Article

This Time It's Different: Decarbonization and Japanese Industrial Policy in 2020

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Abstract

This paper examines the context of Japan's October 2020 commitment to aim at net-zero in carbon emissions by 2050. Prior to the announcement, Japan was generally regarded as a lagging contender in the accelerating global shift to making decarbonization the explicit focus of industrial policy. We describe Japan's strengths and weaknesses, which are not well-addressed in the literature. Among Japan's strengths, our analysis highlights an increasingly inclusive and integrated "platform-style" of industrial policy. By contrast, the country's weaknesses appear most evident in resource-endowments, notably of the critical raw materials required for decarbonization.

Introduction

On October 27, 2020 Japanese Prime Minister Suga Yoshihide announced that his administration would set national policy on course to aim at net-zero in greenhouse gas (GHG) emissions by 2050. Japan's previous commitment had been an 80% reduction in GHG emissions by 2050, with zero emissions depicted as a long-term goal for the latter half of the 21st century. As of this writing, Japanese policymakers are expanding and integrating their decarbonization policy platforms.

Prime Minister Suga's announcement came against a backdrop of increasing national-level commitments to decarbonization, including China's September declaration that it would aim for net-zero by 2060. In recent years, Japan has not generally been regarded as a serious contender in the accelerating global shift to decarbonization as industrial policy. But the October commitment was strongly welcomed in an international climate-policy community shocked by the impact of the COVID-19 pandemic and seeking roadmaps for building back

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better on all fronts.[1]

It is important to note that none of these net-zero commitments are backed up by detailed and credible planning. Even the much-lauded EU goals for a green recovery and decarbonization by 2050 lack clarity. The EU goals remain largely a vision rather than a roadmap. The hard work of land-use changes, lifestyle shifts, the relative proportion of decarbonizing technologies, and other fundamental issues remain to be decided. Hence the myriad suggestions on what to do, as in the December 3, 2020 McKinsey and Company offering of "How the European Union could achieve net-zero emissions at net-zero cost." [2]

The desperation over how to manage the pandemic while reviving economies and confronting climate change was reflected in the December 12, 2020 "Climate Ambition Summit 2020." [3] The Summit was convened by the United Nations, the UK and France, in a effort to bridge the COP26 climate summit that was postponed due to the global pandemic. The event failed to become a venue for anything more than incremental steps,[4] which is no surprise because most of the technological tools of decarbonization are yet to be innovated.

In this context of uncertainty, we describe Japan's strengths and weaknesses, which are generally not well-addressed in the literature. Among Japan's strengths, our analysis highlights an increasingly integrated "platform-style" of industrial policy. Collaborative governance is better at aggregating information and formulating actionable policy. It has shown itself to be valuable in planning for a "build back better" recovery from COVID-19 in addition to the increasing ravages of climate change. The country's weaknesses are shown to be in resource-endowments, notably in the critical raw materials (CRM) required for decarbonization. This vulnerability is not peculiar to Japan, but is perhaps particularly threatening given the country's lack of endogenous resources.

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1) One example is Japan NRG founder Yuriy Humber's article "There are good reasons to celebrate Japan's decarbonization pledge," *Nikkei Asia*, December 12, 2020: https://asia.nikkei.com/Opinion/There-are-good-reasons-to-celebrate-Japan-s-decarbonization-pledge

2) See "How the European Union could achieve net-zero emissions at net-zero cost," McKinsey and Company, December 3, 2020: https://www.mckinsey.com/business-functions/sustainability/our-insights/how-the-european-union-could-achieve-net-zero-emissions-at-net-zero-cost

3) See the proceedings and related items at the Climate Ambition Summit 2020 website: https://www.climateambitionsummit2020.org

4) On the summit, see Jess Shankleman and Laura Millan Lombrana, "Lofty Climate Goals Get Reality Check at Global Summit," *Bloomberg News*, December 13, 2020: https://www.bloomberg.com/news/articles/2020-12-12/lofty-climate-goals-get-reality-check-at-global-summit?sref=n8vchuia

Is Japan a Laggard?

Japan is often depicted as a laggard on decarbonization.[5] It actually scores very high in terms of the comparative deployment of renewable energy, energy efficiency, circular-economy recycling and waste reduction, energy R&D, and other important indices. But the past decade has seen the global decarbonization debate led by the European Union (EU), and particularly Germany. Hence, the dominant narrative of decarbonization is shaped by the EU's choices, such as the EU taxonomy on green and sustainable investment.[6]

But it is unclear whether the EU taxonomy's negative stance towards hydropower and nuclear are suitable to Asia's challenges. Indeed, Swedish, Finnish and other interests have criticized the taxonomy as ignoring many EU countries' road to decarbonization. The large Finnish state-owned utility Fortum warned the EU that "[l]eaving out hydropower and nuclear is a discriminatory decision that will punish most of the Nordic countries that decided early on to decarbonize their energy mix and have been pioneers on the path towards climate neutrality."[7] At the same time, EU climate NGOs exert immense pressure to have the taxonomy allow essentially only wind and solar as scalable decarbonizing energy.[8] Viewing this politicized process, Japanese industry stakeholders at the core of Japan's decarbonization industrial strategy are increasingly (and quite legitimately) concerned that rules "stipulated, regulated and decided by the EU will become the global standard."[9]

5) See for example, the Greenpeace and other environmental groups' coalition "CAN-Japan" denunciation of the Japanese government for not adopting more ambitious GHG mitigation targets including 100% renewable energy. "CAN-Japan Statement: Japan fails to do its part to fight climate crisis – NDC Submission by Government of Japan," March 31, 2020: https://www.greenpeace.org/japan/nature/press-release/2020/03/31/12784/

6) On the taxonomy and its application, see Will Martindale, "From policy to practice: testing the EU taxonomy," UNPRI, September 10, 2020: https://www.unpri.org/pri-blogs/from-policy-to-practice-testing-the-eu-taxonomy/6410.article

7) On this issue, see Anne Filbert, "Fortum raises concerns about 'discriminatory' EU taxonomy," Energy Watch, December 7, 2020: https://energywatch.eu/EnergyNews/Utilities/article12610009.ece

8) One example of the pressure was seen on December 15, 2020, when 130 organizations sent an open letter in regards to the European Commission's draft taxonomy. See "EU Taxonomy: 130 organisations call for science-based green finance rules," Reclaim Finance, December 15, 2020: https://reclaimfinance.org/site/en/2020/12/15/eu-taxonomy-130-organisations-science-green-finance/

9) This concern was expressed on December 6, 2020 to the *Financial Times* by Suntory chief ex-

One prominent area where Japan attracts criticism has been the absence (until September 2020) of pricing on single-use plastics such as shopping bags. This criticism focuses on one aspect rather than the overall reality of Japanese plastic and other waste volumes and disposal. For example, it overlooks the fact that Japan's landfilling of all industrial waste (including plastic) is only 3%. Total volumes of plastic waste declined from over 10 million tons in 2005 to 9.03 million tons in 2017, while the rate of recycling (including thermal recycling) increased over the same period from 58% (2005) to 86% (2017).[10] Like many EU countries, Japan incinerates much of its waste stream to generate energy. This combustion of waste is generally more environmentally effective than trying to recycle many complex amalgams and other such materials. The latter is regarded as virtuous, but it point of fact often requires much more energy for collection, handling, processing and other stages than is saved.[11] Japanese energy generation capacity for burning waste rose from 1.491 GWs in 2004 to 2.069 GWs in 2018. In the latter year, 2018, these assets generated a total of 9.553 GWh of power, or roughly 3.21 million households' worth of demand.[12] Moreover, as table 1 indicates, Japan's per-capita plastic waste generation (kg/year) in 2016 was well below its high-income peer countries. The table shows that Japan 38.44 kg per capita was far lower than environmental leader Germany (81.16 kg) and the average of the EU-28 countries (54.56 kg).

ecutive Niinami Takeshi. Niinami is one of two private-sector advisors on Japan's Council on Economic and Fiscal Policy, which is chaired by the prime minister and oversees integrated green-growth and industrial policy. See Niinami's comments in Robin Harding, et al., "Japan warns against allowing EU to set emission rules," *Financial Times*, December 6, 2020: https://www.ft.com/content/13d09498-54e5-4886-9626-8a259529146b

10) On these data, see (in Japanese) "Basic Facts on Plastic Recycling 2019," Japanese Plastic Waste Management Institute, July 23, 2019: https://www.pwmi.or.jp/pdf/panf1.pdf

11) 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

12) For these data on power generation, see p. 225 (in Japanese) "Japan Environmental, Sustainable Society, and Biodiversity White Paper 2020," Ministry of the Environment Japan: https://www.env.go.jp/policy/hakusyo/r02/pdf/2_3.pdf

Table 1 Comparative per-capita plastic waste, 2016 (kg/year)

Country	Plastic waste generation (metric tons)	Total waste generation (metric tons)	% Plastic in solid waste	2016 Population (millions)	Per capita plastic waste generation (kg ／ year)
United States	**42,027,215**	**320,818,436**	**13.1**	**323.1**	**130.09**
EU-28	*29,890,143*	*243,737,466*	*11.7*	*511.2*	*54.56*
India	26,327,933	277,136,133	9.5	1,324.5	19.88
China	21,599,465	220,402,706	9.8	1,378.7	15.67
Brazil	10,675,989	79,081,401	13.5	206.2	51.78
Indonesia	9,128,000	65,200,000	14.0	261.6	34.90
Russian Federation	8,467,156	59,585,899	14.2	144.3	58.66
Germany	6,683,412	51,410,863	13.0	82.3	81.16
United Kingdom	6,471,650	32,037,871	20.2	65.6	98.66
Mexico	5,902,490	54,151,287	10.9	123.3	47.86
Japan	4,881,161	44,374,189	11.0	127.0	38.44
Thailand	4,796,494	27,268,302	17.6	69.0	69.54
Korea, Rep.	4,514,186	18,576,898	24.3	51.2	88.09
Italy	3,365,130	29,009,742	11.6	60.6	55.51
Egypt, Arab Rep.	3,037,675	23,366,729	13.0	94.4	32.16
France	2,929,042	32,544,914	9.0	66.9	43.81
Pakistan	2,731,768	30,352,981	9.0	203.6	13.42
Argentina	2,656,771	18,184,606	14.6	43.6	60.95
Algeria	2,092,007	12,378,740	16.9	40.6	51.59
Malaysia	2,058,501	13,723,342	15.0	30.7	67.09
Spain	1,832,533	20,361,483	9.0	46.5	39.42

Source: Kara Lavender Law, et al., 2020 [13)]

Japanese policymakers also attract considerable domestic and overseas criticism for emphasizing the role of nuclear energy in the power supply as well as for providing industrial heat. Much of the "laggard" argument directed at Japan in fact directly or indirectly centres on the role of nuclear power. After Japan's March 11, 2011 Fukushima nuclear disaster, close to 30% of the country's generating capacity was taken offline. In its place, a lot of coal and other fossil-fuel capacity was ramped up, restarted or newly built. The result was a spike in Japanese CO2 and other GHG emissions. In the ensuing years, a powerful domestic

13) Kara Lavender Law, et al., "The United States' contribution of plastic waste to land and ocean," *Science Advances*, October 31, 2020: https://advances.sciencemag.org/content/6/44/eabd0288

and international narrative has developed in which Japan's recovery of its once strong green credentials depends on it exiting nuclear, in addition to fossil fuels, in favour of 100% renewables. Many Japanese and overseas analyses insist that the EU example shows that renewable energy, especially solar and wind, can drive coal and nuclear out of the Japanese power mix, and go on to decarbonize the entire energy economy.

