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Article

Critical Minerals and the Digital Decarbonization Challenge

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Abstract

This paper centres on the material issues that underlie transformative challenges. We describe Japan's Society 5.0 (cyber-space + physical space) industrial policy and the draft 6th Strategic Energy Plan. The former emphasizes inclusive resilience in developing and deploying advanced digitalization technology and the latter is aimed at decarbonization. Inclusiveness is embodied in a collaborative platform capitalism, aimed at maximizing public goods. Collaborative platforms are evident in multi-stakeholder SDGs cities, smart cities, local national resilience planning, and related initiatives.

At the same time, Japan's Society 5.0 and energy strategies fall short in recognizing the imperative of integrating the emergent challenge of secure and environmentally sustainable supplies of critical raw materials, or critical minerals. This deficit in policymaking is surprising for a resource-poor country, and needs to be remedied.

Introduction

Japan's Society 5.0 is both a scientific research and development initiative and an industrial-policy regime. It is aimed at melding digital technology and such critical infrastructure as energy, water, transport, health care, and other systems.[1] It remains a somewhat amorphous concept in practice, but has provided an overarching scheme for industrial policy since the 2016-2020 Fifth Science and Technology Basic Plan. Japan evidently chose the "5.0" designation to distinguish its approach from the Germany's Industry 4.0 initiative. Both seek to harness the digital and other smart technologies of the 4 th industrial revolution. But in-

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1) See Atsushi Deguchi, "From Smart City to Society 5.0," in (ed. By Hitachi-UTokyo Laboratory), *Society 5.0: A People-centric Super-smart Society*, Springer, 2020: https://link.springer.com/book/10.1007/978-981-15-2989-4

centivized by disasters, demographics and other challenges, Japan's effort transcends Germany's smart factories and aims to deploy smart systems throughout the entire society, and hence it is designated "Society 5.0."

As noted, the overall emphasis in Society 5.0 is to integrate cyber-space with physical space. In other words, it aims to link the Internet of Things, artificial intelligence, and other aspects of the ongoing digital transformation with the management of social and critical infrastructures. In practice, this integration sees sensing technology deployed on water, transport, power and other networks so as to implement real-time monitoring and control. The aims include reducing the human and fiscal costs of maintenance, increasing disaster resilience, and maximizing responsiveness to other societal needs. And since Japan's digital competitiveness ranking in 2020 was assessed at a low 27th internationally, Society 5.0 is also predicated on a nationwide rollout of the most advanced digital technologies.

In Japan, smart technology is already used to integrate meteorological data from advanced radars to bolster resilience against the extreme weather that is part of climate change. These next-generation radars give rapid and pinpoint advance warning of impending rainfall. That situational awareness allows water managers to adjust dams, river flood control systems, sewerage systems and other critical infrastructures to cope with the hydrological challenges posed by increasingly intense downpours. Tokyo's sewerage division has already deployed this integration of technology. Tokyo uses advanced radar and monitoring technologies to manage its 16,000 kilometers of pipes that in 2018 moved 4.67 million cubic metres of waste-water per day through 84 massive pumping stations and 13 treatment centres.[2] Further diffusion of these kinds of system-integration can be seen in monitoring for renewable energy systems, transport infrastructure, agriculture, and myriad other areas.

Hence Japan's Society 5.0's policy arms are broad-reaching. Prominent among its goals are digital transformation in smart cities, real-time disaster risk reduction, and precise meteorological monitoring for integrating variable renewable energy. Considerable fiscal investment is being targeted towards these objectives. In the 2021-2025 Sixth Science and Technology Basic Plan, total cumulative investment in Society 5.0 is expected to be JPY 30 trillion. And total public and private investment in Society 5.0-related technologies is anticipated to reach JPY 120 trillion.[3]

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2) The data are available (in Japanese) in "Tokyo's Sewerages, 2020," Tokyo Metropolitan Government, December, 2018: https://www.gesui.metro.tokyo.lg.jp/business/pdf/sewerageintokyo2020.pdf

3) See (in Japanese) "The Outline of the 5-Year, JPY 30 Trillion Science and Technology Basic Plan," *Nihon Kogyo Shimbun*, April 6, 2021: https://newswitch.jp/p/26703

Inclusive Governance

Japan's implementation of Society 5.0 is not a top-down initiative. Even before the shock of COVID-19, Japan featured increasing horizontal and vertical governance. For several years, Japan's policy context has been framed by multi-level and multi-stakeholder industrial policy that seeks to maximize the capacity to address such societal challenges as rapid ageing and depopulation in addition to the imperative of climate mitigation and adaptation.

Japan's Society 5.0 was also directly linked to disaster resilience and the other SDGs before COVID-19, and has become even more integrated since. One reason is that COVID-19 lockdowns highlighted the importance of digital networks in tandem with the challenge of maintaining fiscally viable regional economies. Thus, Japan's main business association, Keidanren, drafted a November 17, 2020 policy paper emphasizing the importance of "Society 5.0 for SDGs" as key to building back better from COVID-19.[4] Similarly, Japan's National Governor's Association, reflecting a consensus among subnational governments, explicitly linked Society 5.0 and SDGs actions as critical transformative policies for a resilient recovery from COVID-19. Even before the onset of COVID-19, Japan's multi-level action on SDGs was more robust than other developed countries, in encouraging Japanese subnational governments to address domestic challenges as much as external engagement and global contributions. During the COVID-19 pandemic, Japan's SDGs collaboration deepened as a mechanism for promoting a sustainable recovery. The Suga Administration's September 2020 commitment to net-zero decarbonization by 2050 saw Society 5.0 become nore closely focused on that ambition. For example, the Keidanren has released several reports on "Society 5.0 with Carbon Neutral," detailing the role of clean energy generation (renewables and nuclear), battery storage, and other technologies – together with smart monitoring and management – in reaching the decarbonization goals.[5]

Japan's collaborative context is seen in table 1, which itemizes Japan's broadly inclusive Local SDGs Public-Private Collaborative Platform. The table lists the platform's members by category (eg., subnational governments) and then by the total members per category. By the end of May, 2021, the platform's membership included 907 of Japan's prefectural

4) See (in Japanese) the summary version at the following URL: https://www.keidanrensdgs.com/society-5-0-jp

5) See (in Japanese) "Society 5.0 with Carbon Neutral," Keidanren, December 15, 2020: https://www.keidanren.or.jp/policy/2020/123.html

Table 1 Japan's Local SDGs Public-Private Collaborative Platform

Member Category	Number of Members
Subnational Governments	907
Central Agencies	13
Private Firms and others	4,503
Total Membership (as of May, 2021)	5,423

Source: Future City, 2021 [6)]

Table 2 Japan's Smart City Public-Private Collaborative Platform

Member Category	Number of Members
Subnational Governments	164
Central Agencies	11
Businesses, Research Centres, and others	432
Business Associations	2
Total Membership (as of May 31, 2021)	609

Source: MLIT, 2021 [7)]

and local governments in addition to most of the national government's central agencies. In addition, civil society is very broadly represented by 4,503 business firms, research institutions, NPOs and other organizations. The number of NPO/NGOs alone was 476, with a strong representation by social justice and local sustainability organizations. Importantly, the total membership of 5,423 more than quadrupled compared to the April 2020 total of 1,235 members. This rapid increase in the platform's total membership, in just 6 months, reflects the impact of COVID-19.

Another important vehicle for shaping Japan's inclusive action is its Smart City Public-Private Collaborative Platform. The platform's total organizational membership is itemized in table 2. Of particular note is the growing number of local governments, 164 as of May 31, 2021. This platform is yet another venue via which Japan is implementing broad-based Society 5.0 initiatives, with best practices shared among multiple stakeholders.

Yet another of Japan's key collaborative governance platforms is National Resilience.

6) See (in Japanese) "update of membership," June 10, 2021: https://future-city.go.jp/platform/member/

7) See (in Japanese) "Japan's Smart City Public-Private Collaborative Platform": https://www.mlit.go.jp/scpf/about/index.html

Table 3 Japan's Local National Resilience Plans (NRPs)

Administrative Level	July 1, 2019	August 1, 2021
Local Government	203	1,733

Source: National Resilience, 2021[8)]

Japan's National Resilience initiative dates back to 2014 and emphasizes all-hazard disaster preparation, building back better, and "whole of government" collaboration. Its ambit overlaps with the platforms discussed above, in that it encompasses smart communications, sustainable energy systems, resilient water networks, and the other critical infrastructures. Moreover, the impact of COVID-19 has also accelerated its diffusion among subnational governments. By December of 2020, all of Japan's 47 prefectures had adopted their own regional versions of the National Resilience Planning (NRP). As we see in table 3, as of August 1, 2021, fully 1,733 of Japan's 1,741 cities, special wards, and towns had either adopted their own local versions of the NRP or were formulating plans. That number of local governments doing NRPs was more eight times the 203 total in July of 2019.

Japanese policymaking thus emphasizes several types of inclusiveness. Governance is adapting to climate and other cascading hazard risks that outstrip the capacity of segmented agency, policy, and critical infrastructure to respond effectively. Japan thus offers a lesson on how to expand disaster-risk reduction to include bolstering both the resilience of the social sphere and the built environment in the face of interconnected climate, seismic, demographic, economic, health, and other hazards.

The Draft Strategic Energy Plan

On July 21 of 2021 Japanese policymakers unveiled a draft version of the country's 6th Strategic Energy Plan.[9)] Much like previous iterations of the triennial planning initiative, the goals are both comprehensive and controversial. Unlike previous versions, this draft's ambitions are crafted as much to address international decarbonization commitments as to appease domestic advocacy coalitions. This section discusses the most pertinent details of the draft, which as of this writing remain a focus of media attention and public debate. We

8) See (in Japanese) "Map of Adopted Local National Resilience Plans": https://www.cas.go.jp/jp/seisaku/kokudo_kyoujinka/pdf/210801_keikakumap.pdf

9) The draft of the 6th Strategic Energy Plan is available (in Japanese) at the following URL: https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/opinion/data/01.pdf

address the power-sector targets, including renewables and nuclear, but move beyond those items in keeping with the ongoing evolution of the Japanese specialist and public debate.

Introduction

Japan's strategic energy plans cover the power sector in addition to the larger energy economy. The plans aggregate what is deemed to be the best-available evidence on current and mid-term energy costs, strategic options, and myriad other parameters relevant to shaping policy for a resource-poor industrial economy with the world's 4 th largest appetite for energy. The current draft, released on July 21, is subject to public comment through September of 2021. It is not expected to be formally adopted by the cabinet until after a general election that must be held by October 22 of the same year. As of this writing, Japan's Prime Minister Suga Yoshihide is slated to resign his post at the end of September 2021 and be replaced by a newly elected LDP President. Hence, the strategic energy plan's details may change and this analysis is therefore tentative.

The present draft was developed through a more inclusive process than earlier plans. The consultation process for building earlier plans tended to be centred within the ambit of the Ministry of Economy, Trade and Industry (METI), technocratic deliberation councils, and major business associations. This time, deliberation extended well beyond METI to include other ministries, notably the Ministry of the Environment (MoE). The assessment of energy costs and economic opportunities was also more wide-ranging than in the past. Policies to accelerate smart electrification for decarbonization and disaster resilience were ramped up. And the overall initiative was framed by Prime Minister Suga's commitment to a 46% reduction of Japan's greenhouse gas emissions by 2030 and net-zero by 2050.

The Key Goals

Proposed changes to the previous plan's vision of Japan's 2030 power mix have received the most attention domestically and internationally. Table 4 compares the two plans' essential details. The 2018 5^{th} plan rather grudgingly conceded to making solar, wind, biomass and other renewables 20-22% of the power mix. But the accelerating global diffusion of ever-cheapening solar, wind and storage helped encourage raising the renewable target to 36-38%, which by 2020 was already roughly 18% of Japan's power mix. Also attracting much commentary was the decision to maintain the ambition for nuclear power to compose 20-

Table 4 Comparing Japan's Proposed 2030 Power Mixes (Units: %)

2018 5th Basic Energy Plan		2021 6th Basic Energy Plan (Draft)	
Renewable	22–24	Renewable	36–38
Nuclear	20–22	Nuclear	20–22
Hydrogen–Ammonia	0	Hydrogen–Ammonia	1
LNG	27	LNG	20
Coal	26	Coal	19
Oil	3	Oil	2
Total Generation (billion kWh)	1,065	Total Generation (billion kWh)	930–940

Source: METI, 2021 [10)]

22% of electricity generation, building on the current level of roughly 6 %. Added to the draft's aims for decarbonizing renewable and nuclear are an explicit commitment to about 1 % of power generation via burning hydrogen and/or ammonia. This first-ever explicitly quantified commitment to previous plans' visions for a "hydrogen society" is expected to help boost the zero-carbon share of the power mix to 59%, compared to the aim of 44% in the 2018 plan.

The big losers in the draft are fossil-fuel thermal generation, including liquid natural gas (LNG), coal, and oil-fired power. In 2019, these sources composed 76% of Japan's power mix, their respective shares being 37% (LNG), 32% (coal), and 7 % (oil). LNG is thus projected to drop to 20% by 2030, a far steeper cut than the previous scenario of it declining to 27%. Though coal-fired generation is about twice as dirty than LNG, its rate of decline is less precipitous, down to 19% versus the 26% envisioned in the 5th plan. Projected changes to the role of oil-fired power is minimal with a projected 3 % share falling to 2 %. The draft plan would therefore have fossil-fueled power totaling 41% of the power mix by 2030, down from a 56% share envisioned in the 5th energy plan.

One item not adequately addressed in the continuing debate over Japan's draft plan is its great ambition for energy efficiency. The 6th plan anticipates Japan's power needs to decline to about 930–940 billion kWh, compared to 2019's level of 1,024 billion kWh. The 5th plan, by contrast, expected Japan's power demand to increase to 1,065 billion kWh.

10) The figures are available (in Japanese) in the draft 6th Strategic Energy plan at the following URL: https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/opinion/data/01.pdf

Key Issues

Japan's proposed revisions have been positively assessed by some observers, particularly internationally where there is strong desire to keep decarbonization at the core of the too-easily distracted global agenda. Yet the new goals have attracted an unprecedented deal of concern in the domestic debate. We shall address these in turn.

Renewables

Criticism of the renewable targets includes disappointment that they are not much higher and – somewhat contrarily – worry that they are unrealistically ambitious. Those who advocate for higher renewable numbers insist that the declining international cost of solar and wind present Japan with an opportunity to take back the leadership role it enjoyed decades ago. They insist that the opportunities to build robust domestic renewable industries – especially in offshore wind, hydrogen, and smart-energy management – could help the country play a stronger role in global greening. Many of these advocates argue that the draft plan should target well over 40% renewables by 2030, maintaining that this would lead to lower power costs by 2030.

These advocates compose a Japanese-style Green New Deal (GND), or Green Recovery camp, comparable to those in the EU and the US. As we shall see in greater detail below, whether in Japan or elsewhere their ambitious assertions concerning renewable energy generally ignore critical minerals. As renowned ecological economist William Rees argues in a July 2021 expert collaboration with America's The Real Green New Deal Project's Executive Director:

> "GND proponents are appallingly tolerant of the inexplicable. They fail to address how the gigatons of already severely depleted metals and minerals essential to building so-called RE technologies will be available in perpetuity considering typical five to 30-year life spans and the need for continuous replacement. They offer no viable workarounds for the ecological damage and deplorable working conditions, often in the Global South, involved in metal ore extraction. Green New Dealers advance no viable solutions (technical or financial) for electrifying the many high-heat-intensive manufacturing processes involved in constructing high-tech wind turbines and solar panels (not to mention all other

products in modern society). The waste streams generated by so-called renewables at the end of their short working lives are either ignored or assumed away, to be dealt with eventually by yet non-existent recycling processes. Proposals for electrifying the 80% of non-electrical energy demand overlook crucial facts, namely that the national-scale transmission systems and grids required for electrified land transportation do not even exist today, nor is the needed build-out likely given material, energy, and financial constraints."[11]

Rees and his colleague's arguments are very critical, but are based on some of the best available literature on critical minerals. Rees is also a founding member and past-President of the Canadian Society for Ecological Economics. He is also a co-creator of the concept of the "ecological footprint," which now informs environmental policymaking in many countries and academic studies. In short, the above arguments are backed up by evidence and from an authoritative source. The arguments also show how awareness of critical mineral issues is diffusing in Canada and the US, notwithstanding their massive endowments. So it makes Japanese silence seem all the more surprising, since the country has virtually no significant terrestrial endowments.

