, the recycling rate for PGMs in industrial applications is between 80 and 90%. For electronics it's a mere 0 to 5%. In industrial applications, the PGMs that are used are kept on-site, so collection is relatively easy. Electronics, however, travel far and wide, requiring tremendous coordination to collect them at a recycling facility.
As it stands, the state of electronics waste collection is terrible. The global average of properly collected and recycled e-waste is 20%; where the rest goes is unclear. It's very difficult to estimate where this "hidden" e-waste ends up, in large part due to a lack of well-categorized data (e.g. parts of products not categorized as electronics, such as automobiles, nonetheless contain what we would consider e-waste) and loopholes in how e-waste exports can be declared (e.g. as a "donation"). E-waste sites like Agbogbloshie in Ghana and Guiyu in China have attracted a lot of media attention, though the proportion of e-waste ending up in those locations are small relative to the overall amount (and a lot of that e-waste is reused rather than recycled). One report tracked 314 pieces of European waste electronics and found that 19 pieces (6%) left their original country, with 11 of those (3.5%) going to developing countries. As a percentage that is relatively small, though it should also be noted that some 50% of the 50 million tons of e-waste generated per year comes from the US and Europe, so as an absolute quantity that is still a substantial amount. That finding is on par

with another study which found that 73 to 82% of e-waste moves between countries in the global North. However, another estimate says that 75 to 80% of e-waste ends up in Asia and Africa. What this demonstrates is the inadequacy of current e-waste collection and reporting infrastructure.

Though the actual amount of e-waste ending up in places like Agbogbloshie and Guiyu may be overstated, the environmental and health harms of the waste that does end up there is not. These sites lack infrastructure for safe recycling, relying on open-pit acid baths and plastic burning, access to adequate medical care, and basic protective measures. High levels of metals—including lead—were found in the soil, air, and workers in e-waste recycling sites in Bangalore and Chennai. Similar impacts are found at the Agbogbloshie and Guiyu sites. “Take-home exposure” can spread these effects well beyond the recycling site as hazardous substances end up in clothing and are transported to homes.

Second, in modern technologies metals are used in combinations that are different than those found in nature, requiring specially developed metallurgical processes for mixtures or alloys that may be specific to a particular product, to the point of requiring specialized infrastructure, and increase impurities. These impurities affect the suitability of the recovered metal for specific applications. Recycled lithium, for example, currently has impurities which make it inadequate for use in batteries. One paper likens these processes to separating coffee into milk, sugar, and water. If the metals are especially mixed, the energy required for separation may even exceed that of primary production, undermining much of the environmental benefit.

Product design is also a huge factor. Electronics are designed for compactness, which means that components may be tightly packed and attached with glue, which complicates separation. As miniaturization continues to micro and nanoelectronics, this problem will probably get worse. Further, these metals are also mixed with plastic, paint, and other materials we want to separate out. Current separation practices don’t go much further than shredding, which complicate downstream metallurgical processes, requiring more complex chemical separations that can increase environmental impact. Shredding products with permanent magnets, for example, results in smaller magnetic pieces that stick to everything else, lowering recovery rates. A study comparing manual disassembly of hard disk drives to shredding found that shredding’s recovery rates were less than 10%, whereas manual disassembly was able to recover most or all of the magnets. The problem is that manual disassembly is quite labor intensive and difficult to scale for the amount of electronic waste that is generated. Automated physical separation, in comparison, can be eight times faster than manual disassembly.

There are also physical limits to how much metal can be recovered. Some processes lose metals, and thermodynamic limits mean that some alloys require so much energy that their separation is essentially impossible.

More disappointingly, one major barrier to increased recycling is that it's simply not economically viable under current market conditions. The price point of many metals are too low.

Finally, the imperatives of growth and its deep linkage to increasing material requirements means that we always need to introduce new material into the economy, necessitating further mining. There are some ways to lessen this impact, primarily more efficient use of materials. For example, newer battery designs use less cobalt, and rare earth intensity in electric vehicles has also gone down. However, efficiency gains can lead to a net increase in use of that material, a phenomenon called the "Jevons paradox". Sometimes substitution is proposed as a solution, but that may only shift demand to other materials that are as or more harmful to mine and process. For some metals, such as copper, their unique properties mean that direct substitution is unlikely (though for copper graphene is a candidate).

Many of the models estimating future metal demand with respect to a renewable energy transition find that recycling may be helpful or even necessary in the long-term, but that it will not suffice to meet all demand on its own, even if (somehow) 100% recycling rates were achieved. Even in the short-term recycling is unlikely to have a significant impact. Against expanding demand, recycling will always be insufficient.

A more promising approach follows the burgeoning right-to-repair movement. Of course, repairing and reusing products has the lowest environmental impact compared to both primary production and recycling. The right-to-repair movement's objectives are to foster a regulatory environment which protects people from litigation when they tinker and modify their devices, and compels companies to design products that are more amenable to repair—precisely opposite to the prevailing product design trend of slimmer and slimmer electronics (which not only prohibit repair, but also severely complicate recycling, as outlined above) and use of proprietary components such as Apple-specific screws. Of course, there is again a tension here against the need to maintain and accelerate the circulation of products, which is why repair is so ill-supported in both product design and policy.

A Choice You Can't Refuse

In a recent interview David Wallace-Wells notes that: "When I read about the amount of rare earth mining that has to be done to produce new battery capacity, again, I wish that we didn't have to do that, but I'll take that deal if it stops the planet from warming an additional degree or two degrees, because I think the impacts of that level of warming so outweigh the environmental concerns of that kind that it's worth taking." The importance of avoiding that additional warning is absolutely clear. But who has the choice of taking that deal is precisely what is left out of so many conversations about addressing the climate crisis.

Climate change is so alarming precisely because of its global scale. Its effects threaten practically everyone, including the better off in the global North who are usually insulated from the consequences of their consumption. It is completely possible—maybe more likely than not—that emissions can be reduced in a way that maintains the current regime of global extractivism that localizes ecological and social harm, keeping it out of sight and mind of the wealthier of the world.

Many of the proposals for the Green New Deal are comprehensive, but still overwhelmingly domestically focused (though considerate of domestic communities often overlooked). The better ones address the issue of localizing the costs of both climate change's effects as well as adaptation against those effects—communities disproportionately affected by pollution, fracking, and so on. But mentions of international trade are mostly limited to "green development", emissions reduction, or otherwise refer to under-specified commitments to more environmentally-focused trade policy, and fail to offer any justice or even acknowledge that, though a renewable energy transition is unambiguously necessary, it will be at the continued expense of those who contributed the least to this ecological catastrophe. We need to consider how these strategies for mitigating and adapting to climate change will intensify existing extractivist regimes and how ameliorating those systems can be included in our visions for a post-carbon future.

Source: Inside Out