Yet as we have seen earlier, many EU stakeholders argue that Swedish, Finnish, Norwegian and other decarbonization has been rooted in the hydro and nuclear shunned by the EU taxonomy. And the Japanese scenarios of exiting nuclear in addition to coal generally rely on increased use of natural gas in place of coal over the decade to 2030.[14] But switching from coal to natural gas may not reduce GHG emissions. Recent research points to high rates of methane leakage at all stages of production and use of natural gas.[15] And even research that seeks to advance 100% renewables via the use of natural gas as transitional, back-up generation warns that the risk of lock-in effects are quite strong.[16]

Moreover, the IEA agued back on May 28 of 2019 that exiting nuclear would be very unwise:

> "If other low-carbon sources, namely wind and solar PV, are to fill the shortfall in nuclear, their deployment would have to accelerate to an unprecedented level. In the past 20 years, wind and solar PV capacity has increased by about 580 gigawatts in advanced economies. But over the next 20 years, nearly five times that amount would need to be added. Such a drastic increase in renewable power generation would create serious challenges in integrating the new sources into the broader energy system. Clean energy transitions in advanced economies would also require $1.6 trillion in additional investment over the same period, which would end up hurting consumers through higher electricity bills." [17]

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14) One example (in Japanese, with an English-language summary) is the Japan Renewable Energy Institute's "Proposal for 2030 Energy Mix in Japan (First Edition)," August 6, 2020: https://www.renewable-ei.org/en/activities/reports/20200806.php

15) See "Scientists Discover 50 Methane Leaks in City of Hamburg's Gas Utility Network," Environmental Defense Fund, December 4, 2020: https://www.edf.org/media/scientists-discover-50-methane-leaks-city-hamburgs-gas-utility-network

16) See C. Gürsan, V. de Gooyert, "The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition?," *Renewable and Sustainable Energy Reviews*, November 17, 2020: https://www.sciencedirect.com/science/article/pii/S1364032120308364

17) See "Steep decline in nuclear power would threaten energy security and climate goals," International Energy Agency, May 28, 2019: https://www.iea.org/news/steep-decline-in-nuclear-power-

Thus at a global level the hard math of decarbonization is a major hurdle for the 100% renewable argument. The calculations are even more difficult for Japan, where renewable costs are comparatively high. The majority of detailed and credible assessments of Japan's energy options therefore emphasize that decarbonization will require nuclear power. One recent example is Wood Mackenzie's December 10, 2020 argument that decarbonization:

> "will be particularly difficult for Japan given its high generation costs from renewables. Aggressive policies such as subsidies will be needed given that, with the most expensive power generation in Asia Pacific, Japan will not see renewables compete with coal-fired power until beyond 2030. As such, our carbon neutral scenario can only be realised with an expanded role for nuclear in Japan – a contentious position. We estimate that Japan will need to add an additional 25 GW of nuclear capacity by 2050, equal to over US$150 billion of investment, to meet emissions goals." [18)]

As accelerated decarbonization becomes national policy priority, Japanese advocates of nuclear power have stepped up pressure to refocus the country's energy-environmental debate. Hence on December 7, 2020, Japan's largest business lobby, Keidanren, argued that nuclear energy was essential to decarbonization. The Keidanren made its points in a "Society 5.0 with Carbon Neutral" set recommendations.[19)] Keidanren pointed out that the restart of existing nuclear assets, construction of new reactors, and investment in advanced nuclear power are critical for decarbonization. The Keidanren added that offshore wind and other renewable energy initiatives are important as well, but that nuclear's low cost and reliability make it key to decarbonization.

The Keidanren argument was confirmed by the December 9, 2020 release of the International Energy Agency (IEA) and the OECD Nuclear Energy Agency joint report on the "Projected Costs of Generating Electricity 2020." The report is derived from a survey of 24 countries, including Japan, China, India, the US, European countries. It reveals that even without assessing the overall system costs of renewable energy and other electricity options,

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would-threaten-energy-security-and-climate-goals

18) See the comments in Gavin Thompson, "Nuclear – the cleanest dirty word," Wood Mackenzie APAC Energy Buzz, December 10, 2020: https://www.woodmac.com/news/opinion/nuclear--the-cleanest-dirty-word/

19) See (in Japanese) "Towards Implementing Carbon Neutrality by 2050 (Society 5.0 with Carbon Neutral)," Keidanren, December 7, 2020: https://www.keidanren.or.jp/policy/2020/123.html

Table 2 Power costs in Japan, 2020

Power costs in Japan	
Generation technology	Generation cost (USD/MWh)
Utility-scale solar	172
Offshore wind	200
Onshore wind (>1MW)	140
Nuclear	87
Gas (CCGT)	93
Coal	100

Source: IEA, 2020 [20)]

nuclear is the cheapest in Japan. We can see this fact in table 2, which summarizes the report's numbers for Japan. Calculated in terms of USD/MWh of generation, the study determined that Japan's cheapest renewable option is large (over 1 MW capacity) onshore wind, with a cost of 140 USD/MWh. The next-cheapest is utility-scale solar, at 172 USD/MWh, followed by offshore wind at 200 USD/MWh. Compared to these very high costs, in addition to GHG-intensive fossil fuel generation (gas and coal), nuclear is the least expensive, at 87 USD/MWh.

The IEA report also makes two other very important points. One is that Japan's power-generation options in general are significantly more costly than its regional competitors in India and China, in addition to Europe and the US. Japan's renewable costs are shown to be 2 to 3 times higher than its counterparts. Second, the report highlights the importance of examining the broader power-system context in which a given generation technology is embedded. This system-cost approach is extremely detailed because of the enormous geographical, climatological structural and other variation among power systems and their component inputs, storage, demand profiles and other factors. But the studies undertaken hitherto suggest that solar and other variable renewable generation contributes less value to the power system with rising levels of penetration. Simply stated, the intermittency requires more investment in storage, transmission, and other infrastructure.

It is no surprise therefore that most of Japan's mainstream energy and environmental think tanks regard nuclear as critical to achieving the 2050 decarbonization commitment. On

20) The report is summarized (and available for download) at the "Projected Costs of Generating Electricity 2020," International Energy Agency, December 9 : 2020: https://www.iea.org/reports/projected-costs-of-generating-electricity-2020

December 14, 2020, a subcommittee of the Natural Resources and Energy Commission met to examine renewables and grid modernization in pursuing decarbonization. The subcommittee received proposals from four of Japan's major energy and environmental organization, including the Renewable Energy Institute, the National Institute for Environmental Studies, the Institute of Energy Economics, and the Central Research Institute of the Electric Power Industry. Only the Renewable Energy Institute argued that it was feasible to achieve100% renewable energy and the elimination of nuclear, and that scenario was premised on a significant investment in grid infrastructure coupled with continued declining prices in renewables.[21] As we saw earlier, Japanese solar and wind renewable costs are very high. And as we will see below, the prospects for price reductions appear contingent on critical raw materials whose prices are already trending upwards.

BloombergNEF's Energy Outlook

We have seen that the Japanese are reassessing the role of nuclear in decarbonizing the power mix. But the Japanese are hardly alone in looking to nuclear, and indeed some forecasts see China's decarbonization requiring a nine-fold increase in nuclear energy by 2040.[22] Wood Mackenzie analysts are even more insistent on nuclear in China. A December 10 article by Wood Mackenzie researchers argued that even assuming extremely ambitious deployment of wind, solar and storage, China's prospects for decarbonizing by 2060 would require increasing its nuclear capacity from 50 GW in 2020 to 620 GW by 2060.[23]

The Boston Consulting Group (BCG) also advances ambitious targets for Chinese nuclear in order to decarbonize by 2060. The BCG has spent years working with high-level Chinese think tanks, research institutes and stakeholder companies. Based on those connections and extensive local emissions data, the BCG produced a broad-based decarbonization scenario for China. Their scenario posits nuclear as one-third of total power generation in

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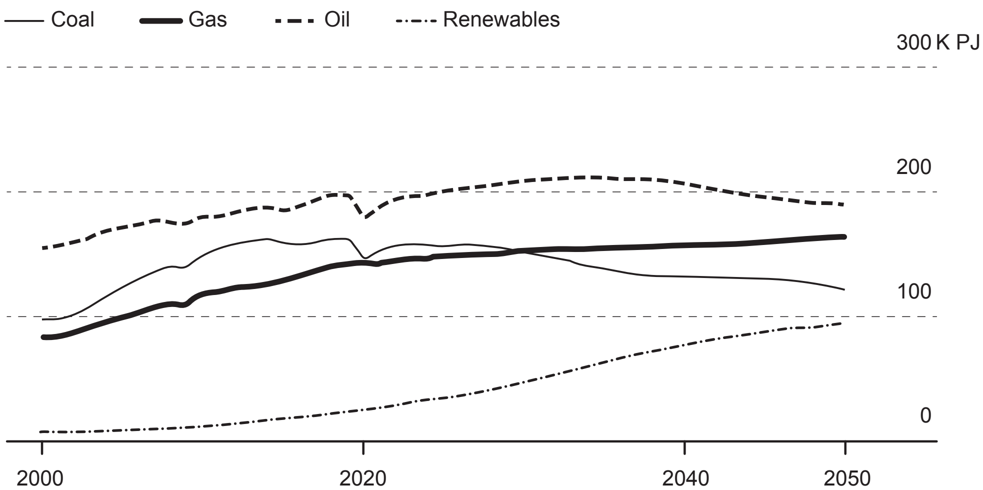
21) On this, see (in Japanese) "Grid bolstering and expansion of renewable energy seen as necessary for decarbonization by 2050," *Nikkei Shimbun*, December 15, 2020: https://www.nikkei.com/article/DGKKZO67318590U0A211C2EE8000