Naturally enough, Japan's dwindling band of critics of renewable energy assert that the raised renewable targets can only be met with expensive (in Japan) solar and wind, and thus increase energy poverty while undermining the country's competitiveness. But concerns about renewables are not restricted to these stalwart critics. During the first half of 2021, Japan's centre-left media – such as the *Asahi Newspaper* – began to emphasize the pecuniary and environmental costs of renewables. Their attention was directed particularly at the utility-scale solar that would presumably comprise the bulk of renewable deployments up to 2030 (since offshore wind is as yet a nascent industry). Indeed, on July 18 Japan's trusted national broadcaster NHK released a survey that revealed roughly 10% of Japan's 500 kW+ solar arrays were in areas of significant landslide risk.[12] The NHK's work increased the spotlight on a large risk-governance gap, where lax rules leave local communities vulnerable to worsened disaster risks in the name of greening. Attention to this kind of issue has also mushroomed because local governments have been increasingly compelled to implement lo-

11) Megan Seibert and William Rees, "Through the Eye of a Needle: An Eco-Heterodox Perspective on the Renewable Energy Transition," *Energies*, 14 (15), July 26, 2021: https://www.mdpi.com/1996-1073/14/15/4508/htm

12) See (in Japanese) "Research on siting of solar projects: Over 1,100 areas confront landslide risks," NHK News, July 18, 2021: https://www 3 .nhk.or.jp/news/html/20210718/k10013145161000.html

cal ordinances, as residents band together and oppose projects they deem to unduly impact local environmental amenities.[13)]

These issues are by no means peculiar to Japan. Bloomberg New Energy Finance has warned that pushback against renewable projects could see Germany's spare power capacity plunge to 3% by 2023 (due to the impending nuclear shutdown in 2022) from 26% before the pandemic. That level of capacity means blackouts during peaks in winter and summer, plus higher power prices for emergency purchases. And German power prices are already highest in the EU. Bloomberg points out that:

> "For a long time, Germany showed the world how renewable energy could be added to make up a substantial share of the power mix. Now, the Norwegian utility Statkraft SF says it takes twice as long to build a wind park in Germany compared with the U.S. Complaints from locals, a lack of space, stricter environmental standards and a longer permitting process are just some of the reasons growth is slowing."[14)]

Added to the Japanese and German cases, Switzerland also presents a challenge. The Swiss government plans to shut down the country's 3 nuclear reactors over the next decade, eliminating approximately one-third of power generation capacity. But variable renewable energy seems inadequate to make up for nuclear, as in 2020 "Switzerland produced just 311 kWh of energy per resident from solar and wind power, according to the Swiss Energy Foundation, a renewable energy think-tank. By comparison, Denmark produced 3,027 kWh, Germany 2,232 kWh and the UK 1,304 kWh." Moreover, building just one large-scale turbine project – the Windpark Gotthardpass that went on-line in October of 2020 – took an astonishing 18 years of negotiations with local communities.[15)]

Moreover, related debate on the Japanese energy draft's details warn about the transmission, storage and other system costs of solar and other intermittent renewables, including the need for back-up by thermal power. The draft plan and related work has yet to calculate

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13) One of the best available summaries of these issues is found (in Japanese) in Kohno Hiroko, "Solar panels and landslides: moving towards solutions," *Toyo Keizai Online*, July 10, 2021: https://toyokeizai.net/articles/-/440093

14) Vanessa Dezem, "Germany Flirts With Power Crunch in Nuclear and Coal Exit," *Bloomberg News*, August 22, 2021: https://www.bloomberg.com/news/articles/2021-08-22/germany-flirts-with-power-crunch-in-nuclear-and-coal-exit

15) See Sam Jones, "Alpine nimbyism freezes Swiss green energy dreams," *Financial Times*, July 5, 2021: https://www.ft.com/content/062ae877-66c8-4782-8838-3a57b3873a1b

these costs in specific terms for Japan. But they are likely to be significant. Infrastructure projects tend to be costly in Japan, and unlike the EU countries Japan lacks the international power-trading that helps balance intermittency.

Nuclear

The decision to maintain the aim of securing about 20% nuclear in the 2030 power mix also satisfied no one. Since the 3-11 nuclear and natural disaster at Fukushima, Japanese public opinion has generally remained cool towards restarting extant nuclear capacity, let alone building more. So advocates of 100% renewables fought to have nuclear eliminated from the 2030 mix, whereas advocates of keeping or increasing nuclear were handicapped by memories of 3-11 coupled with continuing safety and other slip-ups by the industry.

Critics of nuclear power largely base their case on costs and public opinion. They argue that costs have increased with the expanding burden of safety measures, the legacy of 3-11, and the difficulties of decommissioning. These facts are undeniable, as is the stubbornly negative data on public opinion. Critics also emphasize a narrative that nuclear has no future, drawing heavily on debates from within the EU.

In formulating the current draft, the anti-nuclear position was bolstered by several factors. Most importantly, the impending general election and PM Suga's abysmal rankings in the polls put a premium on political risk reduction. Another is an increasing split within the governing Liberal Democrat Party (LDP) on nuclear, with the MoE Minister Koizumi Junichiro openly advocating its reduction in alliance with other LDPers and the LDP coalition Komei Party. These factors worked together to enable the anti-nuclear advocates to secure removal from this draft of any commitments to new nuclear construction. It remains to be seen if this and other wording is changed after the election.

Advocates of nuclear power also base their case on costs, in addition to the imperative of decarbonization. They concede that costs have increased, but also note that Japan's recent permitting of over 40-year lifetimes for extant plant implies reduced costs over their extended lifecycles. They also highlight nuclear's provision of baseload power to complement intermittent wind and solar, indicating that their perspective has evolved considerably from a decade ago when they derided renewables as marginal. In addition, they note that the reassessment of nuclear costs still keeps the technology cheaper than most fossil in the present and foreseeable future. And they emphasize that restarting Japan's roughly 30 viable reactors is the fastest and cheapest way to secure significant cuts in greenhouse gas.

Yet observers point out that without accelerated progress on reactor restarts, Japan seems unlikely to reach the draft plan's 20-22% target for 2030. They also underscore a disturbing lack of investment in training new nuclear engineers and other human resources, critical in a demographic context where lumpy retirements are impending.

Interestingly, potentially one of the most important interventions in Japan's public debate on nuclear came on June 28 from International Energy Agency (IEA) Executive Director Fatih Birol. Birol noted in a Japanese article that Japan's topographic and other challenges essentially required that nuclear restarts and new build complement renewables and efficiency. Birol argued – in English on the IEA website – that "if Japan relied on solar PV and batteries instead, an additional land area equivalent to 12 times the entire Tokyo metropolitan region would need to be covered by solar panels, and storage capacity equivalent to 40 times the world's current largest battery project would need to be built." [16)]

Birol is one of the world's most respected and pragmatic voices on the imperative of accelerated decarbonization and the enormous structural challenges it represents. He is also adamant that all decarbonizing technologies (existing and under development) are essential, a sharp contrast to advocacy coalitions that emphasize preferred technologies – such as solar and wind renewable energy – at the expense of nuclear power, hydropower, carbon capture, and other technologies. Birol has repeatedly insisted that empirical reality must precede idealism.

One indicator that Birol's argument vis-à-vis Japan is persuasive comes from Japan's nearest neighbour, South Korea. South Koreans elected current President Moon Jae-in (Democratic Party) on May 10, 2017, among whose major policy planks were eliminating the role of nuclear energy. But more recently, the Moon Administration's stance on nuclear has changed considerably, and for many of the same reasons that Birol highlights in the Japanese context. Japan *Nikkei Asia* newspaper summarized these facts in a September 2, 2021 article on Moon's abrupt shifts on nuclear power:

> "Moon won the presidency in 2017 in part by campaigning against nuclear power. Once in office, Moon said he would scrap plans to build nuclear plants and forbid aging fa-

16) Fatih Birol, "Japan will have to tread a unique pathway to net zero, but it can get there through innovation and investment," International Energy Agency, June 28, 2021: https://www.iea.org/commentaries/japan-will-have-to-tread-a-unique-pathway-to-net-zero-but-it-can-get-there-through-innovation-and-investment

cilities from prolonging operation.

But he backed away from those declarations after experts argued against the planned cancellations of plant projects already under construction. The administration also restarted plants that were suspended for inspections after businesses and consumers complained of tight power supplies and rate hikes.

South Korea's nuclear plants operated at 67% of capacity in 2018 from over 80% prior to Moon's inauguration in 2017. But the figure returned to 75% as of 2020.

Driving the government's support for SMR research is the stated goal of attaining net-zero greenhouse gas emissions by mid-century.

'We will have to make nuclear power a key source of energy for the next 60 years,' Kim said in a parliamentary debate in June.

Nuclear power accounted for 18.2% of South Korea's energy mix last year, the third-largest category after liquefied natural gas at 32.3% and coal at 28.1%. Megasolar farms are unworkable because South Korea contains little flatland."[17]

Thermal

Among environmental and renewable advocacy coalitions, Japan's ambition to reduce thermal to 41% of the power mix was rapidly declared inadequate in light of accelerating climate change. Certainly there is no denying that, in light of ongoing climate impacts and disturbing revelations on the proximity of various climate tipping points. On the other hand, Japan's thermal targets have also been called into question by the challenges confronting the renewable and nuclear keys to decarbonization.

Japan's aim of reducing coal to 19% from the current 32% of the mix has received faint applause. North American and European/UK coal power is in steep decline, often to single digits, and the perception is that Japan should be in a similar position. Yet Japan's coal fleet is younger than its counterparts among the G7, and it lacks the continental power-trading or cheap natural gas that have enabled the EU and the US to drive a lot of coal from their power mixes. Indeed, the METI experts insist that reducing coal to 19% of Japan's power mix was the limit of the possible, in light of costs, reliability, energy security, and other pertinent aspects.

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17) See Kotaro Hosokawa, "Small is beautiful in South Korea's pivot back to nuclear power," *Nikkei Asia*, September 2, 2021: https://asia.nikkei.com/Business/Energy/Small-is-beautiful-in-South-Korea-s-pivot-back-to-nuclear-power

The aim of nearly halving the role of LNG from 37% currently to 20% by 2030 mainly caught the attention of experts concerned about the signaling effects. They are concerned that LNG (and to some extent coal) exporters might take the numbers seriously and be incentivized to reduce their reliance on Japan in favour of other consuming countries. It is worried that the fallout could be reduced energy security and higher prices.

Interestingly, some of Japan's most ambitious renewable scenarios actually rely on the power mix being roughly half of LNG in 2030 in order to chase out coal and nuclear. Those scenarios are perhaps the most telling evidence that – at least in energy – there is a limit on the number of big things that can be done in a decade. As we have seen earlier, Japan lacks the cross-border power trading, ample usable land, and other low-cost endowments that advantage its counterparts among the advanced countries.

In short, Japan's draft energy plan is inadequate for actually achieving the decarbonization targets while maintaining economic vitality, environmental justice, and other amenities. In the face of constrained material, fiscal, human and other resources – not to mention time – some compromises seem imperative. But those compromises should not include sacrificing the decarbonization goals.

The Critical Mineral Challenge

We have seen that Japan's rollout of Society 5.0 is well-funded and proceeds via inclusive governance. Japan's energy policy update is less impressive, but does attempt to shift towards greater sustainability and decarbonization. However, one prominent issue that Japan's digital and energy policy regimes overlook is the role of copper, cobalt, rare earths and other critical minerals required to integrate cyber and physical space and build renewables, electric cars, and stationary battery storage. All digital and renewable technologies require significant volumes of critical minerals in order to achieve high levels of functionality. Similarly, the digital modernization of physical infrastructures in energy, health, sanitation, and other areas also implies extensive use of critical minerals, in contrast to conventional networks.

Recent European work on the material-intensiveness of digital transformation and renewables makes this clear. The Green Europe Foundation started work on these issues in April of 2021 because it was concerned about the demand for critical minerals implied by European Union (EU) planning. They write:

> "According to the European Commission, by 2030, the European Union (EU) will need up to 18 times more lithium and 5 times more cobalt than its total current consumption, to cover electric car batteries and energy storage alone. By 2050, this is forecast to increase to almost 60 times more lithium and 15 times more cobalt.
>
> Alongside the energy transition, the digital transition is a priority for the EU. It also relies on metals. Many digital innovations enhance our quality of life. Teleworking and videoconferencing have proven particularly useful during the coronavirus pandemic. Sensors, data, and algorithms allow a more sustainable use of resources, including energy and materials. But, in turn, all digital technologies require energy and materials. Despite the ethereal metaphor of 'the cloud,' the data economy has a heavy material footprint, which includes a wide array of metals. Gains in the energy and material efficiency of devices and networks are outpaced by the exponential growth of data, which doubles every two to three years.
>
> The cleantech and digital sectors are competing for the same metals. European demand for rare earths, which are used in electric cars and wind turbines but also in digital devices, could rise tenfold by 2050."[18)]

Though the EU population of 446 million is large, it is only about 6 % of the global population of well over 7 billion people. That means the EU demand for critical minerals would potentially exhaust global supplies unless major trade-offs were made in digital and decarbonization.

The best overview of the energy and mobility aspects of these issues is provided by the May 5, 2021 International Energy Agency (IEA) report on *The Role of Critical Minerals in Clean Energy Transitions* (hereafter, *Critical Minerals*).[19)] *Critical Minerals* was produced in tandem with many other increasingly worrisome studies on mineral demand for digital technology and decarbonization. The report follows a decade of EU-funded scoping and other research that assess global demand across power, mobility, communications, health tech, military, space, and other categories. To quote an editorial in the April, 2021 edition of the academic journal *Materials*, "The indisputable conclusion after about 10 years of finalized

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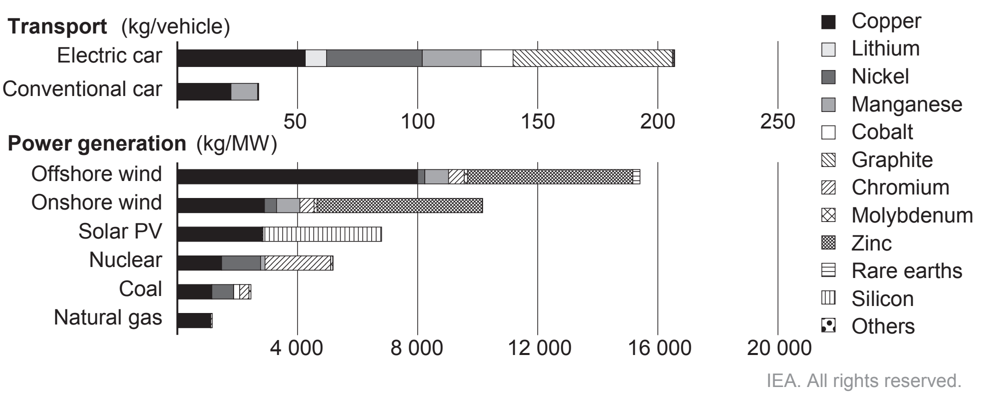
18) See "Metals for a Green and Digital Europe," Green Europe Foundation, April 21, 2021: https://www.wetenschappelijkbureaugroenlinks.nl/metals-for-europe

19) *The Role of Critical Minerals in Clean Energy Transitions*, International Renewable Energy Agency, May 2021 is accessible at the following URL: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

CRM [critical raw materials] projects research is that the most advanced technologies required for the green and digital transition will lead to a drastic increase in demand."[20)]

Detailed quantification of this material-intensity in electrified transport – a core goal of Japan's Society 5.0 and energy strategy – is seen in figure 1, which compares the critical mineral density for electric vehicles and clean power generation. The top section ("transport") in the figure shows that an electric vehicle is dramatically more material-intensive than a conventional car. Electrifyying the vehicle means it will not directly require gasoline or diesel fuel. But in place of those fossil fuels, electrification requires much more copper per vehicle, but also significant quantities of lithium, nickel, cobalt, graphite, and rare earths. Overall, an electric vehicle is 5 to 6 times as mineral-intensive than a conventional vehicle.