22) See Narumi Shibata, "Why China is eager to promote atomic energy," *Japan Times*, December 6, 2020: https://www.japantimes.co.jp/opinion/2020/12/06/commentary/world-commentary/china-nuclear-energy/

23) See the comments in Gavin Thompson, "Nuclear – the cleanest dirty word," Wood Mackenzie APAC Energy Buzz, December 10, 2020: https://www.woodmac.com/news/opinion/nuclear--the-cleanest-dirty-word/

China by 2060.[24)]

The main reason for the increased attention to nuclear energy thus appears to stem from the increasingly widely shared consensus that accelerated decarbonization is necessary. The difficulties of relying only on renewables for decarbonization of the global primary energy mix are seen in **figure 1**, which displays the BloombergNEF's New Energy Outlook 2020. The figure shows the results of their very optimistic forecast of "a huge build-out of super-competitive wind and solar power, the uptake of electric vehicles and improved energy efficiency across industries."[25)] BloombergNEF and Bloomberg News frequently extrapolate trends in renewable energy, and suggest that "cheap renewable power sources will continue to push aside fossil fuels in the energy mix."[26)] Yet the figure reveals that even they expect



Source: Bloomberg NEF
Units are petajoules

Source: Mathis and Hodges, 2020[27)]

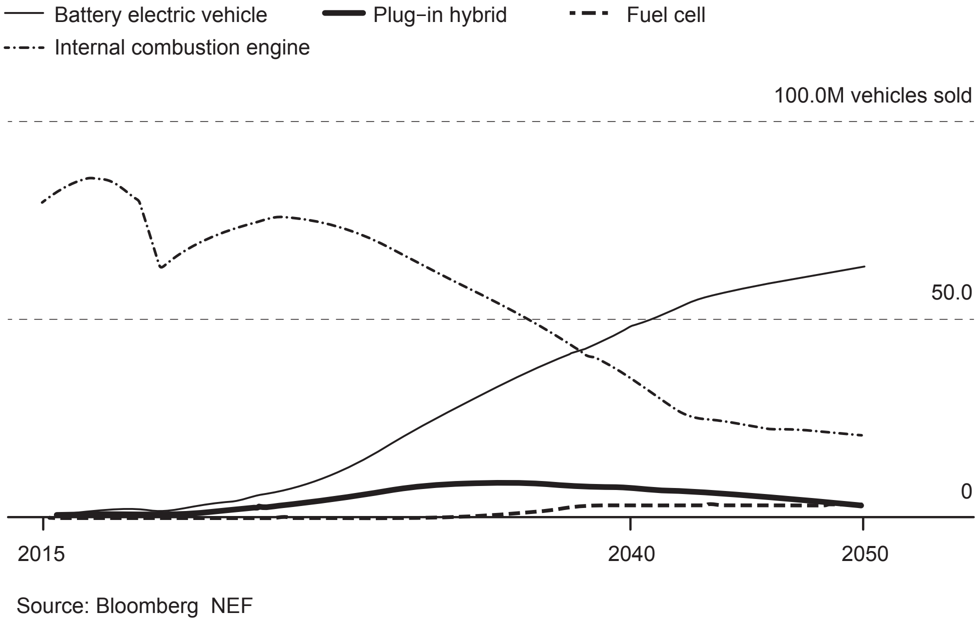
Figure 1 Global primary energy mix, 2000–2050

24) On the scenario, see Baiping Chen, et al., "How China Can Achieve Carbon Neutrality by 2060," Boston Consulting Group, December 14, 2020: https://www.bcg.com/ja-jp/publications/2020/how-china-can-achieve-carbon-neutrality-by-2060

25) See "Emissions and Coal Have Peaked as Covid-19 Saves 2.5 Years of Emissions, Accelerates Energy Transition," BloombergNEF, October 27, 2020: https://about.bnef.com/blog/emissions-and-coal-have-peaked-as-covid-19-saves-2-5-years-of-emissions-accelerates-energy-transition/

26) Will Mathis and Jeremy Hodges, "Green Power to Draw $11 Trillion Investment by 2050: BNEF," *Bloomberg News*, October 27, 2020: https://www.bloomberg.com/news/articles/2020-10-27/green-power-to-draw-11-trillion-investment-by-2050-bnef-says

27) Will Mathis and Jeremy Hodges, "Green Power to Draw $11 Trillion Investment by 2050: BNEF,"



Source: Mathis and Hodges, 2020 [28)]

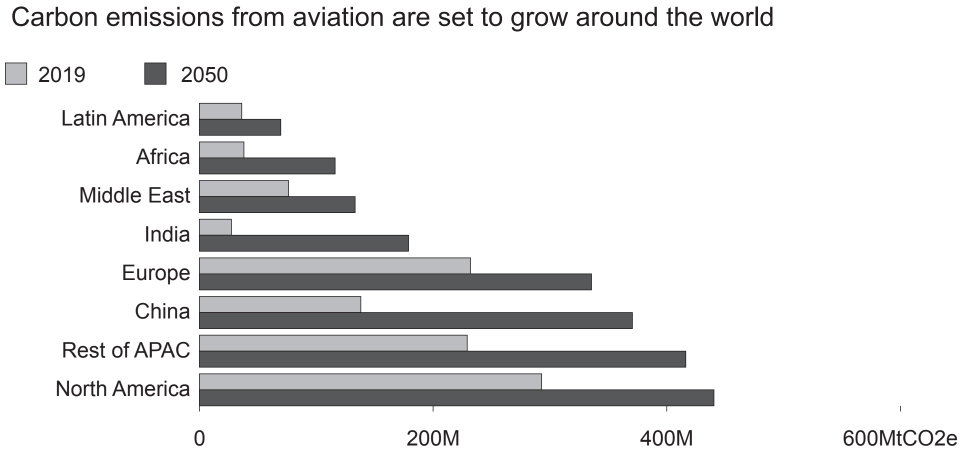
Figure 2 Vehicle types by technology, 2015-2050

oil, gas and coal to remain dominant in the global energy mix out to 2050. In their scenario, renewables certainly increase 360% between 2020 and 2050, from about 27K Petajoules (PT) to 95K PT. But that latter figure is well below the roughly 126K PT role remaining for coal in 2050, let alone natural gas (164K PT) and oil (164K PT).

The projected role of renewables in figure 1 remains below fossil fuels in spite of very ambitious projections for electric vehicles. Figure 2 shows that the BloombergNEF Outlook calculates 2020 sales of electric vehicles as 1.3 million versus 62.8 million internal combustion engine vehicles (and 428,000 plug-in hybrids and 11,300 fuel cell vehicles). The Outlook suggests that by 2050 there will be 62.9 million electric vehicles sold whereas internal combustion engine sales will drop to 20.9 million (and 2.9 million plug-in hybrids and 3.4 million fuel cell vehicles). That projected diffusion of electrified is only a guess, of course, and overlooks the very serious CRM issues we shall discuss below. Even so, it has surpris-

Bloomberg News, October 27, 2020: https://www.bloomberg.com/news/articles/2020-10-27/green-power-to-draw-11-trillion-investment-by-2050-bnef-says

28) Will Mathis and Jeremy Hodges, "Green Power to Draw $11 Trillion Investment by 2050: BNEF," *Bloomberg News*, October 27, 2020: https://www.bloomberg.com/news/articles/2020-10-27/green-power-to-draw-11-trillion-investment-by-2050-bnef-says



Source: Bloomberg NEF

Source: Mathis and Hodges, 2020[29]

Figure 3　Carbon emissions in aviation

ingly limited impact on oil demand, at least compared to what is implied by the narrative of "super-competitive wind and solar" and "cheap renewable power sources" driving fossil fuels out of energy mixes.

It should be noted that the BloombergNEF Outlook for 2020 is also dubious on the potential for batteries and hydrogen to decarbonize such sectors as aviation. Currently, aviation is fueled almost entirely with GHG-intensive jet fuel derived from distilling crude oil. Only a very small amount of jet few is derived from biofuels, and proposals to decarbonize jet fuel through hydrogen are in their infancy. Thus, as seen in figure 3, BloombergNEF project emissions from aviation to double between 2020 and 2050.

We should not be surprised at BloombergNEF's reluctance to simply pencil in more renewable-energy based "green hydrogen" to cover any gaps in decarbonization. One reason is that the required supply of hydrogen to substitute for fossil fuels is staggering. According to one assessment, the global demand for hydrogen would be equivalent to 80 exajoules of hydrogen a year by 2050. To provide comparative context, 80 exajoules is roughly equivalent to the total primary energy provided by coal in China in 2019.[30] *Bloomberg News* revealed in

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29) Will Mathis and Jeremy Hodges, "Green Power to Draw $11 Trillion Investment by 2050: BNEF," *Bloomberg News*, October 27, 2020: https://www.bloomberg.com/news/articles/2020-10-27/green-power-to-draw-11-trillion-investment-by-2050-bnef-says

30) See "Primary energy consumption in China in 2018 and 2019, by fuel type (in exajoules)," Statistica, November 3, 2020: https://www.statista.com/statistics/265612/primary-energy-consumption-

a December 4, 2020 article that "[d]oing that with electrolyzers, the only viable zero-carbon pathway, would require more electricity than the entire world produced in 2019. That will need about nine times more wind and solar generators than exist worldwide to date."[31] As well shall see below, the CRM needed for that kind of expansion of renewable energy would completely outstrip the capacity of supply chains.

Not surprisingly, *Bloomberg News* finds itself compelled address the expanding role of nuclear energy. They note that in the face of prodigious requirements for industrial heat, "[s]mall modular reactors are drawing the attention of policy makers across the U.S. and Europe because of their versatility. They can deliver a steady flow of energy both in the form of heat and electricity. The power helps balance intermittent supplies coming from wind and solar farms. The heat can help decarbonize some of the world's dirtiest industries."[32]

Indeed, in the fall of 2020 the UK government announced a GBP 215 million investment in small modular reactors,[33] and the US Biden Presidency (from January 21, 2021) is expected to continue if not expand support for small modular reactors.[34] Moreover, on December 8, 2020 the French government announced that it would continue to emphasize nuclear power as a key arm of decarbonization. French president Emmanuel Macron announced that France would build its first nuclear-powered aircraft carrier and that the nuclear industry per se would receive EURO 500 million in new investment plus addition funding for modernization. Macron emphasized that France's "energy and ecological future depends on nuclear power; our economic and industrial future depends on nuclear power; and France's strategic future depends on nuclear power."[35]

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in-china-by-fuel-type-in-oil-equivalent/

31) David Fickling, "Big oil seeks redemption in the hydrogen revolution," *Bloomberg News*, December 14, 2020: https://www.bloomberg.com/graphics/2020-opinion-hydrogen-green-energy-revolution-challenges-risks-advantages/oil.html

32) Jonathan Tirone, "Atomic Heat in Small Packages Gives Big Industry a Climate Option," *Bloomberg News*, December 5, 2020: https://www.bloomberg.com/news/articles/2020-12-05/nuclear-power-in-energy-transition-small-modular-reactors-challenge-natural-gas

33) UK Research and Innovation, "UK government invests £215 million into small nuclear reactors," November 19, 2020: https://www.ukri.org/news/uk-government-invests-215-million-into-small-nuclear-reactors/

34) Peter Behr, "Biden, once a critic, may boost nuclear power," *E&E News*, December 3, 2020: https://www.eenews.net/stories/1063719675

35) Concerning the details of France's announcement, see "Macron stresses importance of nuclear energy for France," *World Nuclear News*, December 9, 2020: https://www.world-nuclear-news.org/Articles/Macron-stresses-importance-of-nuclear-energy-for-F

What About Wind?

Many Japanese and overseas renewable energy advocates insist that wind power, especially offshore wind, could be key to decarbonizing. The Japan Wind Power Association has argued that Japan's total potential is "128 GW for fixed bottom and 424 GW for floating wind."[36] And to be sure, the European Commission has argued that installing a capacity of 300 GW offshore wind could meet 30% of Europe's energy demand by 2050. In addition, the Ocean Renewable Energy Action Coalition foresees a 1.4 TW deployment of offshore wind and other marine energy by 2050, meeting about 10% of projected global power demand.[37]

In Japan in 2020, as we see in figure 4, there are just over 13 GW of offshore wind potential under consideration by Ministry of Environment environmental impact assessments (in the figure, EIA). That 13 GW is a considerable amount of power capacity, though actual output would generally be at best 30-50% of rated capacity due to the inherent intermittency of offshore wind generation.

Moreover, it is unclear whether the ambitions for hundreds of gigawatts of offshore wind could ever be realized. One reason is that surveys of Japan's marine environment reveal that there is less available space for projects than is generally assumed. One recent assessment indicates that 12% of Japan's territorial waters appear suitable for wind generation, but that this figure declines to 2% when shipping lanes, fishery rights, and other issues are added to the calculation. That assessment indicates that total capacity might only be 5.3 GW for bottom-fixed wind and 37.9 GW for floating wind.[38]

Cost is another factor that may hinder Japan's offshore wind. As we saw in table 2, the IEA "Projected Costs of Generating Electricity 2020" assesses Japan's offshore wind costs at a 200 USD/MWh. This cost is more than twice the 90 USD/MWh average reported in Europe, and even lower costs in China (82 USD/MWh) and the US (66 USD/MWh).

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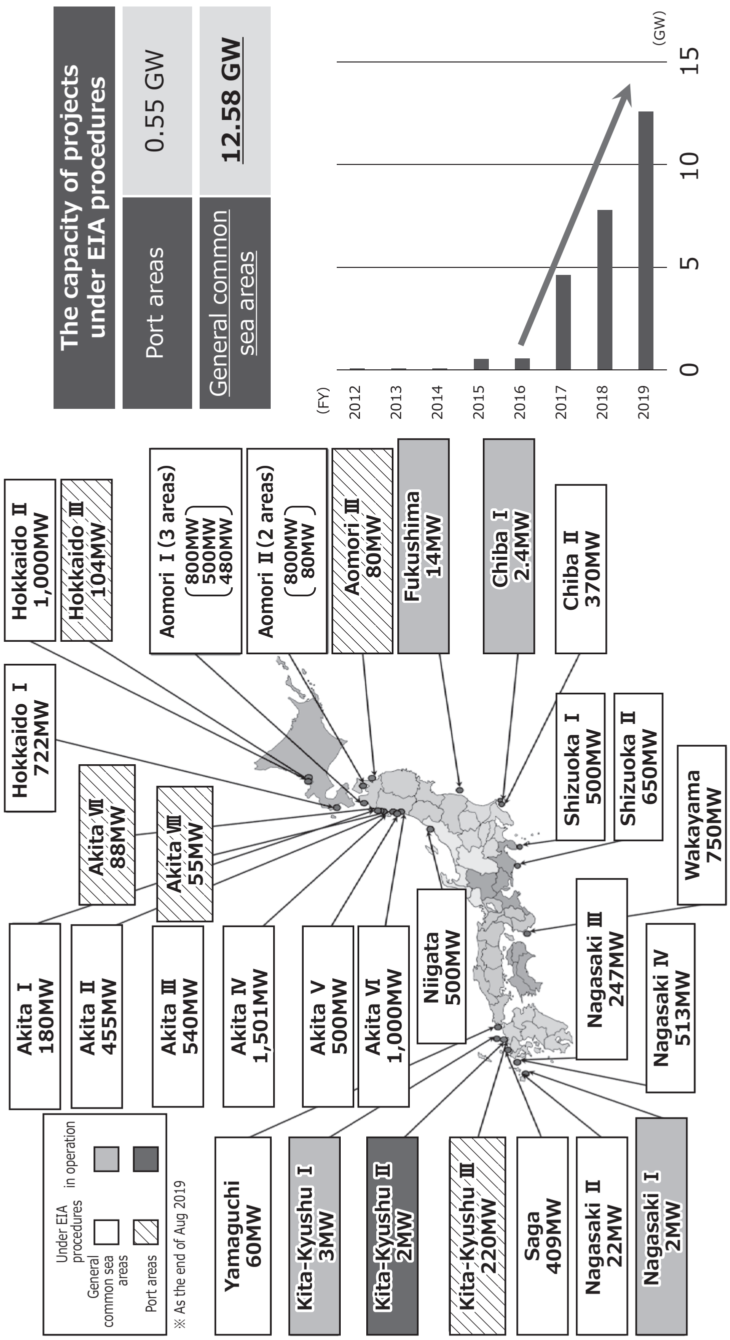
36) See "Japan aims for 10 GW offshore wind energy capacity by 2030," EVwind, July 30, 2020: https://www.evwind.es/2020/07/30/japan-aims-for-10-gw-offshore-wind-energy-capacity-by-2030/76153

37) On this see, "The Power of Our Ocean," Ocean Renewable Energy Action Coalition, December 2020: https://gwec.net/oreac/

38) On this, see Hideaki Obane, et al., "A study on level of possible conflict for developing offshore wind energies in Japanese territorial waters," Socio-economic Research Center, Japan Central Research Institute of Electric Power Industry, October 21, 2020: https://criepi.denken.or.jp/jp/serc/discussion/download/20005dp.pdf



Source: Shimizu, 2020[39]

Figure 4 Offshore wind projects in Japan, as of 2020

39) See (in Japanese and English) "Renewable Energy Policy in Japan," Renewable Energy Institute of Japanese Ministry of Economy, Trade and Industry Presentation, March 3, 2020: https://www.renewable-ei.org/pdfdownload/activities/16_JuntaroShimizu.pdf

Whether Japan can reduce these costs in addition to associated system costs remains to be seen. The general assumption is that accelerated diffusion of a given generation technology leads to reduced costs. But in Japan, even the world's 3 rd largest deployment of solar power has seen its utility-scale solar cost remain high, at 172 USD/MWh, compared to 51 USD/MWh in China and 35 USD/MWh in India.

An additional potential constraint on the massive deployment of offshore wind, in Japan and elsewhere, is its massive critical raw material (CRM) requirements. CRM are a list of materials that vary by country and over time, because they include materials that are critical to economic activity in addition to having uncertain supply chains. But in general, CRM include rare earths and other minerals and metals essential to high-technology, variable renewable energy such as offshore wind, electric vehicles, and myriad other products. Offshore wind depends on many CRM in the magnets and other components. It is particularly dependent on copper, which is often included among the CRM.[40)]

Curiously, Japanese and other 100% renewable energy advocates express little concern over whether there are adequate supplies of copper and other CRM to achieve dramatic wind deployments in addition to satisfying the myriad other sources of demand for CRM. But as we see in **figure 5**, from an assessment by Wood Mackenzie, there are good reasons to be concerned at wind's share of finite supplies of copper. The figure portrays the role of copper in both onshore and offshore wind, and highlights offshore wind's very high requirement for copper in cabling. Indeed, the International Renewable Energy Association calculations of copper and other materials used in wind power indicate that 500 MW of offshore wind requires 190,656 tonnes of copper.[41)] The Wood Mackenzie analysis points out that wind is the most copper-intensive form of renewable energy generation. It also estimates that between 2018 and 2028 650 GW of onshore and 130 GW of offshore wind will be deployed, implying a copper consumption of 5.5 million tonnes. The Wood Mackenzie study moots the possibility of advances in aluminum technology, to substitute for some of required copper cabling. But at present copper is advantaged by being far more malleable, corrosion-resistant, easy to maintain, and other factors.[42)]