Similarly, figure 1 demonstrates that clean power generation technologies – another core goal of Society 5.0 and the energy strategy – have significantly higher material-density, expressed as kilogrammes/megawatt (kg/MW) of generation capacity. Carbon-intensive natural gas and coal-fired generation require only moderate amounts of copper, nickel and other materials for the pipes and other infrastructure that compose their plant. By compari-



Notes: kg = kilogramme; MW = megawatt. Steel and aluminium not included. See Chapter 1 and Annex for details on the assumptions and methodologies.
Source: IEA, 2021[21)]

Figure 1 Minerals used in selected clean energy technologies

20) See Girtan, Mihaela, et al. "The Critical Raw Materials Issue between Scarcity, Supply Risk, and Unique Properties," *Materials*, April, 2021: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8067847/

21) *The Role of Critical Minerals in Clean Energy Transitions*, International Renewable Energy Agency, May 2021: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

son, a nuclear plant has, per MW, more than double the material footprint of coal and triple that of natural gas, with an especially heavy reliance on chromium. But solar and wind generation have even heavier reliance on such base metals as copper in addition to rare earths for offshore wind and silicon for solar. Moreover, the aggregate per-MW amount of critical minerals balloons from a couple of metric tons for a natural gas plant to nearly 16 tons for offshore wind. Since wind and solar have considerably lower capacity factors – meaning percent of actual power generation versus rated generation capacity – than fossil-fuel and nuclear plant, their total volume of critical minerals required to produce a given amount of power is even higher than expressed in the figure.

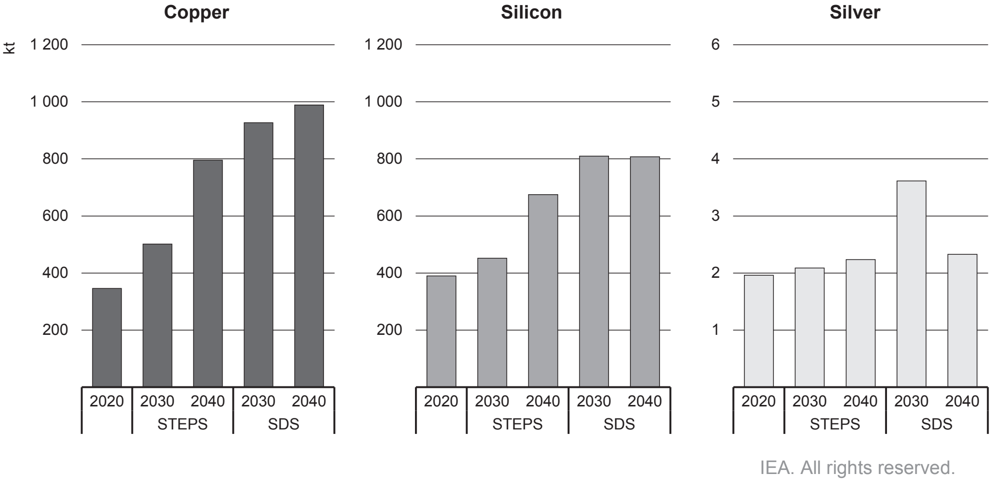
Additionally, the IEA data suggest that distributed energy systems may need rethinking. Japan's Society 5.0 vision and energy strategy are in part predicated on smart, distributed energy networks as the core infrastructure of smart cities. But the more distributed the power generation the higher the material-intensity: "Distributed solar PV systems tend to have string inverters or microinverters, requiring about 40% more copper than utility-scale projects, which typically use central inverters. Other mineral intensities are similar between utility-scale and distributed applications."[22)]

This above point is of particular relevance to Japan. Because of the pushback against large-scale solar, many of Japan's renewable energy advocates emphasize distributed solar generation. But there is as yet no debate on the increased material-intensity of this distributed strategy.

Figure 2 offers more data on key mineral demand for solar power. It enumerates the 2020 demand, in kilotons (kt), for copper, silicon and silver in global solar deployments. The figure then assesses the likely increased demand according to two scenarios: the Stated Policies Scenario (STEPS), which currently implies global warming of over 3 degrees Celsuis, and Sustainable Development Scenario (SDS), which aims to limits global warming to well below 2 degrees Celsius, and ideally to 1.5 degrees. STEPS and SDS are used throughout the report. The SDS and STEPS scenarios for solar vary greatly for the years 2030 and 2040. Copper demand more than doubles in SDS 2040, compared to 2020. Silicon, in turn, doubles, by SDS 2040, but then levels off through technological change and recycling. Silver in fact declines in the SDS scenario for 2040 compared to a large increase in SDS 2030.

The IEA concludes that the aggregate demand for the 30-odd critical minerals used

22) See p. 56, *The Role of Critical Minerals in Clean Energy Transitions*, International Renewable Energy Agency, May 2021: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions



Note: kt = thousand tonnes.
Source: IEA, 2021 [23)]

Figure 2　Demand for copper, silicon and silver for solar PV by scenario

in clean-energy technologies may increase by six-fold or more. Within that increase, depending on the 11 technological pathways used by *Critical Minerals*, individual materials confront varying demand profiles. For example, in utility scale storage under the SDS, between 2020 and 2040 nickel demand is projected to grow 140 times, cobalt by 70 times, and manganese by 58 times.

In theory, the prospect of such massive demand increases should see market mechanisms induce much more investment in critical-mineral mining, greater efficiency, and substitution. The IEA experts do not deny that markets play a powerful role, but they caution that they are “typically accompanied by price volatility, considerable times lags or some loss of performance or efficiency.” [24)] Later in this paper, we see that these developments are indeed occurring.

The overall message is that critical mineral constraints could increase the cost of Society 5.0 digitalization and decarbonization while also slowing its pace and reducing its depth in difficult areas.

23) *The Role of Critical Minerals in Clean Energy Transitions*, International Renewable Energy Agency, May 2021: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

24) See p. 117, *The Role of Critical Minerals in Clean Energy Transitions*, International Renewable Energy Agency, May 2021: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Mining Lead Times

Increased investment in mining critical minerals is not simply a matter of throwing more money at producers. One major problem in this respect is the very long lead times for mining projects. *Critical Minerals* reveals that, between 2010-2019, the global average lead time – from discovery to production – for the world's top 35 critical minerals mining projects was well over 15 years. The fastest average projects the IEA team identify in their report was 4 years for mining lithium in Australia. But finding and developing nickel and copper mines take well over a decade, and often closer to 2 decades. Even halving these lead times would do little to address the demand gaps opening up in the present.

The IEA's analyses of projects in the pipeline also suggests that this concentration is very unlikely to change much, at least over the next 5 to 10 years, even though many of the production sites have poor performance on governance, human rights, and other indicators. That means the complication of long lead times is compounded by ESG challenges. To be sure, the severe human rights concerns surrounding cobalt – 70% of which is mined in the Democratic Republic of the Congo – have led to efforts to substitute for it. But these efforts have not been successful in the aggregate. The IEA therefore anticipates demand for cobalt to increase 21 times between 2020 and 2040, under an SDS scenario.

The IEA also warns that processing of critical minerals is also geographically concentrated, especially in China, something we shall examine in detail in a subsequent section. The very high volatility of demand, the environmental costs of refining, and other drivers underlie this concentration. In short, China is better able to bear environmental costs and build robust policies that dampen the disincentive effects of volatility. Among countries dependent on China, especially the US and the EU, there is significant talk of more domestic mining and relocating processing and related supply chains. But the evidence suggests it is a lot easier to talk about doing those things than actually get them done. Among the many hurdles, business incentives are not adequate. And most environmentalists oppose reshoring critical mineral mining and refining, even as they insist on the most material-intensive pathways for decarbonization.

Declining Ore Grades

An additional matter of concern is declining ore grades and their impact on mining's pecuniary and environmental costs. The IEA and other data show that average ore grades declined significantly over the period, raising the energy intensity measured in gigajoules (GJ) of energy use per Mt of copper. A similar trend is event in other materials.

Declining ore grades in such critical minerals as copper and nickel leads to higher tailing and waste rock for a unit volume of ore extraction. The volumes of material are immense, as is their impact on communities. One paper prepared for the 2020 Global Tailings Review reported that waste rock volumes in 2016 totaled 72 billion tonnes and mine tailings 8.85 billion tonnes. Contrast those numbers with the fact that the projected 2021/22 total global production of cereal grains is 2.287 billion tonnes.[25)] In addition, the footprint of copper mining is startling, as it represents 10.8 billion tonnes of waste rock and 4.1 billion tonnes of mine tailings. The latter figure is 46% of the global total of mine tailings, which include significant quantities of heavy metals and other health hazards.[26)]

An additional matter of grave concern is that many critical minerals – particularly copper and lithium – are mined in South America and other areas with high water stress. Climate impacts are generally worsening water stress in these areas, as was highlighted in the August 7, 2021 report of the IPCC report on Climate Change 2021.[27)] But mining the minerals requires large volumes of water that it often pollutes, rendering it unfit for human consumption and agriculture. In consequence, increased mining risks exacerbating water stress in the absence of robust and perhaps costly countermeasures such as water recycling and desalinization.

Recycling and Substitution

Most work on energy transitions looks to recycling in "circular economy" strategies as one key means to reduce the need for new mining of copper, cobalt, rare earths and other metals and minerals. Substitution strategies complement this approach, by seeking new materials to replace the role of supply-constrained minerals used in batteries, solar panels, and

25) See "IGC sees record global grain production in 2021/22 season," Reuters, March 25, 2021: https://www.reuters.com/article/grains-igc-idUSL1N2LN1OL

26) See Baker, Elaine, et al, "Mine Tailings Facilities: Overview and Industry Trends," September, 2020: https://globaltailingsreview.org/wp-content/uploads/2020/09/Ch-II-Mine-Tailings-Facilities_Overview-and-Industry-Trends.pdf

27) See p. 33 of "Climate Change 2021: The Physical Science Basis Summary for Policymakers," International Panel on Climate Change, August, 2021: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

the like. For example, recycling and substitution are key elements of Japan's approach, with Panasonic's 2170 lithium-ion batteries for Tesla reducing the share of problematic cobalt with increased nickel.

But *Critical Minerals* does not expect recycling to become a significant source of supply for at least a couple of decades. Its modeling shows that the 2020 stock of spent batteries is negligible, meaning their recycling cannot meet any of the escalating demand for battery storage. By 2030, recycled battery materials are at best a source of 1% of new materials demand, and even as late as 2040, recycling provides only about 8% of demand.

These results confirm earlier concerns about over-reliance on the circular economy. The IEA's findings on this point are consistent with other recent empirical work, such as the German Fraunhofer Institute's November 2020 study on "The Promise and Limits of Urban Mining."[28] Another example is the December 10, 2020 survey from the Hague Centre for Strategic Studies (HCSS). The HCSS released a very detailed, book-length report on "Securing Critical Materials for Critical Sectors: Policy options for the Netherlands and the European Union," which examined the critical mineral implications of the Dutch and EU commitments to decarbonization. Their broad-based analysis included critical mineral demand for renewable energy (wind, solar, geothermal), energy grid infrastructure, carbon-capture and storage, electric vehicles, and semiconductors. The HCSS warned that recycling and other "circular economy" policies would quite inadequate to address the massive increase in required critical minerals volumes implied by decarbonization. They pointed out one cannot simply recycle critical minerals that are being dug up and processed for use in a massive rollout of energy, EVs, and other systems that will be in use for one or a few decades.

To be sure, *Critical Minerals* does not deny the importance of recycling and substitution. In fact, the report emphasizes recycling and substitution's importance in a broad strategy of investment, innovation, recycling, supply chain resilience and sustainability standards. The report suggests that there is significant room to raise end-of-life recycling rates for many critical minerals. At the same time, achieving these increased rates confronts constraints due to the role of amalgams, which make critical minerals difficult to separate.

The IEA analysis confounds hopes that Society 5.0 digitalization and decarbonization can avoid hard choices by simply fostering the circular economy and harvesting the "urban

28) See some of the data in Luis Tercero Espinoza, et al., "The promise and limits of Urban Mining: Potentials, Trade-Offs and Supporting Factors for the Recovery of Raw Materials from the Anthroposphere," Fraunhofer ISI, November, 2020: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/ccn/2020/Fraunhofer_ISI_Urban_Mining.pdf

mine" of discarded smart phones, appliances, and conventional cars. To take a recent example, Japan recycled about 80,000 tons of mobile phones and other e-waste to get about 2 tons of copper for Olympic medals.[29] But in energy-transition terms, that nationwide project secured only 1/4 of the 8 tons of copper needed for a single MW of offshore wind capacity.

To reiterate, the IEA data show that the global community is only beginning to build a stock of energy-transition infrastructure, including long-distance networks, distributed grids, battery storage, electric vehicles, and offshore turbines. Once that huge stock is in place and portions of it have reached the end of their useful life, then one can expect substantial critical mineral flows from recycling. So while we certainly need to adopt much stronger policies right now on recycling and substitution, we should not expect them to bear ample fruit for decades.

Key Issues with Critical Minerals

The key constraints regarding critical minerals include their relative scarcity, increasing costs, geopolitical risks, and other factors. **Figure 3** summarizes some of the key issues relating to these factors for batteries, wind power and solar generation. These technologies are represented by iconic symbols. As we see, the core critical minerals for each item are in the main dominated by China in terms of supply, processing, components and assembly. Concerning batteries, for example, China is the source of 32% of raw materials (including cobalt, lithium, niobium, magnesium, silicon, and others), but that share rises to 52% for processed materials in cathodes and anodes. And by the assembly phase, China's share is 66%.

Concerning wind power, China dominates raw materials, with a 54% share. This lion's share of the supply chain is maintained throughout processing and components, though assembly of final products is largely (58%) undertaken in the EU.

Solar is even more a China-centred story. It dominates in each category, enjoying 53% of raw material through to an astounding 89% of components and 70% of assembly.