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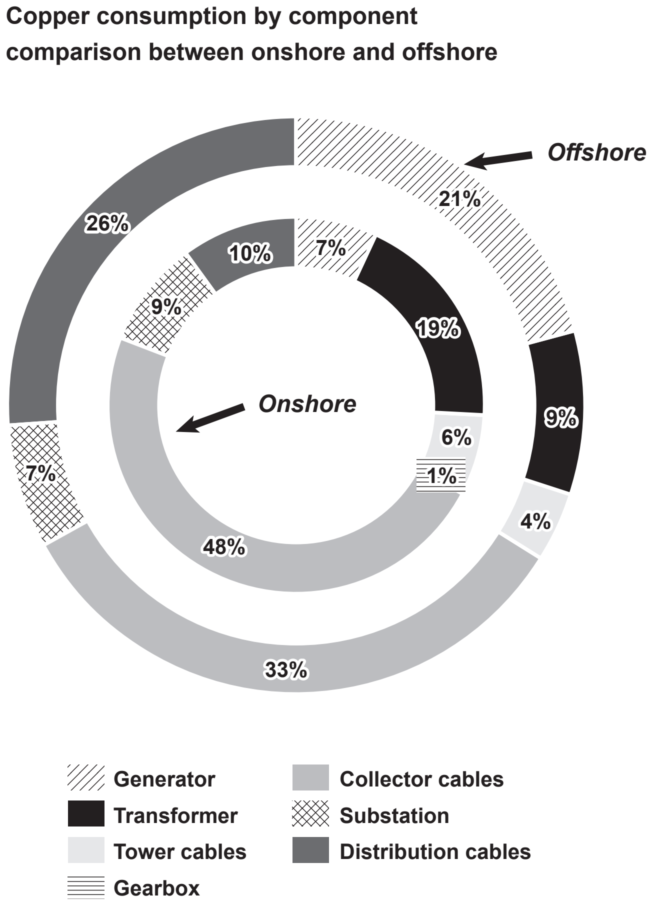
40) See Dieuwertje Schrivers, et al., "A review of methods and data to determine raw material criticality," *Resources, Conservation and Recycling*, Vol. 155, April 2020: https://www.sciencedirect.com/science/article/pii/S0921344919305233

41) See the "Future of Wind," International Renewable Energy Association, October: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Oct/IRENA_Future_of_wind_2019.pdf

42) On copper's advantages, see "Why use copper rather than aluminum as the conductor in power cables?" Leonardo Energy, November 16, 2020: https://help.leonardo-energy.org/hc/en-us/arti-



Source: Wood Mackenzie, 2019 [43]

Figure 5 Copper consumption per component in global wind

The enormous demand for copper in wind installations should be compared to total global annual mined production of copper, which was roughly 20 million tonnes in 2019.[44] Moreover, wind's additional new demand for this copper output has to be assessed in tandem with new demand for copper from electric vehicles, cooling, and other expanding areas. That comprehensive assessment suggests that copper and other CRM supply will become a con-

cles/205394842-Why-use-copper-rather-than-aluminium-as-the-conductor-in-power-cables-

43) See "Global wind turbine fleet to consume over 5.5Mt of copper by 2028," Wood Mackenzie, October 2, 2019: https://www.woodmac.com/press-releases/global-wind-turbine-fleet-to-consume-over-5.5mt-of-copper-by-2028/

44) See "Copper," U.S. Geological Survey, Mineral Commodity Summaries, January 2020: https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-copper.pdf

straint on renewable expansion, on top of NIMBY and other issues. Indeed, rising prices for copper and other CRM, driven by demand increases and supply constraints, seem likely to dampen recent years of cost declines in renewables, and perhaps drive price increases.

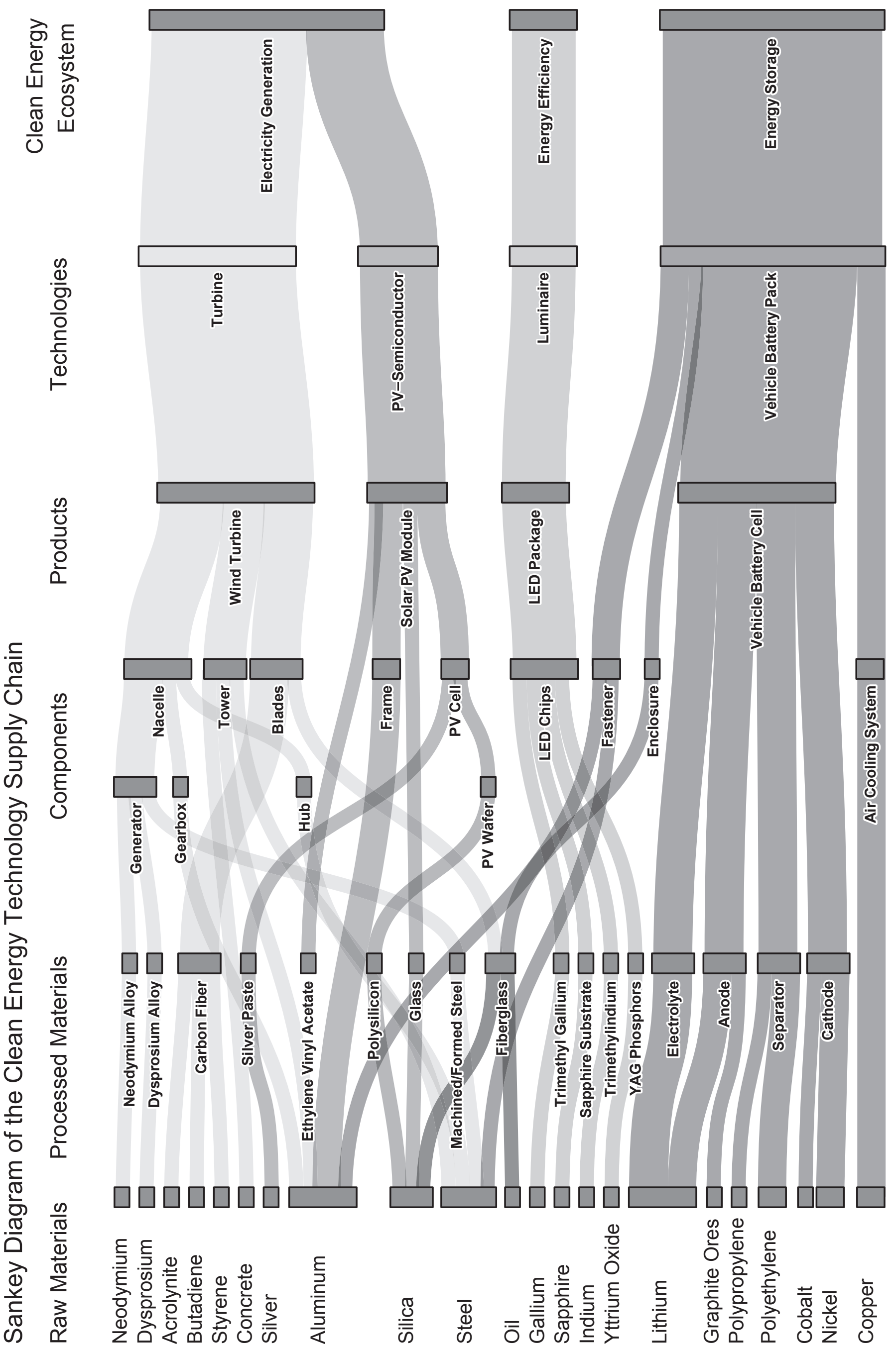
CRM and Other Materials for Decarbonization

The importance of CRM and other materials (including steel) are highlighted in **figure 6**. The figure is from the US Energy Futures Initiative February 2019 report on "Advancing the Landscape of Clean Energy Innovation." The report was led by Ernest Moniz, former head of the US Department of Energy and President and CEO of the US Energy Futures Initiative. The Initiative has also prepared numerous reports on decarbonization and energy transitions for several US states, the American Federation of Labor and Congress of Industrial Organizations, and other interests.[45] The present report is aimed at innovation in decarbonizing energy rather than complete decarbonization per se by any particular year. It is thus not a roadmap but rather an analysis of the energy innovation ecosystems in the US. What make the report especially valuable is its analysis of the role of critical and strategic materials in energy options as well as the larger built infrastructure (such as smart cities) in which they are or will be deployed.

Figure 6, taken from the above report, portrays three separate ecosystems of energy generation, efficiency and storage. It depicts the flow of copper and other raw materials from the start of the supply chain, through processing and into the products and technologies that embody the respective ecosystems. It is important to note here that the figure's portrayal of copper in cooling does not imply that copper, is only used in, but rather that copper is used in cooling as well as the myriad other processes. This is a recognition that copper's role is far larger than acknowledged by 100% renewable energy advocates. Indeed, the report warns that "[l]ithium, cobalt, graphite and other critical materials are becoming strategic resources for enabling a clean energy future. Their supply chains should be closely monitored by an impartial entity that interfaces with both public and private stakeholders. Regular updates should be publicly available." [46] The advice is a warning of poor information concern-

45) The US Energy Futures Initiative reports are available at the following URL: https://energyfuturesinitiative.org/efi-reports

46) See page 116 of "Advancing the Landscape of Clean Energy Innovation," Energy Futures Initiative, February 6, 2019: https://energyfuturesinitiative.org/news/2019/2/6/clean-energy-innovation-report



Source: Energy Futures Initiative, 2020[47]

Figure 6 Supply chains for clean energy technology

47) See "Clean Energy Innovation Report Identifies Breakthrough Technologies," Energy Futures Initiative, February 6 , 2019: https://energyfuturesinitiative.org/news/2019/ 2 / 6 /clean-energy-innovation-report

ing CRM supply chains. The warning captures the present, in which electric vehicle companies and renewable-energy advocates propose exponential growth of solar, wind and storage systems without asking whether sufficiently robust CRM supply chains are in place to make them.

Is Recycling Sufficient?

Of course, many 100% renewable advocates, such as Greenpeace, sidestep the material challenges by insisting that recycling and reuse will suffice to meet increasing demand.[48)] This is in spite of the fact that the same advocates are calling for a global energy transformation through decarbonizing energy systems, smart communications, and all the other aspects of modern power, water, transport, communications and other infrastructure systems. Such a transformative, decarbonizing built environment cannot be based on recycling present stock. Even present stock requires new copper. Indeed, a November 17, 2020 study of recycling via "urban mining" indicates that, for copper, total additions to stock in use generally exceed reductions from stock. The report determined that global copper stock in use was about 450 million tonnes in 2018, with 24 million tonnes added and 13 million tonnes subtracted. That left a total of 13 million tonnes on net new addition. In other words, relying on recycling would not suffice.[49)] The data are reproduced in visual summaries of the 2018 stocks and flows of copper for the global community, China, the EU28, Latin America, North America, and Japan.[50)]

Clearly, too many proposals are based on inadequate grasp of material facts, which is why the US Energy Futures Initiative called for evidence-based argument. This point about the need for information extends to the EU as well. On December 10, 2020, the Hague Centre

48) For example, the author of a December ９, 2020 Greenpeace report opposing seabed mining for CRM insisted that "nations should focus more on reusing and recycling existing supplies of minerals" (cited in Jonathan Waits, "Deep-sea 'gold rush': secretive plans to carve up the seabed decried," *The Guardian*, December ９, 2020: https://www.theguardian.com/environment/2020/dec/09/secretive-gold-rush-for-deep-sea-mining-dominated-by-handful-of-firms).