Figure 4 exemplifies the critical-mineral debate underway in the US as the President Joe Biden Administration seeks to make decarbonization via clean energy a core feature of "Build Back Better" from COVD-19. On August 17, 2021, the Biden White House emphasized these ambitions in a special release:

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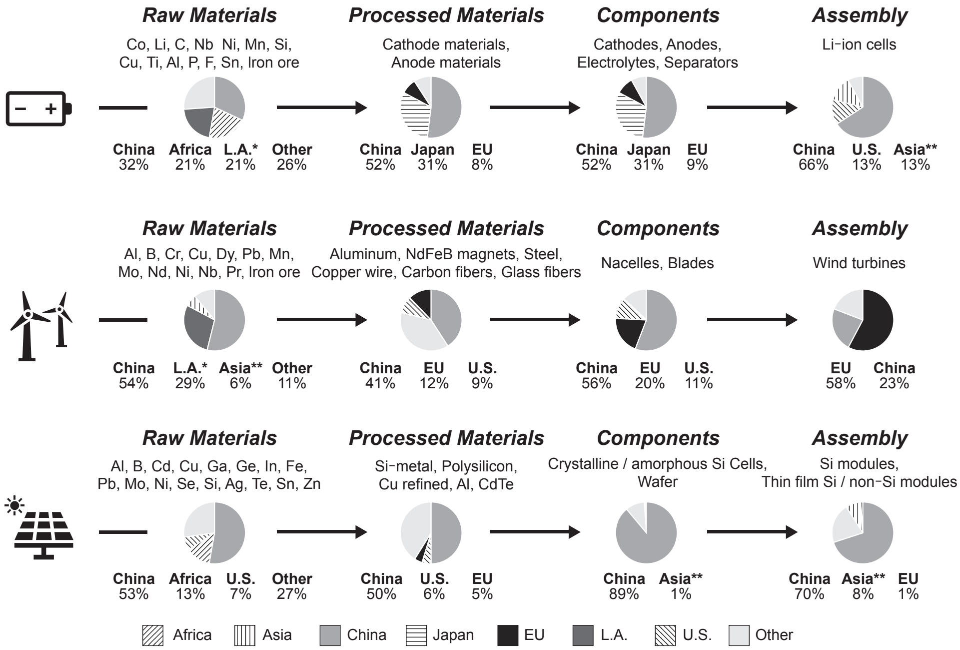
29) On this project, see "Tokyo 2020 Medal Project: Towards an Innovative Future for All," Tokyo 2020: https://olympics.com/tokyo-2020/en/games/medals-project/



Source: Nakano, 2021[30)]

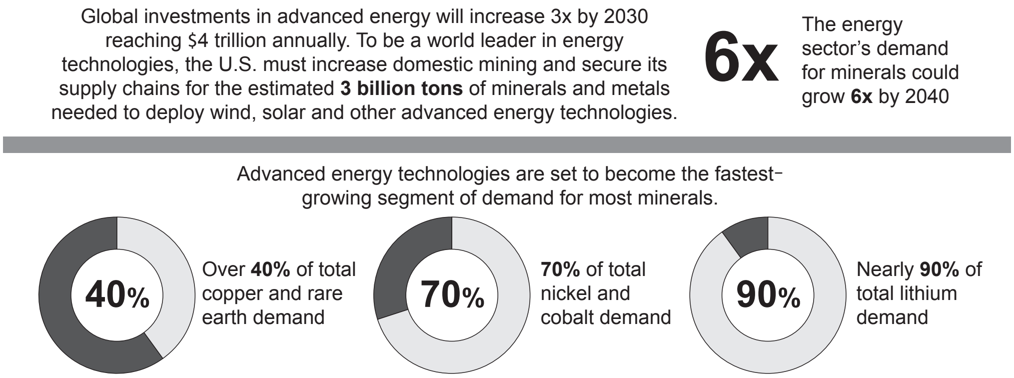
Figure 3 Clean energy technology and critical mineral supply chains

"Solar will play an important role in reaching President Biden's 2035 clean electricity goal – alongside other sources of carbon-pollution free electricity, including onshore and offshore wind, existing power plants retrofitted with carbon capture or green hydrogen, geothermal, hydropower, and nuclear ... To reach a largely decarbonized electricity sector by 2035, solar deployment would need to accelerate to three to four times faster than the current rate by 2030. Large scale decarbonization of the electricity sector could move solar from 3 percent of generation today to over 40 percent by 2035." [31)]

These ambitions imply a massive increase in critical mineral demand, not only because there is such an emphasis on solar but also because it highlights the very rapid deploy-

30) See Jane Nakano, "The Geopolitics of Critical Minerals Supply Chains," Presentation to the USEA, April 27, 2021: https://usea.org/sites/default/files/event-/USEA_April2021_presentation%20Jane%20Nakano.pdf

31) "FACT SHEET: Bipartisan Infrastructure Deal and Build Back Better Agenda Present Bright Future for Solar Power, Good Jobs, and More Affordable Energy," The White House Briefing Room, United States, August 17, 2021: https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/17/fact-sheet-bipartisan-infrastructure-deal-and-build-back-better-agenda-present-bright-future-for-solar-power-good-jobs-and-more-affordable-energy/



Source: Minerals Make Life, 2021[32)]

Figure 4　Mining and critical minerals

ment of distributed solar. We have already seen that distributed solar is especially material-intensive.

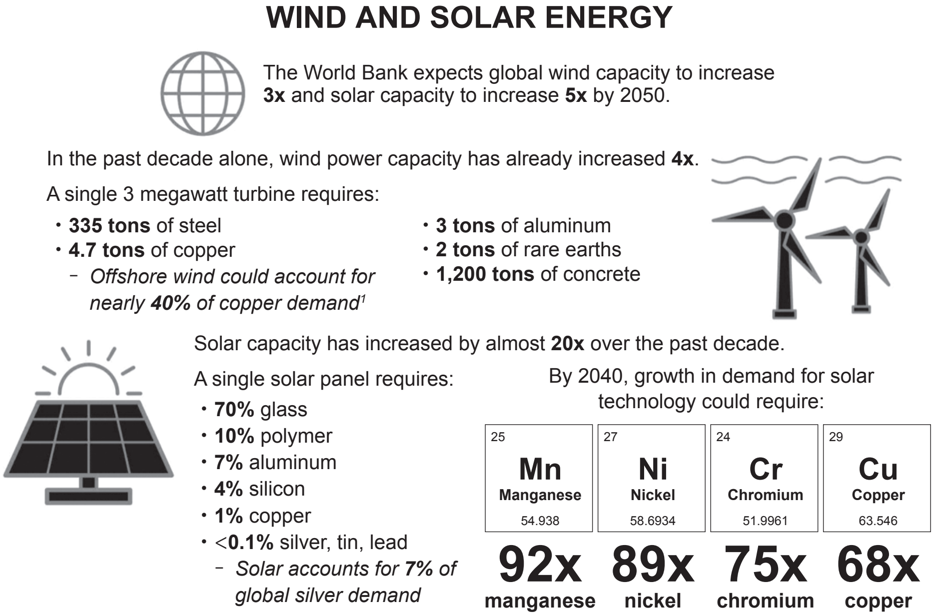
Because China dominates supply chains, as seen in figure 3, the American mining community and other advocates are calling for greater domestic mining and processing. The evidence they use is the rough quantification of critical material demand for achieving even moderate diffusion of batteries, wind, and solar. Using IEA, World Bank, and other reputable evidence, the figure highlights that security of supply requires an increase in domestic mining.

We have already seen earlier, however, that US environmentalists tend to downplay the critical mineral challenges. The general argument is that recycling and substitution will suffice. As a September 3, 2021 summary of the US public debate describes, "[e]nvironmentalists argue the best option is to forgo all mining and gather critical materials instead through electronics recycling."[33)] The lack of attention to material issues is such that a 2021 academic review of 148 peer-reviewed papers on published in English between 2000 and 2018 revealed a "forward flow supply chain" focus on technologies and deployment rather than attention to integrating material constraints.[34)] Yet the IEA and others have already

32) "Our Energy Future Depends on Mining," Minerals Make Life, June 22, 2021: https://mineralsmakelife.org/resources/our-energy-future-depends-on-mining/

33) See Alexandra Gillespie, "Your Next Car May Be Built With Ocean Rocks. Scientists Can't Agree If That's Good," NPR, September 3, 2021: https://www.npr.org/2021/09/03/1031434711/your-next-car-may-be-built-with-ocean-rocks-scientists-cant-agree-if-thats-good

34) Maria A. Franco and Stephan N. Groesser, "A Systematic Literature Review of the Solar Photovoltaic Value Chain for a Circular Economy," *Sustainability*, 2021, 13 (17), August 26, 2021: https://



Source: Minerals Make Life, 2021[35)]

Figure 5 Wind and solar energy material demand

shown that even aggressive recycling will supply only a few percent of demand in a decade or two. That denial of empirical fact is one reason the US mining community has produced these data-rich materials. In figure 5, they drill down on the precise quantities of critical minerals used in wind turbines and solar panels. They are not in the least opposed to renewable energy, but rather seek to show the material implications of a dramatically accelerated rollout. The many multiples of possibly increase demand for manganese, chromium, copper, and other minerals of course assumes that chemistries will not dramatically change. But that assumption seems realistic in light of advocates' emphasis that energy transition can be achieved with already existing technologies.

Figure 6 too builds on World Bank, IEA and other studies concerning the transport sector's demand for critical minerals. The data confirm the IEA *Critical Minerals* report and myriad other studies that have emerged in 2021. As with the material impacts of renewable generation technologies, increases in electric vehicle diffusion from 3 million in 2020 to 70 million in 2040 would result in many multiples of lithium, cobalt and other material demand

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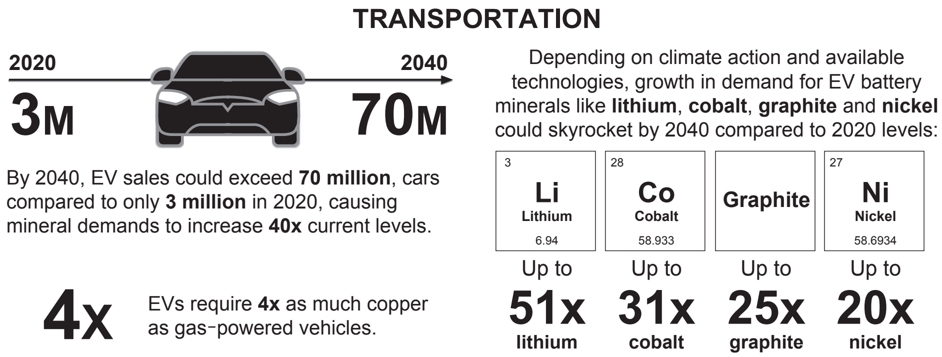
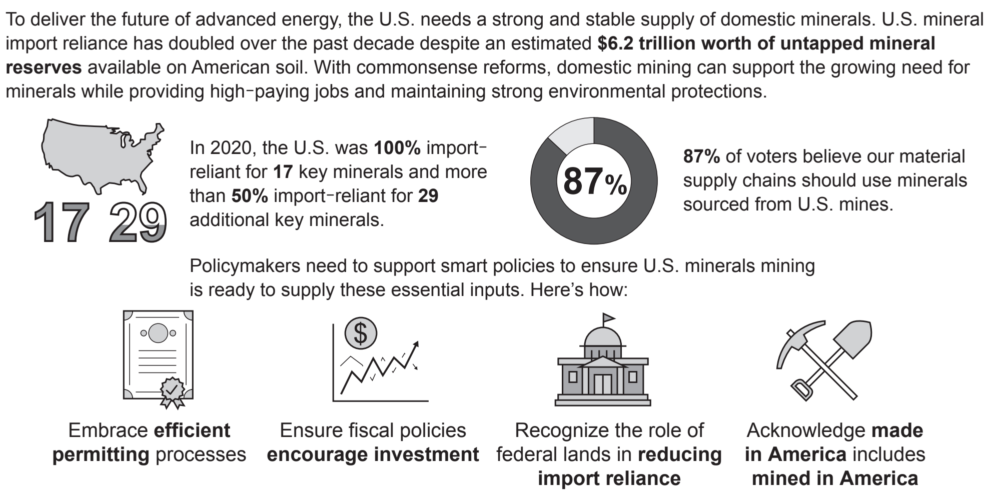
www.mdpi.com/2071-1050/13/17/9615

35) "Our Energy Future Depends on Mining," Minerals Make Life, June 22, 2021: https://mineralsmakelife.org/resources/our-energy-future-depends-on-mining/



Source: Minerals Make Life, 2021[36)]

Figure 6 Critical minerals in transport



Source: Minerals Make Life, 2021[37)]

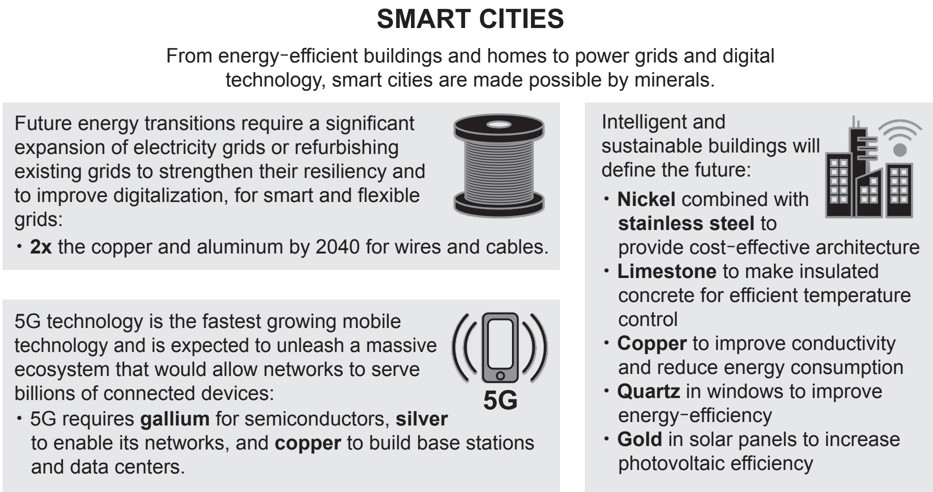
Figure 7 US critical mineral endowments

for transport.

Figure 7 highlights the US mining community's argument that the country has ample reserves of critical minerals, worth an estimate USD 6.2 trillion. They lobby for reforms to tax and regulatory regimes, so as to build a domestic industry that can reduce extreme reli-

36) "Our Energy Future Depends on Mining," Minerals Make Life, June 22, 2021: https://mineralsmakelife.org/resources/our-energy-future-depends-on-mining/

37) "Our Energy Future Depends on Mining," Minerals Make Life, June 22, 2021: https://mineralsmakelife.org/resources/our-energy-future-depends-on-mining/



Source: Minerals Make Life, 2021[38)]

Figure 8 Smart cities and mining

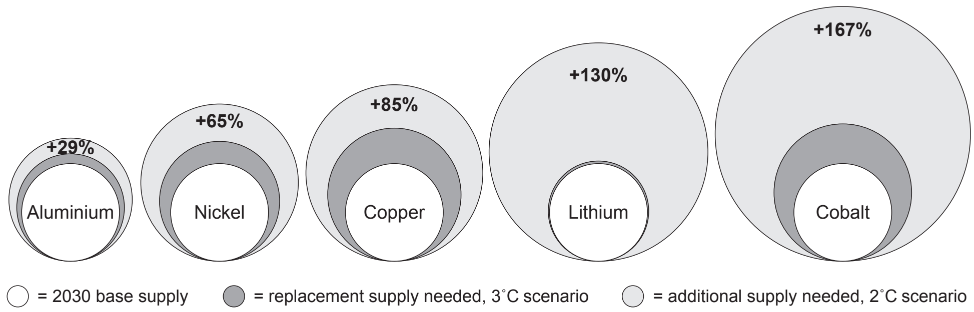
ance on Chinese critical minerals as well as supply the projected massive increases in demand. They also highlight polling data that suggests 87% of the US public desires stronger domestic supply chains.

Figure 8 adds to the argument with a focus on smart city technologies and their critical mineral requirements. These data are generally not addressed in studies that centre on renewable energy, electric vehicles, and stationary batteries. But the evidence increasingly suggests that 5G, data centres, semi-conductors, and other advanced "smart" technologies require prodigious quantities of critical minerals. For example, the "fabrication of high-speed, high-capacity integrated circuits required only 12 minerals in the 1980s but more than 60 by the 2000s. Building a modern cell phone now requires materials containing 75 minerals, comprising elements covering about two thirds of the periodic table."

Is This All Hype?

Even efforts to explore exaggerations in the critical mineral argument run into hurdles. In July of 2021, Wood MacKenzie sought to apprehend the degree of hype in critical mineral "supercycle" debates. Their data – reproduced in figure 9 – show that business as

38) "Our Energy Future Depends on Mining," Minerals Make Life, June 22, 2021: https://mineralsmakelife.org/resources/our-energy-future-depends-on-mining/



Source: Wood Mackenzie, 2021[39)]

Figure 9 The Wood MacKenzie material demand projections

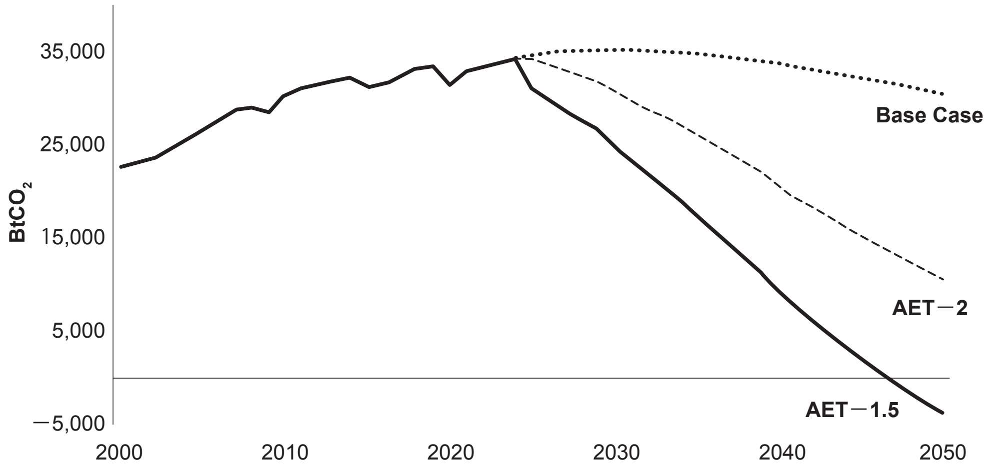
usual has only moderate implications for aluminum and other commodities over the decade to 2030. But efforts to pursue a 2°C warming scenario clearly imply large expansions of demand. The figure shows that Wood MacKenzie forecast significantly increased demand for critical minerals.

Figure 10 portrays the Wood MacKenzie outlook for carbon dioxide reductions out to 2050. Their data show the profound pace of cuts required to reach an Accelerated Energy Transition (AET) that keeps projected warming to 2°C or even. The figure shows that the deep but temporary global reduction in emissions from COVID-19 pales in comparison to the even steeper and permanent cuts required for the AET scenarios.

And how do Wood MacKenzie propose to achieve these cuts? Their AET -1.5 (ie, 1.5°C) is predicated on a USD 50 trillion investment "over the next three decades to electrify infrastructure and engineer out the aspects of modern life that most significantly contribute to carbon emissions." The core technologies of decarbonization are depicted in their data reproduced in figure 11. They calculate the weight, in kilograms per unit or per kilowatt (Kw), for critical minerals used in electric vehicles and charging stations, solar and offshore wind. Their data are roughly consistent with the IEA and other data seen earlier, meaning potentially a huge global increase in demand if decarbonization via these technologies is generalized.

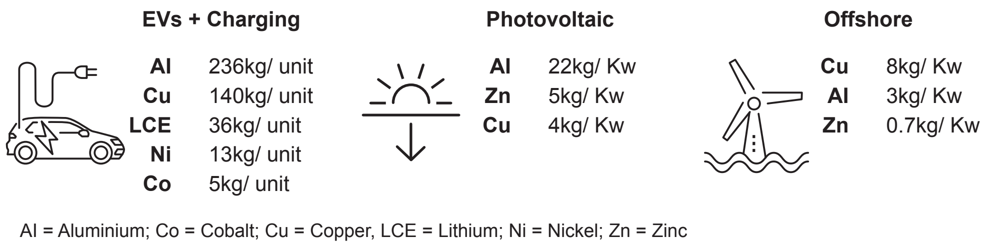
Wood MacKenzie also stress – as shown in figure 12 – that China's role in critical minerals grew from 2000 to 2020 because of the intersection of its own growth and dependence on external supplies. Their assumption is that Chinese dominance will not readily yield, as it

39) "Champagne supercycle: taking the fizz out of the commodity boom," Wood Mackenzie, July 2021: https://www.woodmac.com/horizons/champagne-supercycle-taking-the-fizz-out-of-the-commodity-boom/



Source: Wood Mackenzie, 2021[40)]

Figure 10 The Wood MacKenzie AET scenarios



Source: Wood Mackenzie, 2021[41)]

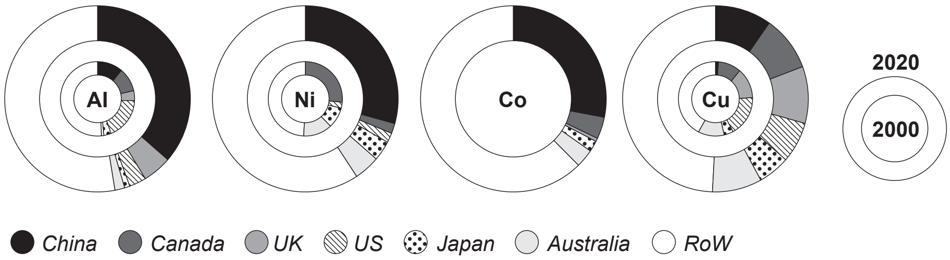
Figure 11 The Wood MacKenzie calculations

is deepening its downstream control over critical minerals. They add that "[w]ith China dominant in its control of energy transition value chains, non-Chinese entities face an ever-diminishing share of any commodity windfall. With greater cash comes greater investment capability, enabling China to realise a strategy of supply security at any cost."

But then the Wood MacKenzie report veers off into speculation about "emerging technologies – such as next-generation electrofuels, polymeric energy storage and low/zero nick-

40) "Champagne supercycle: taking the fizz out of the commodity boom," Wood Mackenzie, July 2021: https://www.woodmac.com/horizons/champagne-supercycle-taking-the-fizz-out-of-the-commodity-boom/

41) "Champagne supercycle: taking the fizz out of the commodity boom," Wood Mackenzie, July 2021: https://www.woodmac.com/horizons/champagne-supercycle-taking-the-fizz-out-of-the-commodity-boom/



Source: Wood Mackenzie, 2021[42)]

Figure 12　China's critical mineral control in comparison, 2000-2020

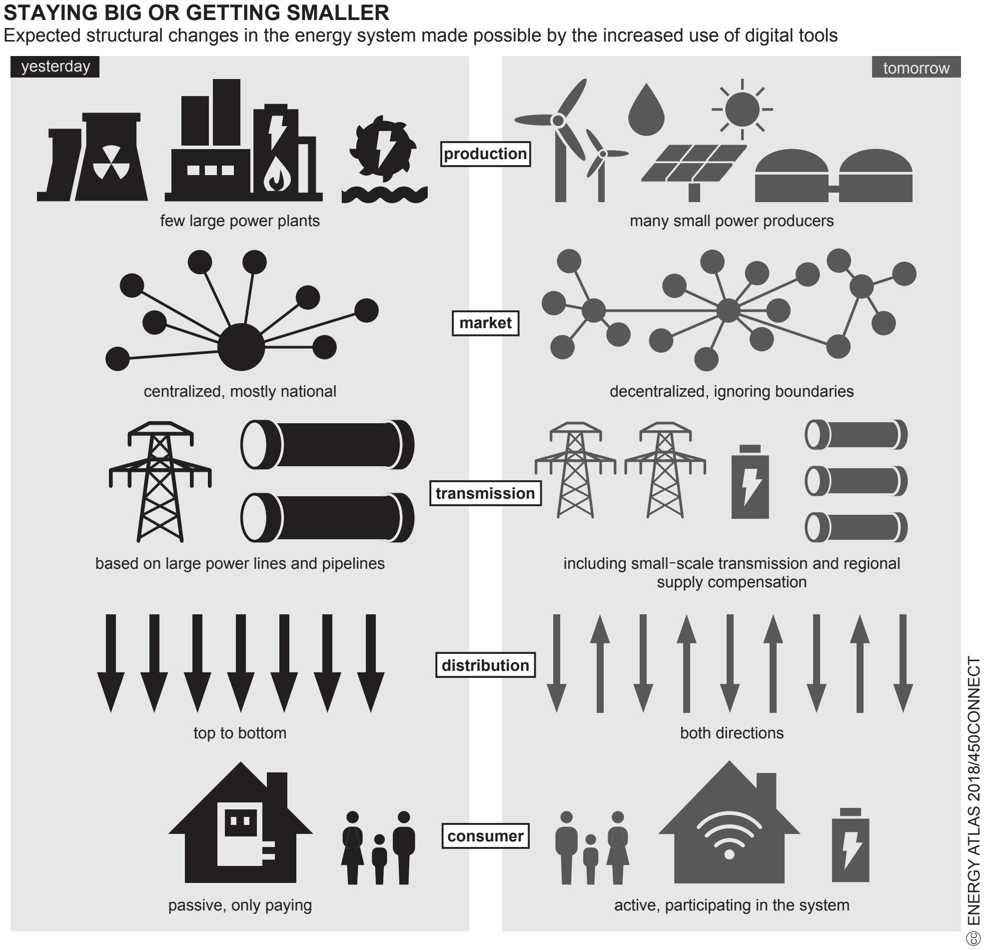
el- and cobalt-free, high-energy-density batteries – that could dramatically alter the clean-energy landscape." They suggest that these technological changes "may push those metals expecting to benefit from the impending supercycle into obscurity." Yet as the IEA and myriad other studies have shown, the trajectory over the past few decades has been a deepening of critical-mineral demand in transport, energy, smart technology, and other areas. That fact suggests the Wood MacKenzie report is unreasonably optimistic.

Mining for the Distributed Future

Indeed, as we have already seen earlier, most scenarios of energy transition rely on the most material-intensive distributed paradigm. We see this in figure 13, which presents one recent summary of the shift from centralized to distributed energy systems. The enormous appeal of the distributed paradigm is that it provides local communities and consumers with a direct role in energy generation, transmission, storage and management. In an world marked by increasing income inequality and political polarization, this democratizing aspect is certainly laudable. But democratic ideals do not trump geological realities and other facts of ongoing energy transitions.

Indeed, the diversity of energy transitions is beginning to become a core theme of advanced work. We see this is in "New Energy Outlook, 2021," by Bloomberg New Energy Finance (BNEF), whose idealized types are separated into green, grey and red scenarios as seen in figure 14. Bloomberg New Energy Finance is one of the world's most respected organizations for work on energy and climate. Their work hitherto has been marked by at best a

42) "Champagne supercycle: taking the fizz out of the commodity boom," Wood Mackenzie, July 2021: https://www.woodmac.com/horizons/champagne-supercycle-taking-the-fizz-out-of-the-commodity-boom/



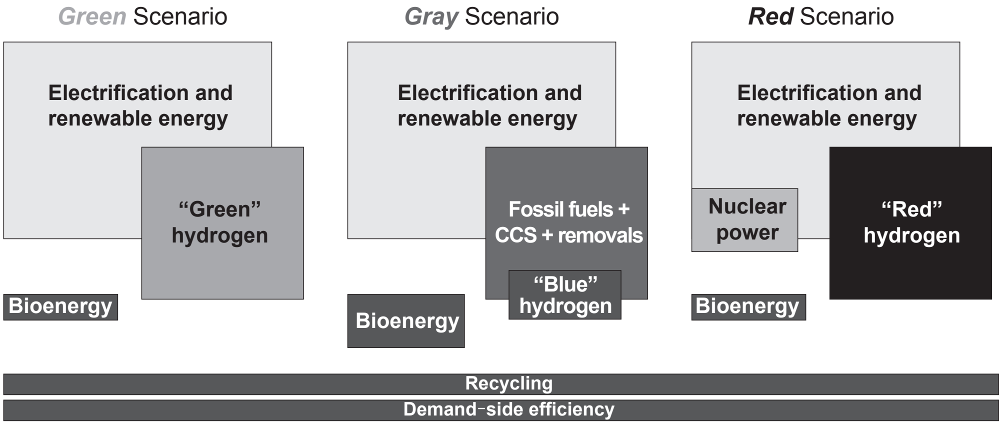
Emmerich, 2021[43)]

Figure 13 Centralized versus distributed power systems

grudging acceptance of nuclear energy, in contrast to a marked enthusiasm for solar and wind. Yet their awareness of the scale of climate and critical mineral challenges, coupled with stubborn facts on the ground, has driven them to develop diverse scenarios. Notably, the red scenario includes a massive commitment to nuclear energy.

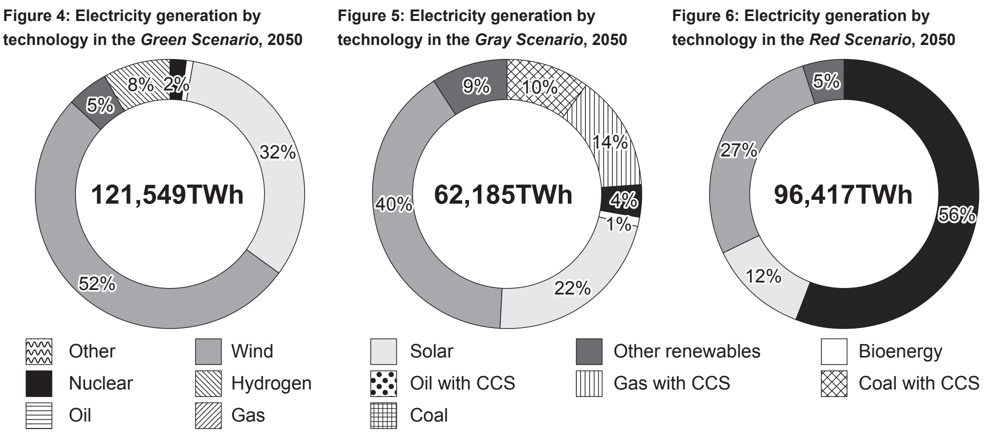
Figure 15 affords more detail on the BNEF approach, which the organization plans to apply on a country-level basis from 2021. They acknowledge that these are idealized scenari-

43) Philip Emmerich, "How smart grid technologies are disrupting the energy sector," Energy Transition, July 22, 2021: https://energytransition.org/2021/07/how-smart-grid-technologies-are-disrupting-the-energy-sector/



BNEF, 2021[44]

Figure 14 The green, red and gray scenarios



BNEF, 2021[45]

Figure 15 Electricity generation in the green, red, and gray scenarios

os, and almost certainly will not be evident in any particular country's actual 2050 power mix. What is important is that they recognize that decarbonization is almost certainly going to involve a diverse portfolio of technologies.

The explicit recognition that nuclear power is likely to play a larger role than many

44) "New Energy Outlook, 2021," Bloomberg New Energy Finance, July 2021: https://about.bnef.com/new-energy-outlook/

45) "New Energy Outlook, 2021," Bloomberg New Energy Finance, July 2021: https://about.bnef.com/new-energy-outlook/

believe is, ironically, demonstrated by China. Though the US at present remains the world's largest nuclear producer, with half of its low-carbon power being generated by nuclear, China is rapidly gaining ground. Indeed, Wood Mackenzie Asia Pacific Head of Markets and Transitions, Prakash Sharma made it clear that "[b]y 2050, the country (China) will account for nearly half of global operational nuclear capacity which is expected to rise 88% from 2020 to hit 685GW under a 2-degree Celsius scenario." This assertion belies many concerns that nuclear is unsafe, expensive, and has no waste disposal. In point of fact, "an increasing number of stakeholders and institutions have reiterated nuclear as a safe, friendly and green energy resource for the environment." Because of that, Wood Mackenzie's position is that "small modular nuclear reactors could play a crucial role in meeting Paris Agreement targets." [46)]

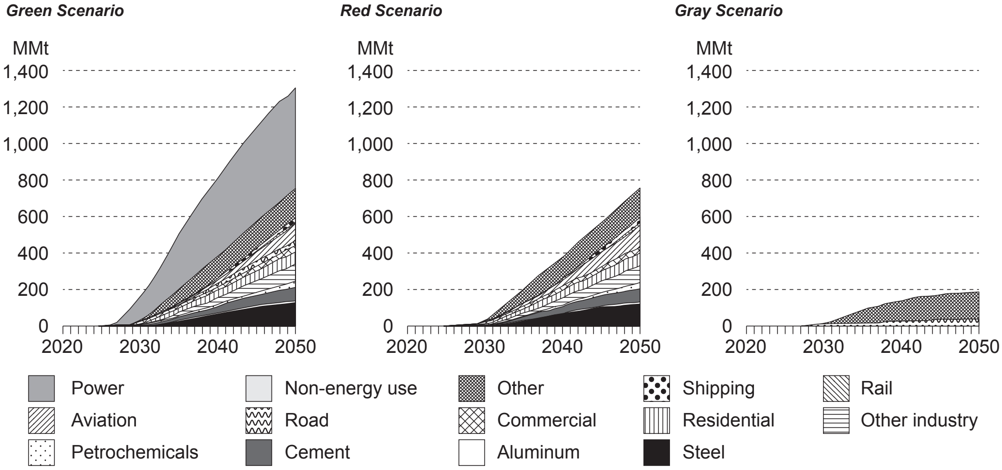
Indeed, even Canada's Green Party membership is split on the role of nuclear. A policy vote held during the summer of 2021 determined that 39.6% of party members opted to maintain federal government funding for nuclear energy research whereas 37.3% voted to end it and 23% opted not to take a position.[47)]

The diversity of the BNEF scenarios is also seen in **figure 16**, which depicts the volumes of hydrogen used in decarbonization. The green scenario clearly relies on it extensively, to balance power systems and otherwise serve as an input in myriad processes. The grey scenario relies on very small amounts, because it is fossil-fuel intensive. The red scenario differs from its green counterpart in requiring almost no hydrogen in power. That aspect implies a lower critical mineral footprint, as producing green hydrogen requires massive investments in renewable capacity coupled with a lot of catalysts.