49) The data on copper are just one aspect examined in the International Copper Association-funded study 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

50) The data are available at "Stocks and Flows,"Copper Alliance, 2020: https://copperalliance.org/about-copper/stocks-and-flows/

for Strategic Studies (HCSS) released a very detailed, book-length report on "Securing Critical Materials for Critical Sectors: Policy options for the Netherlands and the European Union." The HCSS analysis examined the CRM implications of the Dutch and EU commitments to decarbonization. Their broad-based analysis included materials demand for renewable energy (wind, solar, geothermal), energy grid infrastructure, carbon-capture and storage, electric vehicles, and semiconductors. They note that the EU has been concerned about dependence on Chinese supply of CRM since the first EU list of CRM in 2011. But that list did not induce action on increasing EU self-sufficiency, so in 2020 the EU updated its CRM list and focused on "European self-sufficiency and autonomy in the procurement of critical materials and strategic technologies." The HCSS point out that recycling and other "circular economy" policies are simply not enough to address the massive increase in required volumes in CRM implied by decarbonization. And reflecting the US Energy Futures Initiative's concerns about information, the HCSS highlight a generalized lack of stakeholder awareness. They highlight the current magical thinking about CRM supply chains, not simply among policymakers but also industry participants, academics, and other stakeholders. The HCSS depicts it as "knowledge erosion" and their arguments merit quotation in full:

> "Market actors are responsible for ensuring resilient supply chains for themselves, while the role of the government has been marginalized. A lack of long-term strategic direction and a phenomenon of knowledge erosion have resulted from reduced government involvement.
>
> Policy makers have become unfamiliarized with issues of security of supply and, at the same time, the role of technical expertise has been increasingly neglected in policy-making. Situational awareness and context must be created so that policy interventions to secure supply become meaningful. Foresight capabilities on the governmental level should be strengthened in order to facilitate the development of long-term strategies. Technological foresight into future technology and material requirements is pivotal in realizing durable strategies.
>
> The phenomenon of knowledge erosion did not occur solely on the governmental level, but also on the industrial and academic levels. Due to heavy reliance on global value chains for imports of materials, intermediate and end products, the EU and the Netherlands currently lack the industrial knowledge and facilities to become self- sufficient. There is a lack of academic and professional focus on developing industrial expertise for mining, refining and other supply chain stages."

The HCSS thesis of "knowledge erosion" seems only partially correct, however. The problem seems more to be a combination of knowledge erosion coupled with the more generalized problem that green narratives do not grasp the CRM implications of exponential growth. Certainly it is true that governments have become less sensitive to security of supply through decades of emphasizing outsourcing and offshoring so as to reduce costs. The fetishization of efficiency at the expense of supply chain security has likely reached its limits due to the global coronavirus pandemic. Covid-19 produced an unprecedented and global spike in demand for medical masks and other equipment that most developed countries had offshored to China, India and other low-cost producers. The result was scarcity of supply and massive price spikes through panic buying. In one survey by the US Society for Healthcare Organization Procurement Professionals, the average cost for specialized masks and other personal protective equipment at nationwide nursing facilities had reportedly rose an astounding 1,064% by early April of 2020.[51] The United Nations Economic Commission for Europe (UNECE) was very quick to highlight the link between shortages of materials to cope with Covid-19 and the lack of sufficient CRM to realize the "green recovery" that many advocates were emphasizing. The UNECE summarized the conundrum as follows:

> "The immediate response to the COVID-19 pandemic and the recovery from the severe economic downturn it will trigger will require a massive fiscal response. Many such measures have been announced by numerous countries and multilateral financial institutions.
>
> If we are to stay on course to meet the goals of the 2030 Agenda for Sustainable Development, it is crucial that the related massive investments are directed towards a 'green,' and not a brown recovery,' stressed UNECE Executive Secretary Olga Algayerova.
>
> However, the materials required for a green energy transition, such as copper, cobalt, lithium or rare earth elements (REEs), are currently not sufficiently accessible.
>
> 'The metals and minerals required for technologies such as solar photovoltaics, batteries, electric vehicle motors, wind turbines, and fuel cells already face key sustainability challenges,' highlighted Michael Haschke, R&D Manager at DMT Group in Germany, member of UNECE's Expert Group on Resource Management. 'Pressure put on supply chains

51) The study is summarized by James M. Berklan, "Analysis: PPE costs increase over 1,000% during COVID-19 crisis," McKight's Long-Term Care News, April 9, 2020: https://www.mcknights.com/news/analysis-ppe-costs-increase-over-1000-during-covid-19-crisis/

by the pandemic has increased the challenges'." [52)]

In other words, the conviction that solar and wind plus electric vehicles must be the focus of a decarbonizing "green recovery" has overwhelmed concerns for CRM supply chains. Advocates of 100% renewable transitions certainly are reluctant to consider evidence that CRM constraints may require difficult choices, including maintaining existing nuclear (which supplies 10% of global electricity)[53)] let alone expanding it. Yet the current emphasis that solar and wind are the cheapest source of power clearly overlooks the precarious logistics of CRM supply chains. We have already seen that the "cheapest cost" argument relies on ignoring the larger system costs, especially as solar and wind penetration levels increase. Were the component CRM costs needed for the solar and wind to spike due to supply shortages, that could seriously impair the overall project of decarbonization. Supply shortages could ensue from outstripping the logistical capacity of supply chains. But even before those limits are reached, the crisis could arise from political instability in producing countries, strikes in the mining sector, or deliberate export restrictions by China. Indeed, the past has seen massive price spikes in REE, such as from 2010-2012 when China revised its public policies concerning their export.[54)] Were global progress on decarbonization undermined by price increases, that complication could conceivably lead to a return to coal in power systems.

Planning Supply Chains

One indication of how difficult it is to plan supply chains for rapid growth is seen in China's 2020 shortage of glass for solar panels. This shortage became an issue through the summer and fall of 2020, as in 2018 Chinese officials placed constraints on highly polluting glass factory capacity. The result was that by November "[s]olar panel producers like Longi

52) See "Securing critical raw materials supply is key to the response to COVID-19," United Nations Economic Commission for Europe, April 17, 2020: https://www.unece.org/info/media/presscurrent-press-h/sustainable-energy/2020/securing-critical-raw-materials-supply-is-key-to-the-response-to-covid-19/doc.html

53) The data are in "Nuclear Power in the World Today," World Nuclear Association, November, 2020: https://www.world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx

54) The REE price spike in 2010-2012 is generally depicted as a deliberate effort of China to punish Japan. But a more nuanced analysis of the prior and subsequent history of Chinese public policies on REE can be found in Yozhou Shen, et al., "China's public policies toward rare earths, 1975–2018," *Mineral Economics*, 33, January 7, 2020: https://link.springer.com/article/10.1007/s13563-019-00214-2

Green Energy Technology Co. have asked the government in China, home to most solar manufacturing, to address the situation by approving new factories. Otherwise price hikes risk making solar power too expensive and halting the industry's momentum." [55] Other reports indicated that "shortages of solar module raw material polysilicon, solar glass and the EVA used for module backsheets had driven up their prices between 50% and 100% during the third quarter." [56] One would have thought the shortage would lead to mainstreaming of the debate lesson on the need for broad decarbonization portfolios and comprehensive planning of supply chains, siting, and end use. But as we see from the evidence, that learning remains confined to specialist work. Hence, there is serious risk that renewable price declines could go into reverse.

A further warning comes from the Canadian provincial government of Quebec, in documents prepared for its Plan for the Development of Critical and Strategic Minerals 2020-2025. [57] The Plan's reference to 22 "critical and strategic minerals" is generally comparable to this paper's usage of CRM. It defines "critical minerals" as those which are essential for "key sectors of the economy, present a high supply risk, and have no commercially-available substitutes." And the Plan's critical minerals include "antimony, bismuth, cadmium, cesium, copper, gallium, indium, tellurium, tin and zinc." The Plan then defines "strategic minerals" as those which are prominent for achieving provincial policy objectives, including the green economy and related initiatives for decarbonization and coping with climate change. Quebec's list of strategic materials includes "cobalt, graphite, lithium, magnesium, nickel, niobium, platinum group elements, rare earth elements, scandium, tantalum, titanium and vanadium."

Quebec is both a producer and consumer of these materials, as its mineral production constitutes one-fifth of the Canadian total. Quebec's power system is the most decarbonized in Canada, since over 95% of its electricity is generated by hydro whose GHG emissions are extremely low. [58] Quebec also has the most diverse mineral resource development in

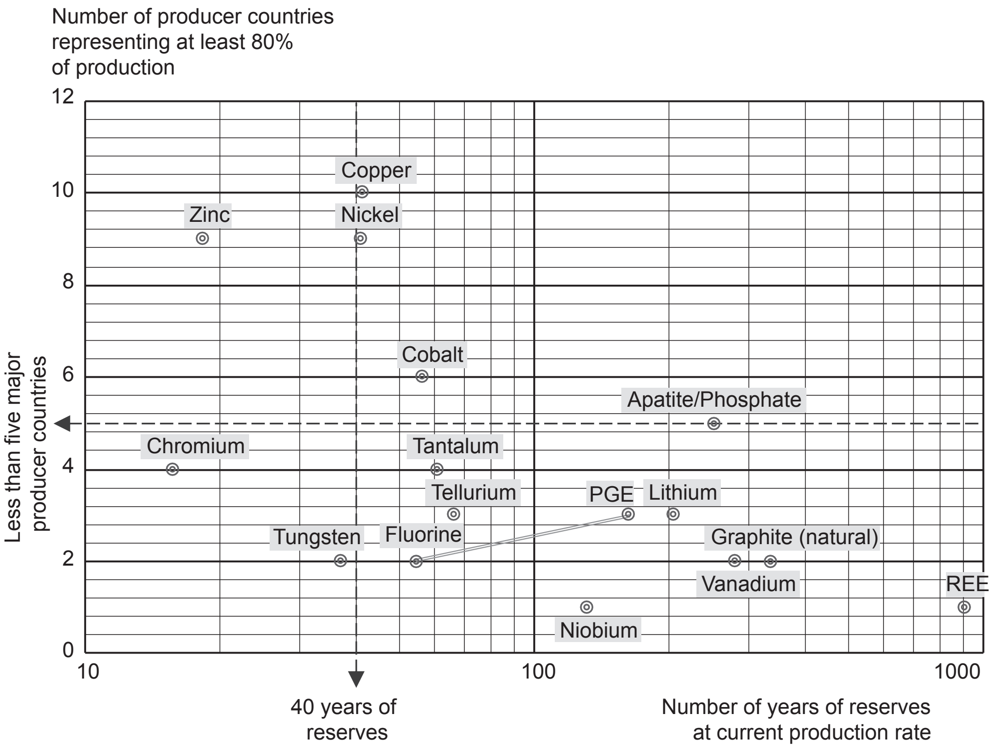
55) See Dan Murtaugh, et al., "Glass Shortage Threatens Solar Panels Needed for Climate Fix," *Bloomberg News*, November 5, 2020: https://www.bloomberg.com/news/articles/2020-11-05/a-glass-shortage-is-threatening-china-s-solar-power-ambitions

56) See Max Hall, "Canadian Solar flags up polysilicon, glass and EVA shortages," pv magazine, November 19, 2020: https://www.pv-magazine.com/2020/11/19/canadian-solar-flags-up-polysilicon-glass-and-eva-shortages/

57) A summary of Quebec's Plan for the Development of Critical and Strategic Minerals 2020-2025 can be found at "Development of critical and strategic minerals in Quebec," Government of Quebec Ministry of Energy and Natural Resources, 2020: https://www.quebec.ca/en/agriculture-environment-and-natural-resources/mining/critical-and-strategic-minerals/

58) Quebec's reservoir hydro emits little methane because the water in the reservoirs is very cold

Canada, producing 13 metals and 16 non-metallic minerals such as copper, nickel, zinc, rare earths, and several others. On October 29, 2020, the Government of Quebec announced that it would ramp up its critical and strategic mineral (CSM) policy, including public investment, because "[t]elecommunications, aerospace, renewable energy production, energy storage, the medical sector and transportation electrification are all high-growth sectors in which the CSM supply is vital. In the current context of transition to a lower-carbon economy and eco nomic upheavals accentuated by the COVID-19 pandemic, several countries are also looking to secure their CSM supply. It is also projected that the demand for CSMs will continue to



Source: Government of Quebec, 2020 [59)]

Figure 7　Relative availability of mineral resources

and well-oxygenated. See "Our energy is clean and renewable," Hydro Quebec, 2020: https://www.hydroquebec.com/about/our-energy.html

59) See figure 2, page 6, "Discussion Paper: Review of Quebec's Role in the Development of Critical and Strategic Materials," Government of Quebec Ministry of Energy and Natural Resources, 2020: https://cdn-contenu.quebec.ca/cdn-contenu/adm/min/energie-ressources-naturelles/Fichiers_mineraux/GU_review-development-critical-strategic-minerals_MERN.pdf

rise.” [60]

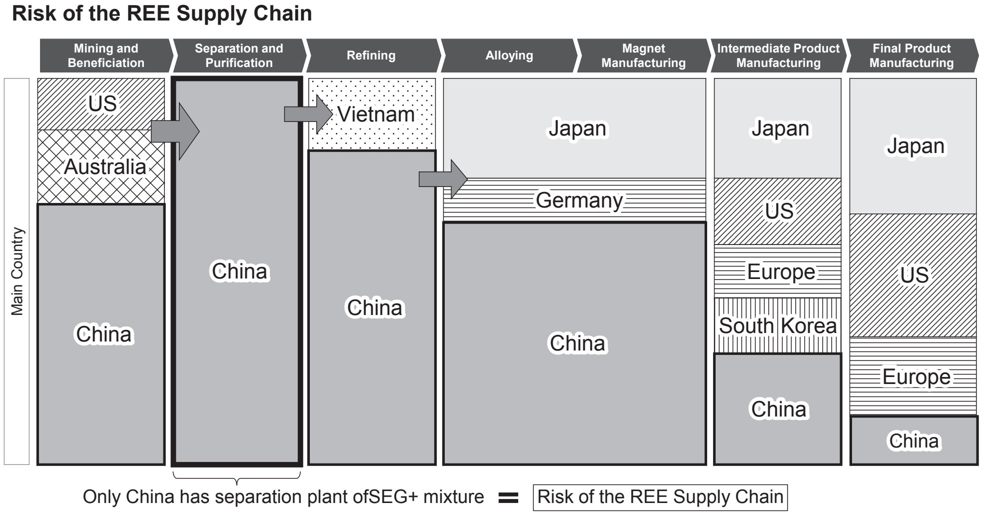
One of the Plan’s supporting documents is a discussion paper that reviews the state of CRM and Quebec’s role in mining and processing them. The document includes figure 7, which graphically illustrates the degree of concentration of producing countries (the y-axis) and the years of known reserves at current production rates (the x-axis). The figure reveals that a large number of CRM – including rare earths, niobium, and tungsten – are produced in fewer than 5 countries. It also shows that many CRM – such as copper and nickel – are less concentrated in terms of production, but that known reserves provide only 40 years of supply at current rates of production. To be sure, reserves are almost certain to increase, as they have in the past, through new discoveries. But these data points are striking indicators of CRM vulnerability. For many of the CRM, substitution is either not possible or at least very difficult with current technologies. In many cases, substitution involves using more of one CRM and less of another, as when the role of cobalt in lithium-ion battery chemistries is reduced in favour of increasing the proportion of nickel. The figure shows that nickel (most of which is used in making stainless steel) itself has lower reserves, and thus a vulnerable substitute.

Risks in Rare Earth Supply Chains

Figure 8 provides a detailed look at the supply chain risks for rare earth elements (REE), a subset of the CRM. The figure is from a February 2020 report for the Japan Oil, Gas and Metals National Corporation (JOGMEC), which coordinates CRM supply and related policy in Japan. The analyses is part of an effort to understand the risks of CRM supply chains, from the mining end of the supply chain through to processing and then on to final manufacturing.

We saw in figure 7 that REE are quite plentiful, with known reserves being roughly 1,000 years of current annual production. But the data in figure 8 reveal that China is dominant in many of the crucial initial phases of the supply chain, particularly separation and purification of the mined ores. Some diversification away from China’s dominance as a source of mined-ore supply has been undertaken over the past decade, with production in the US and

60) See “The Gouvernement du Québec launches the Québec Plan for the Development of Critical and Strategic Minerals: future resources for a greener Québec,” Government of Quebec Ministry of Energy and Natural Resources, October 29, 2020: https://mern.gouv.qc.ca/en/plan-development-critical-strategic-minerals-future-resources-greener-quebec-2020-10-29/



Source: JOGMEC, 2020 [61)]

Figure 8 Risks in the rare earth supply chain

Australia. But China has a singular role in purification and refining the materials, even those mined elsewhere. Hence the figure notes that only China has the capacity to separate and purify the SEG (samarium, europium, and gadolinium) in the REE group of minerals.

To provide some indication of the significance of the REE, note that the EU is extremely concerned by the fact that it is 100% dependent on imports for its needs. The EU aims to develop a European REE industry because the "REE are essential raw materials for a wide range of applications, including metallurgy (metal refining and metal alloying), catalysts in the automotive and the petro-chemical industry, colouring of glass/ceramics, phosphors (LEDs, compact fluorescent lamps, flat panel displays), lasers, rechargeable solid state batteries (Ni-MH), fibre optics and others. Additionally, REE are vital elements in emerging technologies such as solid state fuel cells, superconductors, magnetic cooling, hydrogen storage and high performance permanent magnets. The latter are crucial in a variety of high-tech applications ranging from wind-turbines and hybrid cars to HD drives and cell phone speakers and microphones." [62)] In short, it is quite difficult to imagine modern industry with-

61) See (in Japanese) "Final report on research concerning the state of rare earth supply chains in North America," Japan Oil, Gas and Metals National Corporation, February 28, 2020: http://mric.jogmec.go.jp/wp-content/uploads/2020/05/ree_supply_northamerica20200228.pdf

62) See "What are Rare Earth Elements?," EURARE, 2017: http://www.eurare.eu/RareEarthElements.html

out the REE, and particularly a decarbonizing energy transition based largely on wind and solar generation with battery storage.

Evidence of Price Increases

We suggested earlier that CRM demand could lead to price increases, possibly undermining the arguments of 100% renewables advocates. The evidence indicates that in the fall of 2020 these price increases were already occurring and could accelerate. We examine one recent report that surveys the situation with copper.

Copper's price had plummeted in the early months of 2020, as the pandemic's economic impact undermined immediate demand for goods in addition to growth and investment outlooks. But prices began to rebound from their nadir of March 23, 2020, driven by supply constraints in addition to expected demand increases. The supply constraints were primarily from reduced mining activity, due to the pandemic. COVID-19 hit during a period when copper miners had restructured their operations and were undertaking conservative investments in new production. Many of these projects were shut down for months.[63)]

The demand increases in copper stemmed from the recovery of infrastructure investment in China coupled an increasingly powerful global narrative of "green recovery." The green recovery argument focused on ramping up renewable energy and electric vehicle investment in order to decarbonize the recovery from COVID-19. As we have seen earlier, experts on CRM supply chains began to highlight the implied material demand of decarbonization focused on CRM-intensive solar, wind and batteries. Concerns about CRM supply capacity for decarbonization have a long history, but during COVID-19 the undeniable, quantifiable precariousness of supply chains in general suddenly led to increasingly focused attention.

Is there Enough Copper for the Green Wave?

By the fall of 2020, mainstream financial analysts began to point out that copper prices were rising and that the copper supply chain was facing a structural supply deficit. Analysts at Jefferies Equity Research put out perhaps the most detailed report on November 23, 2020.