The realism of the red strategy is in part reflected in **figure 17**. This data is also from BNEF, but focused on demand for battery metals. The BNEF assessment tells us that between 2021 and 2030 (a short period in which little substitution can be expected) copper demand in batteries is likely to rise by 550%, aluminum by 570%, and so on. That demand would be directly competing with the demand for critical minerals in solar, wind, and other renewable generation. Overall, the critical mineral demand in this sector alone rises from under 2 million metric tonnes in 2020 to just below 14 million metric tonnes in 2030. That vol-

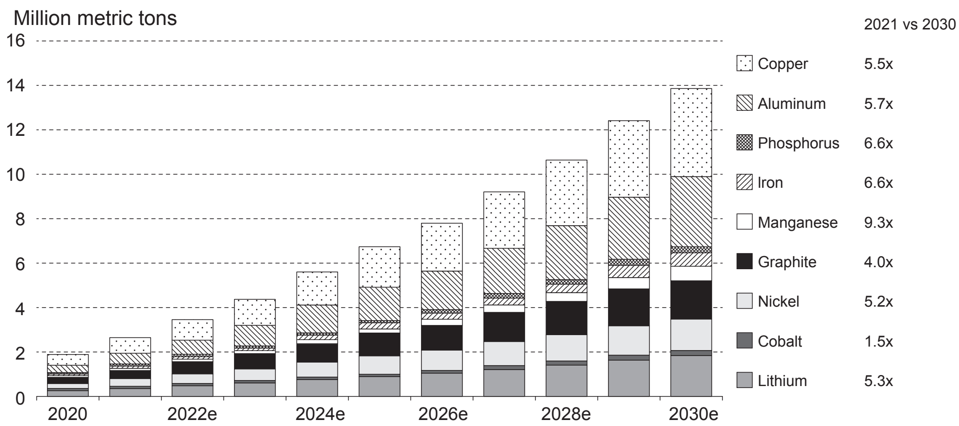
46) "China to lead small modular reactor market by 2050 – report," *Power Engineering*, August 30, 2021: https://www.powerengineeringint.com/nuclear/china-to-lead-small-modular-reactor-market-by-2050-report/

47) Jacques Poitras, "Greens divided over taxpayer funding for small nuclear reactors," *CBC News*, August 24, 2021: https://www.cbc.ca/news/canada/new-brunswick/green-party-nuclear-vote-1.6150577



BNEF, 2021[48)]

Figure 16　Hydrogen in the green, red and gray scenarios



Source: BloombergNEF. Note: Metals demand occurs at mine mouth, one-year before battery demand. All metals expressed in metric tons of contained metal, except lithium, which is in lithium carbonate equivalent (LCE).

Green Car Congress, 2021[49)]

Figure 17　Critical mineral demand in batteries

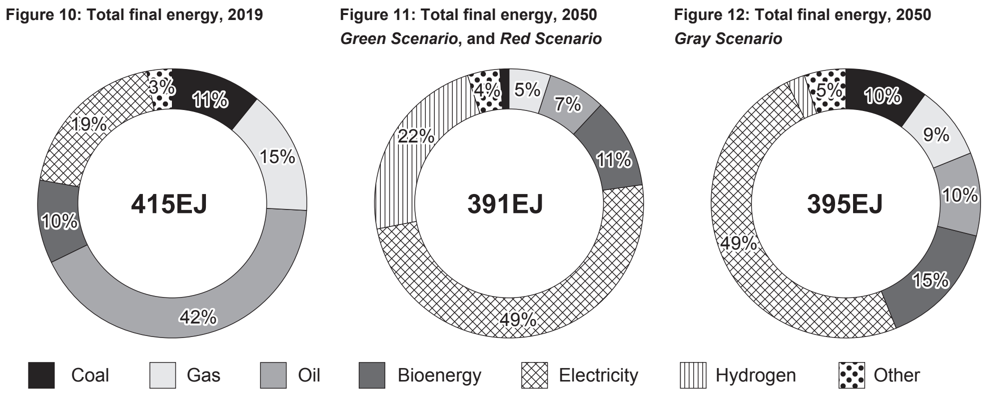
ume of minerals also implies prodigious quantities of energy, water and other inputs.

48）“New Energy Outlook, 2021,” Bloomberg New Energy Finance, July 2021: https://about.bnef.com/new-energy-outlook/

49）“BloombergNEF: battery metals rebounding; by 2030, annual Li-ion battery demand to pass 2 TWh,” Green Car Congress, July 1, 2021: https://www.greencarcongress.com/2021/07/20210701-bnef.html

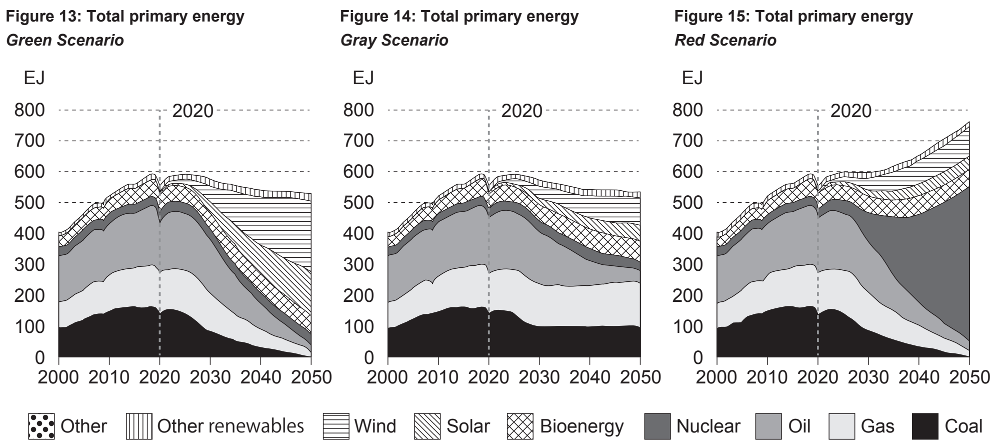
Figure 18 summarizes BNEF's vision of changes in final energy from 2019 to the 2050 scenarios. We see that electrification rises from 19% to 49% in all the scenarios, almost entirely displacing the role of oil. Even the gray scenario includes only 29% fossil fuels.

Interestingly, the BNEF data in figure 19 suggest that the red scenario may provide more primary energy. The extra primary energy supplied by nuclear power is often seen as anathema to observers who emphasize the need for conservation. On the other hand, it could



BNEF, 2021[50]

Figure 18 Total final energy, 2019 and 2050



BNEF, 2021[51]

Figure 19 Total primary energy, by scenario

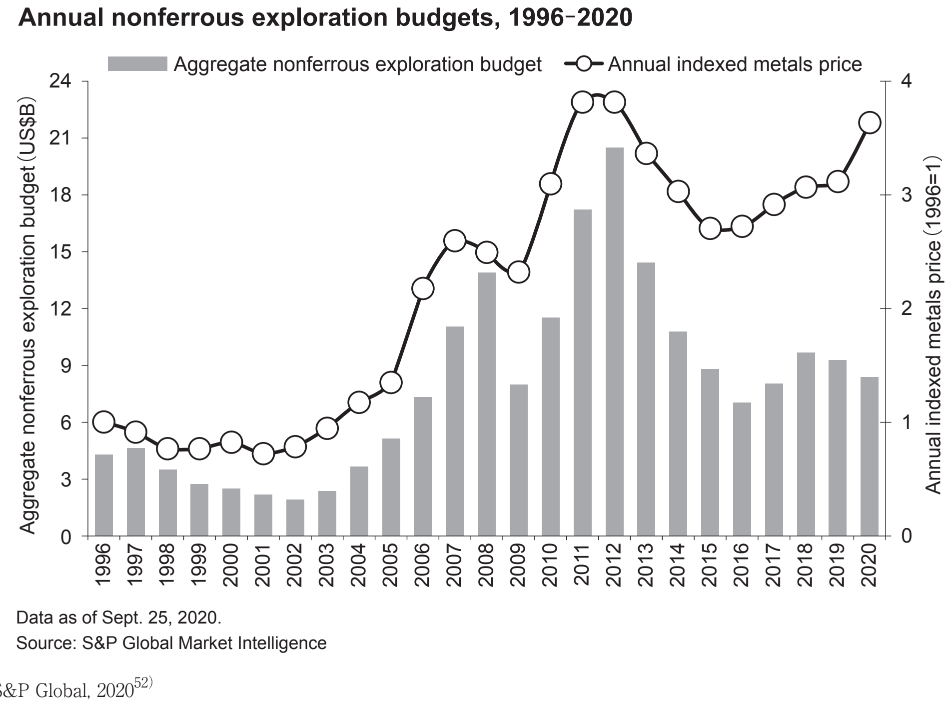
50) "New Energy Outlook, 2021," Bloomberg New Energy Finance, July 2021: https://about.bnef.com/new-energy-outlook/

51) "New Energy Outlook, 2021," Bloomberg New Energy Finance, July 2021: https://about.bnef.com/new-energy-outlook/

be valuable for powering increasing developing-country demand for cooling, refrigeration and other essential and energy-intensive counter-measures to accelerating climate change.

What About Mining Investment?

Were critical mineral supplies not at issue, then realizing scenarios would be largely political choices. But as we see in subsequent data, supplies are likely to be squeezed due to under-investment in mining. The data in figure 20 thus show the 1996-2020 aggregate investment in non-ferrous metal exploration versus indexed prices for metals. We see that recent years reveal a seriously delayed investment response to increased materials prices. This is in large measure a consequence of very high investment in the early 2010s in anticipation of a sustained secular rise in prices. But metal prices dropped between 2012 and 2015, undermining the economics of a lot of project investment. In consequence, mining firms have be-



S&P Global, 2020[52)]

Figure 20 Annual nonferrous exploration budgets, 1996-2020

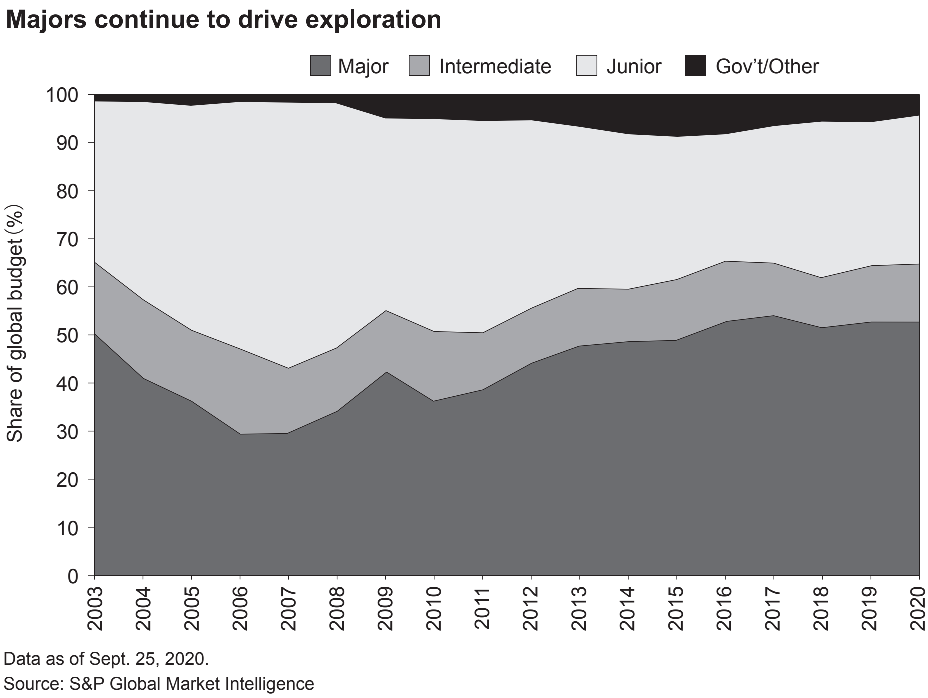
52) "COVID Restrictions Push Exploration Budgets Down 11% In 2020," S&P Global, October 7, 2020: https://www.spglobal.com/marketintelligence/en/news-insights/research/covid-restrictions-push-exploration-budgets-down-11-percent-in-2020

come rather risk-averse.

Figure 21 affords a further insight into the impact of changing incentives. We see that the price uncertainty saw small-scale producers pull back most.

The pullback depicted in figure 21 is further contextualized in figure 22. This data show that investments were increasingly focused on minesite and late-stage projects. This flight to presumed safety is understandable but also means that higher ore-grades are sacrificed. Late-stage projects are, by definition, projects in their declining phase, so increased ore grades are not likely. Greenfield investments are where the higher ore-grades and more new supply can be expected, but higher risks have disincentivized that.

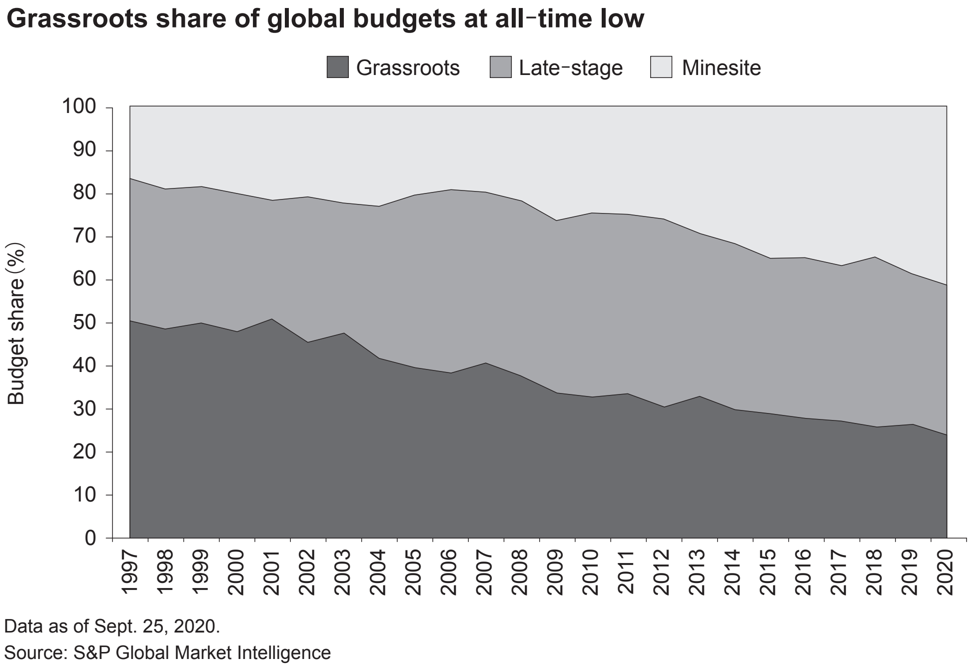
Figure 23 provides a summary of what this means for copper, often referred to as "the new oil" of the energy transition. We see that the dramatic decline in exploration budgets has led to a declining trend in serves and resources. There is certainly a lot of copper re-



S&P Global, 2020[53)]

Figure 21 Project investor scale, 2003-2020

53) "COVID Restrictions Push Exploration Budgets Down 11% In 2020," S&P Global, October 7, 2020: https://www.spglobal.com/marketintelligence/en/news-insights/research/covid-restrictions-push-exploration-budgets-down-11-percent-in-2020



S&P Global, 2020[54)]

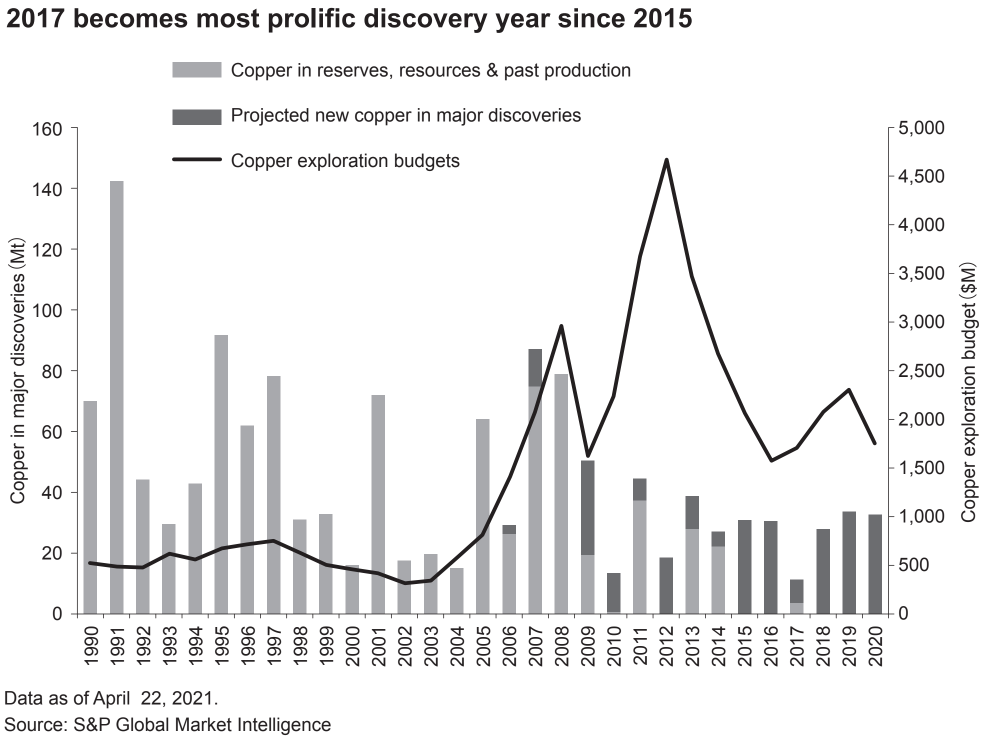
Figure 22　Grassroots share of project investment, 1997-2020

maining to be found, as the data on projected new discoveries indicates. But that potential is not being actualized, even as demand for copper is set to balloon in energy, transport, and other areas.

Of additional concern is that Latin America still represents roughly 40% of global copper supply. To be sure, there are significant discoveries being made in other regions, as we see in figure 24. But turning those discoveries into actual output of refined metal takes a decade or two of preparations, including assessing environmental impacts, building infrastructure, training and recruiting workers, constructing refining capacity, and other items.

On this, it is instructive to pay heed to observations by geopolitical analyst Jacob Shapiro. His analysis highlights some of the myriad issues concerning the regional concentration and declining ore grades of copper:

54) "COVID Restrictions Push Exploration Budgets Down 11% In 2020," S&P Global, October 7, 2020: https://www.spglobal.com/marketintelligence/en/news-insights/research/covid-restrictions-push-exploration-budgets-down-11-percent-in-2020



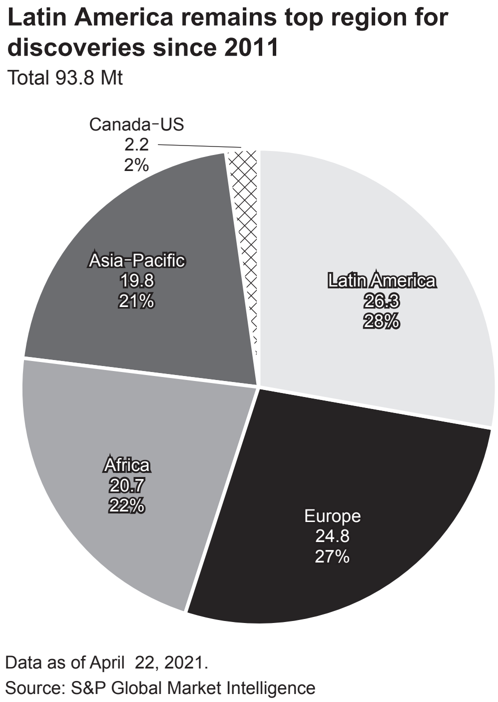
S&P Global, 2021[55)]

Figure 23 Copper investment and discoveries, 1990-2020

“Even though copper production is 30 percent greater today than a decade ago, production at many of the world’s largest copper mines has decreased considerably. In Chile, which accounted for 30 percent copper ore exports last year, the average grades of concentrate have decreased by 30 percent. (Yes, that’s a lot of 30s – a coincidence, not a typo!) According to the IEA, the copper continent in Chilean ore is now just 0.7 percent. In practical terms, that means mining copper is getting costlier, which will also increase prices.

This is not just a Chilean problem – ore grades at major copper mines in Australia, Canada, the U.S., and Peru have also declined. Growth in production will have to come from places like Peru (where new President Pedro Castillo has threatened to nationalize mining interests), the Democratic Republic of Congo (a geopolitical nightmare) and

55) “Recent copper discoveries fail to alter downward trend,” S&P Global, May 18, 2021: https://www.spglobal.com/marketintelligence/en/news-insights/research/recent-discoveries-fail-to-alter-downward-trend



S&P Global, 2021[56)]

Figure 24　Latin American and copper discoveries since 2011

Indonesia. There may be enough copper in the world but it is getting harder and costlier to reach." [57)]

Schapiro's concerns appear to be quite warranted. Both Chile and Peru have been deeply affected by the COVID-19 pandemic, in fiscal and political terms. On top of that, the clearly increasing value of copper – coupled with its environmental impact – is driving a focus on making it more ESG-compliant in addition to maximizing its value domestically.

In Chile, for example, "[h]ardship wrought by the pandemic, coupled with social protests over inequality, has also prompted an ideological shift in the country, with a specially-

56) "Recent copper discoveries fail to alter downward trend," S&P Global, May 18, 2021: https://www.spglobal.com/marketintelligence/en/news-insights/research/recent-discoveries-fail-to-alter-downward-trend

57) Jacob Shapiro, "Copper: The Red Metal of the Future or Runt of the Portfolio?," Catalyst Insights, August 25, 2021: https://catalyst-insights.com/copper-the-red-metal-of-the-future-or-runt-of-the-portfolio/

elected body drafting a new constitution to cover thorny issues such as water and property rights largely made up of leftist delegates. Chile's Congress, dominated by a left-leaning opposition, is also weighing legislation that would impose greater royalty taxes on mining companies and strengthen protection of glaciers, which abut some major mines."[58] In addition to that, the Chilean government indicates that doubling ESG-compliant copper output by 2050 – to 9 million tonnes – would require cumulative investment of USD 150 billion.[59]

These trends towards cleaner critical mineral production are positive developments for the health and well-being of the local communities in areas where critical minerals are mined. But they do raise the costs of producing the minerals, and thus of achieving material-intensive pathways to digitalization and decarbonization.

The Supply and Price Shocks of 2021

We have seen that projecting the supply of and demand for critical minerals confronts myriad issues. On the supply side, it is impossible to assess how much copper, nickel, rare earths, tin, silicon and other materials will be available in the short run, let alone over longer time frames. This supply uncertainty has many causes, including depressed investment in mining and processing, the impacts of the COVID pandemic, political shifts in producer countries, and a broad range of other uncertainties. At the same time, forecasting demand increases is equally difficult. There are about three dozen critical minerals and hundreds of areas where they are used, in addition to the renewable energy and electric vehicles that draw most attention. Even within renewables and electric mobility, no expert agency can accurately predict the short-run volume of investment in material-intensive wind and solar, power networks, and electric vehicles, let alone the battery chemistries and other parameters that determine material demand.

As we have seen earlier, the currently best-available evidence is a variety of calculations of the energy and other transformations required to decarbonize over the coming decades. And these assessments are quite fluid. Up to 2020, most analyses assumed that ever-

58) Fabian Cambero, "Chile outlines plans for mining to increase traceability, use less water," *Reuters News*, September 1, 2021: https://www.reuters.com/world/americas/chile-outlines-plans-mining-increase-traceability-use-less-water-2021-08-31/

59) Fabian Cambero, "Chile needs $150 bln to boost green copper output, minister says," *Reuters News*, September 2, 2021: https://jp.reuters.com/article/chile-mining/exclusive-chile-needs-150-bln-to-boost-green-copper-output-minister-says-idUSL1N2Q324K

cheapening renewable energy would rapidly drive coal, nuclear, and other generation out of power mixes. It was also believed that massive overbuild of wind and solar generation would allow for the production of "green hydrogen" and other alternatives to natural gas and other fuels. But in 2021, as we have seen, Bloomberg New Energy Finance reassessed its outlooks to include gray and red scenarios towards decarbonization.

For our purposes here, this diversification of decarbonization assessments should also be seen as an admission that material demand is a guess. We also saw that Wood Mackenzie expects significant advances in technology to change the material demand profiles of renewable generation, electric mobility, and so on. Yet the IEA's work suggests that significant short-run changes in battery chemistries and power-plant designs are not likely. And over longer time frames, technological advances are unlikely to alter the one key fact of the past two decades: critical mineral density is increasing across the broad frontier of infrastructure investment in advanced power, water, communications, health care, mobility, and other core systems in developed and developing countries.

We also see in 2021 that these uncertainties cannot be set asides as issues for the future. Rather, material prices have become an immediate problem in addition to a mid- and long-term challenge. They are already driving up solar and other renewable energy, electric vehicle, and electric network costs.

One indicator is price spikes. The September 14 *Asia Nikkei* summarized the year-on-year critical mineral price increases and those materials' multiple areas of use. Their data indicated that lithium carbonate prices had increased a startling 150%, while tin was up 81.8%, aluminum up 55.4%, cobalt up 51.5% and copper up by 37.3%.[60]

Tin may seem an unimportant material, and it certainly does not get the attention accorded to cobalt and rare earths. However, it is the "glue" of the smart and clean transformation from carbon-intensive and low tech industries. As a September 16 article in *Mining News* put it, "[a] 2018 Rio Tinto-commissioned study carried out at MIT [Massachusetts Institute of Technology] found that tin beat out more likely technology metal candidates like lithium, cobalt, and graphite it when comes to being impacted by new technologies such as autonomous and electric vehicles, advanced robotics, renewable energy, and computers."[61]

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60) "Tech industry braces for skyrocketing rare earth prices," *Asia Nikkei*, September 14, 2021: https://asia.nikkei.com/Business/Technology/Tech-industry-braces-for-skyrocketing-rare-earth-prices

61) Shane Lasley, "Tin has been critical for 5,500 years," *Mining News*, September 16, 2021: https://www.miningnewsnorth.com/story/2021/09/16/critical-minerals-alliances/tin-has-been-critical-

Aluminum is also often taken for granted in discussions of critical minerals. Indeed, it is often depicted as a ready substitute for copper in electrical networks, air conditioning, and other copper-intensive applications. But aluminum's price was already up more than copper, limiting the capacity to substitute. And by the 22nd of September, 2021, the *Asia Nikkei* was warning that aluminum prices were up 60%. It also highlighted the uncomfortable fact that 60% of aluminum is smelted in China, producing 4% of Chinese emissions, but that aluminum is crucial to decarbonization. Most of China's low-emission hydropower for producing aluminum is situated in Yunnan Province, whose dams provide 70% of local power. But these power assets were already locked up by aluminum in addition to other heavy power users such as silicon and magnesium.[62] With China seeking to reduce the environmental impact of its own mining and processing, particularly in advance of the February 2022 Winter Olympics, cheap and clean power was emerging as a bottleneck for aluminum and other materials.

Even more surprising was the spike in prices for silicon metal used in a variety of applications. By the end of September 2021, the price of solar-grade polysilicon had surged by over 300% as compared to June 2020. Bloomberg News emphasized that the price spike was being driven by a complex of cyclical and structural factors:

> "Silicon, which makes up 28% of the earth's crust by weight, is one of mankind's most diverse building blocks. It's used in everything from computer chips and concrete, to glass and car parts. It can be purified into the ultra-conductive material that helps convert sunlight into electricity in solar panels. And it's the raw material for silicone — a water- and heat-resistant compound used widely in medical implants, caulk, deodorants, oven mitts and more.
>
> Despite its natural abundance in crude forms such as sand and clay, there have been warnings in recent years that surging industrial demand risks creating improbable shortages for raw materials like gravel. Now, with China curbing production of high-purity silicon metal, the unlikely fragility of the silicon supply chain is being exposed to an alarming degree.
>
> The knock-on consequences are also particularly alarming for automakers, where

for-5500-years/6988.html

62) "Aluminum prices hit 13-year high amid power shortage in China," *Asia Nikkei*, September 22, 2021: https://asia.nikkei.com/Business/Markets/Commodities/Aluminum-prices-hit-13-year-high-amid-power-shortage-in-China

silicon is alloyed with aluminum to make engine blocks and other parts. Along with silicon, they're also facing a surge in magnesium, another alloying ingredient that's faced production issues during China's power crunch." [63)]

Startling as it is, the spike in the silicon price only highlighted the potential for other surprises. The constraints on silicon processing appeared likely to be dealt with by the fall of 2022, relieving price pressures from that aspect. But the lessons of 2021 would appear to be that costs can be driven up by unforeseen factors, ranging from natural disaster through to escalating fossil-fuel prices.

Moreover, even if silicon supply constraints are addressed by expanded factory capacity, it seems unlikely that most other critical minerals can be dealt with so readily. Hence *Bloomberg News* warned that the energy transition posed the urgent question of "whether miners, financiers and governments can mobilize enough capital fast enough to bring on new supplies in line with demand." *Bloomberg* cited analysts who suggested that "raw materials and the companies that produce them should offer higher returns - though also more risk - than component manufacturers, equipment makers or electric car producers." Yet this was not happening. The latter fact is due to mining firms' wariness of ESG pushback and the risk that price increases may not last were EV, RE, 5G and other deployment to decline. Added to that, material-abundant countries like Peru seek to increase royalties to pay down COVID-19 fiscal deficits. These uncertainties in the mining and processing sectors are a sharp contrast to the confident and robust scenarios painted by automakers, the solar industry and other producers who take mining for granted.[64)]

Ironically, the fossil-fuel price shocks of 2021 emerged as perhaps the key indicator to pay closer attention to critical minerals. As of this writing, coal, LNG and other prices were increasing at historic rates in Europe and Asia. One reason is that recovery from COVID-19 economic downturns drove the demand for power well past the capacity of renewable energy. Indeed, the latter's output had generally declined due to reduced wind and hydro generation. In addition, under-investment in upstream and downstream fossil fuel projects meant

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63) Krystal Chia, et al., "Silicon's 300% surge throws another price shock at the world," *Bloomberg News*, October 1, 2021: https://www.bloomberg.com/news/articles/2021-10-01/silicon-s-300-surge-throws-another-price-shock-at-the-world

64) Andrew James, et al, "There's a Fortune to Be Made in the Obscure Metals Behind Clean Power," *Bloomberg News*, September 21, 2021: https://www.bloomberg.com/graphics/2021-materials-silver-to-lithium-worth-big-money-in-clean-energy

global demand exceeded supply. And this was true, even though global growth was still sub-par due to low international transport and other lagging sectors. As with critical minerals, the supply issues were not merely cyclical but also structural. One important piece of evidence was the restricted global capacity to satisfy massive demand for liquefied natural gas (LNG). In 2019, most observers believed that there was over-investment in LNG,[65] which like other forms of fossil fuel delivery was dubbed a "stranded asset" and at historic lows. Yet by September of 2021, the narrative had changed abruptly as structural problems suddenly emerged. As the October 2, 2021 edition of the online Business and Industry Connection ("BIC") magazine put it, prices had surged from historic lows to historic highs in a mere 19 months, but there was little prospect of a short-term reversal:

> "Most major LNG producers are operating at or close to full capacity and have allocated the vast majority of their shipments to specific customers, leaving little prospect of a short-term fix.
>
> According to the International Gas Union, only 8.9 million tonnes per annum (mtpa) of a total 139.1 mtpa of planned new liquefaction capacity is expected to come online in 2021.
>
> Some of that additional capacity has been delayed by COVID-19 movement restrictions that have stopped or dragged out construction and maintenance work at several key sites including in Indonesia and Russia over the past year.
>
> So far this year, 288.1 million tonnes of LNG has loaded for exports globally, just 7% growth over the same period last year, Refinitiv data shows."[66]

In other words, it took only a relatively low increase in LNG demand from COVID-19 lows to drive a massive price spike. With little excess capacity slack in the supply chain, and only incremental increases planned, the likelihood is that the problem is structural more than cyclical. Indeed, LNG is the fuel of choice for China and other countries that aim to reduce their massive dependence on coal-fired power while balancing the intermittency of wind and solar renewable energy. Most of these countries are still developing and demographically

65) See Avi Salzman, "There's a Worldwide Energy Crunch. Here's How to Play It," *Barrons*, October 1, 2021: https://www.barrons.com/articles/natural-gas-prices-stocks-51633102086

66) "Explainer: What's behind the wild surges in global LNG prices and the risks ahead," BIC Magazine, October 2, 2021: https://www.bicmagazine.com/industry/natgas-lng/what-is-behind-the-wild-surges-in-global-lng-prices/

young, meaning their demand for power is increasing. The intensive fall-off in LNG and other fossil-fuel demand induced by COVID-19's economic fallout obscured these patent facts. But they appear to have re-emerged with an urgency that cannot be ignored.

These developments are not just a warning of possible mayhem in critical minerals. One reason is that the energy required to mine and process critical minerals is largely derived from fossil fuels and will continue to be over at least the next decade. The already-inadequate investment in critical minerals also means that the faster we try to substitute renewable energy and electrification in the mining and materials processing sectors, the greater the pressure on critical mineral supply chains. Considering the imperative of rapid decarbonization, the challenges here are clearly without historic precedent.

Coping with the Challenges

We have seen that critical mineral demand is already accelerating and almost certain to expand further. Prices of copper, aluminum, cobalt and other critical minerals are already increasing to historic levels.[67] The IEA and other work emphasize the urgency of comprehensive and inclusive policy, such as broad-based collaborations on recycling, substitution, and innovation that helps increase the efficient use of critical minerals. The IEA's *Critical Minerals* report also underscores the imperative of clear policy goals within decarbonization. The reasoning is that clear goals would reduce the risks of critical minerals price volatility and other impediments to expanded supply via mining and processing. Yet we have also seen that achieving these aims is very difficult. One reason is that there are so many competing scenarios of decarbonization and digital transformation, such as within Japan. Advocacy coalitions seem quite unwilling to make compromises concerning their favoured decarbonization solutions, and this is reflected in party politics and policymaking. It seems clear that rapid decarbonization led by variable renewable energy – especially at the expense of existing nuclear capacity – implies unsustainable demand for critical minerals, but that is not yet part of the Japanese public debate.

The IEA and other actors also stress the need for a regime of ESG-compliant critical minerals, both to protect the environment and human wellbeing as well as to foster new sup-

67) Japanese concerns about this trend are increasing, though there is still a lot of suspicion that price increases are driven largely by speculation. On this, see (in Japanese) "Skyrocketing prices for Chinese rare metals," *Nikkan Kogyo Shinbun*, September 2, 2021: https://www.nikkan.co.jp/articles/view/00610567

ply.

A further recommendation is much stronger and integrated international governance. At present, there is a patchwork of international institutions and initiatives that address various aspects of critical mineral mining and processing. But these efforts are poorly coordinated and often lack adequate transparency. The IEA suggests that its energy security framework could be of service in this regard, by facilitation the collection and dissemination of credible data, regularly assessing the vulnerabilities of supply chains, enhancing flows of knowledge and sharing of best-practices, and raising ESG-type standards "to ensure a level playing field."[68)]

Japan's Policy Strengths and Weaknesses

Japan is already doing a few of the items highlighted by the IEA, and in fact receives a degree of acknowledgement in the report. Japan's stockpiling and recycling are also referenced in other reports. This is to be expected, as Japan has long been a leading manufacturer of high-tech, critical mineral-intensive goods. Japan has also been assessing its critical material vulnerabilities since the early 1980s.

Japan initially undertook stockpiling of 7 key minerals including cobalt. But as we entered the new millenium, with the rise of material-intensive digital and other related smart technologies, Japanese policymakers reassessed their approach. Since the mid-2000s Japan has undertaken an explicit and increasingly robust strategy for designating critical minerals, and addressing supply risks by emphasizing overseas projects, advanced recycling, substitution and stockpiling.

In tandem, Japan's list of critical minerals has increased to a few dozen from the original 7. Japan has also built good clusters of expertise and initiatives in recycling and substitution, linking those with US and other centres of excellence. One example from October 2011 is the US-Japan-EU Trilateral Workshop on Critical Raw Materials. Also, since 2013 Japanese specialists have been working with the US Department of Energy's Ames Institute on the "effective use of critical materials."[69)]

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68) See p. 173, *The Role of Critical Minerals in Clean Energy Transitions*, International Renewable Energy Agency, May 2021: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

69) See "Cooperation between the United States and Japan on Effective Use of Critical Materials," NEDO, September 10, 2013: https://www.nedo.go.jp/content/100536586.pdf

Advanced recycling is a major priority for Japanese policymakers. An emerging strategy is to become a hub for recyclable high-value materials domestically and from overseas. Japan does have comparatively good initiatives on recycling and substitution. There is also a new effort to drill-down on tungsten, cobalt and 3 select rare earths.

As of March 2020, Japan instituted a New International Resource Strategy.[70] This policy covers 34 critical minerals – referred to as “rare metals” – and includes increased and fine-tuned goals for stockpiling of emergency reserves and a greater ability for the Japan Oil, Gas and Metals National Corporation (JOGMEC) to support private-sector mining and smelting initiatives. JOGMEC is also empowered to work with foreign firms in exploration activities. The country also officially aims at 80% self-sufficiency by 2030 in base metals such as copper and nickel (and 100% by 2050), and is aiming to undertake commercial exploitation of its Exclusive Economic Zone seabed critical minerals from 2028.[71]

Yet it is questionable that Japan can expect these high levels of self-sufficiency by 2030 and 2050. There is almost no transparency in how these targets are determined, which is quite odd considering that the IEA, BNEF, World Bank and other agencies highlight potentially dramatic increases in demand for critical minerals. Emerging issues in supply – such as copper in South America – would also indicate the need for closer and more collaborative scrutiny of Japan’s self-sufficiency levels and targets. One new analysis by Chinese geology specialists suggests that Japan (along with South Korea and Spain) is one of the critical countries of high risk in the global copper material supply chain, and more of this work needs to be undertaken.[72] The uncertainty concerning which pathway Japan (not to mention the rest of the world) will take towards decarbonization suggests that Japan’s self-sufficiency numbers need to be developed according to multiple scenarios.

Japan has made some initial efforts to quantify the enormous scale of its own critical mineral challenge. A report to the Ministry of Economy and Industry (METI) deliberation committee on energy on February 15, 2021 pointed out that installing just 10GW of offshore

70) While the strategy per se is in Japanese, a brief outline in English is available at “New International Resource Strategy Formulated,” Ministry of Economy, Trade and Industry, March 30, 2020: https://www.meti.go.jp/english/press/2020/0330_005.html

71) Japan’s policies are put in a comparative context by Jane Nakano in “The Geopolitics of Critical Minerals Supply Chains,” Center for Strategic and International Studies, March 11, 2021: https://www.csis.org/analysis/geopolitics-critical-minerals-supply-chains

72) See Baqihua Li, et al., “The global copper material trade network and risk evaluation: A industry chain perspective,” *Resources Policy*, Volume 74, December 2021: https://www.sciencedirect.com/science/article/abs/pii/S0301420721002865

wind – about 3 nuclear reactors' worth of power generation – by 2030 would require about 10% of Japan's 2018 copper consumption and 20% of Japan's niobum rare earth consumption.[73] The METI seems likely to aim for 45 GW of offshore wind by 2040, but that goal requires massive critical mineral demand that will not be met by recycling and substitution.

And that critical mineral demand is on top of critical mineral requirements for other clean energy generation, transmission and storage, electrified mobility, 5G (and post-5G) communications, data centres, aerospace and satellites,[74] smart military weapons systems, and other elements of Japan's critical material-intensive Society 5.0, decarbonization, smart city, and related industrial policy ambitions.

Yet Japanese policymakers and academics have yet to publish figures on the overall critical mineral requirements for the country's Society 5.0 and decarbonization goals. There are no comprehensive critical minerals assessments from within Japan, in spite of its lack of terrestrial critical mineral endowments. Indeed, the METI calculation of copper and niobium requirements for offshore wind is derived from IEA data. But offshore wind systems differ greatly in their critical mineral requirements. Japan's offshore wind may be more material-intensive than the average. This is because Japan's offshore wind projects will have to be developed in greater oceanic depths and distance from the shore and centres of power consumption. That suggests that – compared to the average – Japanese offshore wind could require a great deal of material-intensive investment in power transmission, storage and distribution networks.

Indeed, on May 13, 2021 Japan's respected Research Institute of Innovative Technology for the Earth released a multi-scenario study on energy options. In its 100% renewable energy scenario, power prices quadrupled by 2050 because intensive deployment of solar and wind would require extensive investment in new transmission, battery storage, and back-up from fossil-fuel peaker plant.[75] Due to these issues, one would expect Japanese specialists to

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73) See (in Japanese) p. 21, The Metal and Mineral Policies Towards Realizing Carbon Neutrality by 2050," February 15, 2021: https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/kogyo/pdf/007_03_00.pdf

74) Recent studies of satellite technology (which uses a lot of critical minerals) suggests there is an ongoing explosion in numbers as civil, military and private agents turn from large assets to distributed "constellations" of satellites. Moreover, the current stock of about 3,000 active satellites orbiting the planet is expected to multiply dramatically. On theswe issues, see Lauren Napler, "Thousands more satellites will soon orbit Earth – we need better rules to prevent space crashes," *The Conversation*, January 28, 2021: https://theconversation.com/thousands-more-satellites-will-soon-orbit-earth-we-need-better-rules-to-prevent-space-crashes-154014

75) See (in Japanese) "Scenario analyses of 2050 carbon neutrality (mid-term report), Research In-

be producing detailed analyses of Japan's critical mineral requirements. We have already seen that this kind of work is ongoing in the EU countries, the US, and elsewhere. But language barriers, shortages of skilled people, and a generalized complacency appears to impede Japanese academe, government and civil society from engaging with overseas initiatives.

This status quo seems unacceptably dangerous. New critical mineral mining and processing infrastructure generally take many years to put in place. So in the short run Japanese Society 5.0 and energy policy should perhaps emphasize innovative approaches to coping with critical mineral supply and price risks. These options include:

1) If possible, Japan should work with new US-Canada-Australia "Earth MRI" (Critical Minerals Mapping Initiative),[76] which deploys the most advanced 3D mapping technologies to identify CRM deposits in addition to natural disaster risks, and renewable energy resource potential. Japan has developed and diffused a lot of advanced mapping technology through its Society 5.0, National Resilience, and other initiatives. Japan could conceivably contribute a lot to collaborative and multi-parameter mapping.

2) Japan could be working with India on exploring critical minerals (while also mapping disaster risks and renewable energy potential), as only 10% of India has been explored and both countries need critical minerals.[77] At present, it would appear that both Japan and India are instead looking toward Australia as a secure source of supply. Yet neither Australia's endowments nor its extant production capacity seem sufficient to satisfy both countries' demand.

3) Japan's seafloor mining of critical minerals is expected to start in 2028. But Norway appears to be planning on an earlier start.[78] Japan's initiative could perhaps be accelerated,

stitute of Innovative Technology for the Earth, report to basic policy subcommittee, May 13, 2021: https://www.enecho.meti.go.jp/committee/council/basic_policy_subcommittee/2021/043/043_005.pdf

76) See "Critical Cooperation: How Australia, Canada and the United States are Working Together to Support Critical Mineral Discovery," USGS, October 16, 2020: https://www.usgs.gov/news/critical-cooperation-how-australia-canada-and-united-states-are-working-together-support

77) The details are at Biplop Chatterjee and Rayesh Chadha, "Non-Fuel Minerals and Mining: Enhancing Mineral Exploration in India," Brookings India Discussion Note, April, 2020: https://www.brookings.edu/wp-content/uploads/2020/04/Enhancing-Mineral-Exploration-in-India.pdf

78) Nerijus Adomaitis, "Norway eyes sea change in deep dive for metals instead of oil," *Reuters*, January 12, 2021: https://www.reuters.com/article/us-norway-deepseamining-insight-idUSKBN29H1YT

opening up a new source of critical minerals. This could help bolster the credibility of the self-sufficiency numbers and targets, in addition to bolserting the national economy from potential price shocks.

4) In tandem with the above, Japanese should partner with ongoing collaboration to confirm whether deep-sea mining is potentially more ESG-compliant than terrestrial mining.[79] This work seems imperative, as BMW, Volvo, Google, Samsung and other global firms are already pledging not to use critical minerals mined offshore until the environmental risks are "comprehensively understood."[80] In the absence of evidence that deep-sea sources of critical minerals are ESG-compliant, Japan invites reputational risk for its firms should they harvest, process, and include those materials in their products.

5) Japan's decarbonization goals are curiously uninformed by its significant climate adaptation strategy,[81] even though the IPCC and other global agencies highlight the synergies of mitigation and adaptation. Japan might consider the critical mineral implications of these synergies in its linkage of Society 5.0 and SDGs.

Conclusion

As 2021 unfolded, it became increasing clear that the critical mineral challenge is multi-faceted and global. Though Japan has an ambitious Society 5.0 industrial policy and integrated governance, its inclusiveness has yet to embrace critical minerals. And Japan's energy strategy appears to be unduly complacent concerning critical mineral demand scenarios and self-sufficiency goals. Japan conspicuously lacks in the think tanks and comprehensive public-policy schools seeking to build on the IEA and other work. Japan should remedy this knowledge deficit, by assessing its myriad smart city, decarbonization and other targets in terms of Japan-specific critical mineral requirements.

Second, Japan should find options for material-efficiency. There is limited evidence

79) See Paulika, Daina, et al. "Life cycle climate change impacts of producing battery metals from land ores versus deep-sea polymetallic nodules," *Journal of Cleaner Production*, December 2020: https://www.sciencedirect.com/science/article/pii/S0959652620338671

80) Henry Sanderson, BMW, "Volvo and Google vow to exclude use of ocean-mined metals," *Financial Times*, March 31, 2021: https://www.ft.com/content/e618a555-2d21-4f33-b6b5-46564197f834

81) On this, see "Japan and Singapore Submit 2020 NDCs," SDG Knowledge Hub, April 2, 2020: https://sdg.iisd.org/news/japan-and-singapore-submit-2020-ndcs/

that this kind of thinking is – for example – animating discussion among the myriad stakeholders involved in ongoing deliberations on Japan's strategic energy policy and its Society 5.0 policies. It is unlikely that we will see sudden substitution, recycling and other silver-bullet breakthroughs that dramatically reduce risks. So it would appear that strategic prioritizing of the use of scarce critical minerals will be necessary. That scoping of trade-offs ought to become an arm of policymaking, built on inclusive engagement of domestic and international awareness.

As it considers the sobering critical mineral implications of accelerated digitalization and decarbonization, Japan may be able to get more traction in these areas. One reason for cautious optimism is that because of ageing, depopulation, and other challenges, Japan is getting increasingly good at focusing scarce human, fiscal, material and other resources by addressing multiple problems simultaneously. We have seen that Japan has a lot of Society 5.0, smart city, and other decarbonization industrial policies. The looming crisis in critical minerals may work to foster more pragmatic, multi-stakeholder agreement on pathways to decarbonization and digital transformation.