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63) On these developments and their backdrop, see Karina Fernandez-Stark, et al., "COVID-19 and the new age of copper: Opportunities for Latin America," VOX EU, October 7, 2020: https://voxeu.org/article/covid-19-and-new-age-copper

Table 3 Base case copper sectoral demand scenario, 2020-2030 (cumulative annual growth rate: CAGR)

(thousand tonnes)	2020E	2030E	CAGR (%)
Construction	6,471	7,809	1.9%
Electrical Network	6,276	8,462	3.0%
Wind	403	1,205	11.6%
Solar	589	698	1.7%
Other	5,285	6,559	2.2%
Consumer and General	4,853	5,898	2.0%
Transport	2,941	5,142	5.7%
EVs	168	1,689	26.0%
Other	2,773	3,453	2.2%
Industrial Machinery	2,461	3,065	2.2%
Total demand	23,002	30,376	2.8%

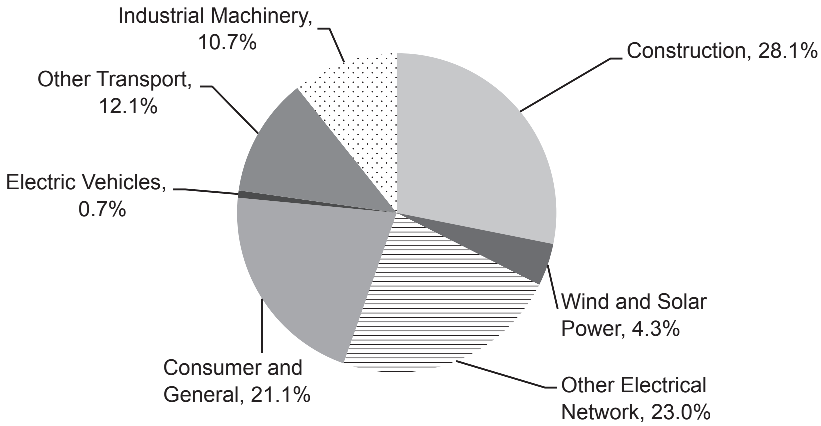
Source: Jefferies, 2020 [64]

They titled the report "Is there Enough Copper for the Green Wave?" Jefferies Equity Research suggested the evidence indicates that copper demand is no longer cyclical and that supply deficit risks are likely even under a minimal green scenario. Some of the Jefferies Equity Research data are reproduced below.

In their extensive, 80-page analysis, Jefferies Equity Research examined 2020 demand for copper, across various sectors. Then they generated 3 different scenarios for the diffusion of renewable energy (solar and wind) and electrified transport. These scenarios were a "bear" case where green demand is subdued, a "base" case scenario where demand grows at the norm of previous years, and a "bull" case where demand accelerates along the lines of the green recovery narrative. Table 3 reveals that the implications of just a base case scenario are for massive annual growth rates in copper demand for wind (11.6%) and electric vehicles (26%) between 2020 and 2030.

The Jefferies Equity Research data also show, in figure 9, that wind and solar power together with electric vehicles represented only 5 % of total copper demand in 2020. This

64) The Jefferies Equity Research report is titled "Is there Enough Copper for the Green Wave," Jefferies Equity Research, November 23, 2020. The report was analyzed to some extent by Neil Hume, Natural Resources Editor for the *Financial Times*, in "Copper hits 7-year high as Goldman calls bull market," *Financial Times*, December 1, 2020: https://www.ft.com/content/36fe5230-e24f-4fbf-8690-fd211f655347



Source: Jefferies, 2020 [65)]

Figure 9 Copper sectoral demand, 2020

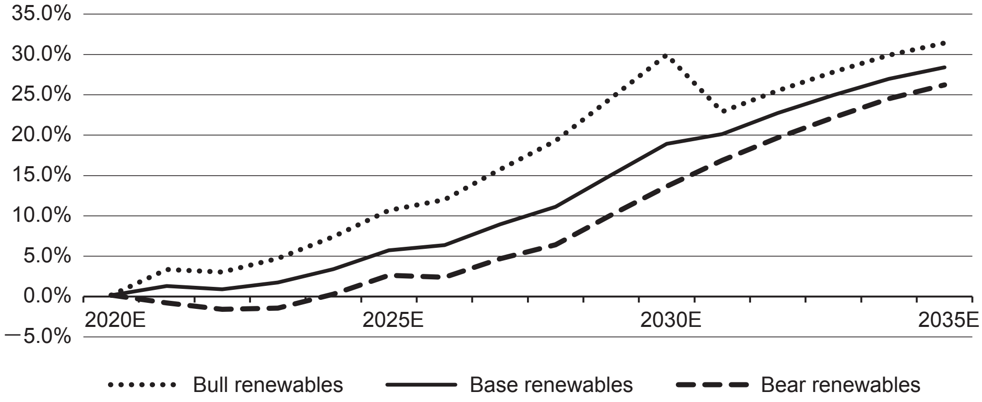
green share of demand for copper was already significant, considering 1) the low level of penetration of solar, wind and electric vehicles in global power and mobility; and 2) the near-certainty that the global share of solar, wind and electric vehicles would dramatically increase.

Figure 10 highlights the increasing risk of supply constraints in the very near future. The Jefferies Equity Research report shows that even bear-case assumptions of demand for wind and solar plus electric vehicles lead to a deficit in copper supply by 2025. In the base and bull cases, the deficit arises in 2021 or shortly thereafter, driving "substantially higher prices." And in all cases, the deficit increases to 25% or more of the total global copper market by 2035.

Note that the modeling of deficits is derived from projected supply through existing mines and approved projects. That may seem unrealistic. There is a virtual certainty that structural (as opposed to cyclical) supply shortages would drive increased investment. Indeed, one can expect an acceleration of ongoing CRM-related industrial policy initiatives in the EU, North America, and the Asian countries (including Japan). These initiatives all feature incentives for investment in new CRM projects, as we noted earlier in the case of Quebec.

But new copper mining (and other CRM) capacity takes at least several years to build as do other components of the upstream supply chain. In many countries, "it takes 20

65) ibid.



Source: Jefferies, 2020 [66]

Figure 10 Global copper deficit as a % of total demand, 2020-2035

years to go from discovery through permitting to mining." [67] And the global average lead time for a project has nearly doubled since 2012, from 6 years to over 10 years. [68] And as we have seen earlier, the possibilities for substituting (eg., aluminum instead of copper in wind and solar plus electric vehicles) are limited as is the potential to fill the demand gap with ramped-up recycling.

As the Jefferies Equity Research report notes in its summary, "renewable power systems are at least five times more copper-intensive than conventional power. Offshore wind is the most copper intensive, at around 15 tonnes per megawatt (MW) of installed capacity, due to extensive copper cable requirements. This compares to onshore wind and solar at around five tonnes per megawatt and conventional power at around one tonne per megawatt." Moreover, the Jefferies Equity Research study sought to add in related copper requirements for green, such as charging stations. They noted that global public charging stations have grown from nearly none in 2010 to 1 million in 2020, and that each requires several kilograms of copper (the amount depending on the capacity of the station).

Yet in figure 11, solar turns out to have the highest copper-density. The key reason is

66) Ibid.

67) Concerning this point, see mining expert Rick Mills, "Copper, the most critical metal," Mining.com, December 6, 2020: https://www.mining.com/web/copper-the-most-critical-metal/

68) On this, see the summary of comments by Saad Rahim, Chief Economist and Global Head of Research, Trafigura, in "JEF U: Commodity Market Perspectives from Trafigura's Chief Economist," Jefferies University, December 16, 2020.

that solar is inherently inefficient in its use of copper (and other CRM). The Jefferies Equity Research analysts cite one of the leading research papers on copper demand under decarbonizing energy scenarios.[69] The research shows that wind has the highest density of copper for installed capacity but that solar has the highest density in actual use. The reason is that, with solar,

> "utilization is significantly lower than that of wind applications due to the fact that solar PVs' hours of generation are roughly limited to 3 hours either side of midday — i.e. 6 hours per 24, whereas wind farms could in theory run 24/7 depending on wind strength. The result is that on a g/kWh basis, copper intensity for solar PVs come in higher than that of wind technologies, but on an installed capacity basis (MW), copper intensity for wind (both onshore and offshore) applications come in higher."[70]

Returning to the role of copper in wind and solar capacity, figure 12 provides one indicator of how the Jefferies Equity Research Solar analysts modeled their bull case. The data in the figure are for kilotonnes (kt) of copper. We see that between 2016 and 2020, the increase in global solar and wind had brought their copper demand to an estimated new annual demand of 991 thousand tonnes versus 771 thousand tonnes in 2016. The years subsequent are based on IEA and International Renewable Energy Association estimates for solar and wind deployment. And the projected increase in total installed wind and solar results in a 2030 total cumulative copper use of 39.3 million tonnes, just under twice total global annual production in 2019.

It is very difficult to foresee how those massive quantities of copper could be supplied, even if policymakers and political economies were able to engineer dramatic increases in recycling, copper substitution in power systems, and other measures. As we have seen in earlier research results, the role of copper remains under-estimated in cooling and other critical networks for coping with climate change. Experts point out that current copper projects are 33% smaller than the average project in 2012, and undertaken by smaller firms with less ex-

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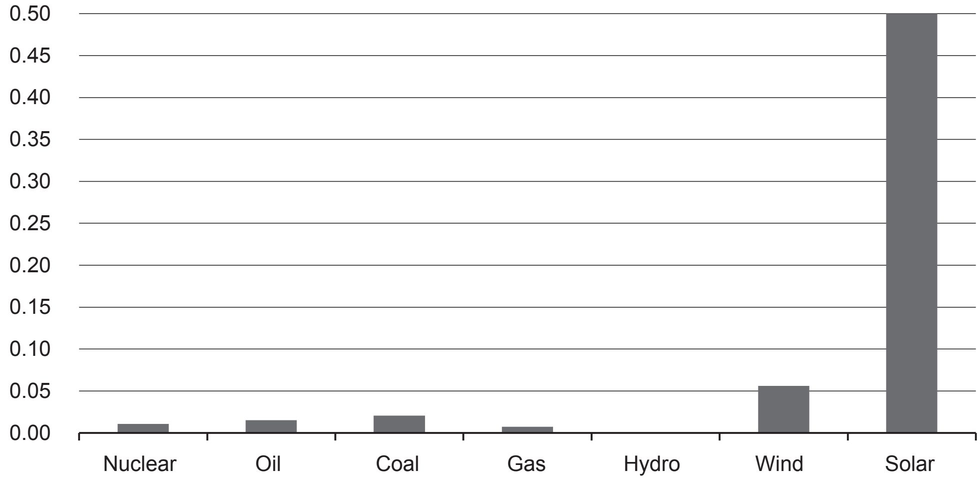
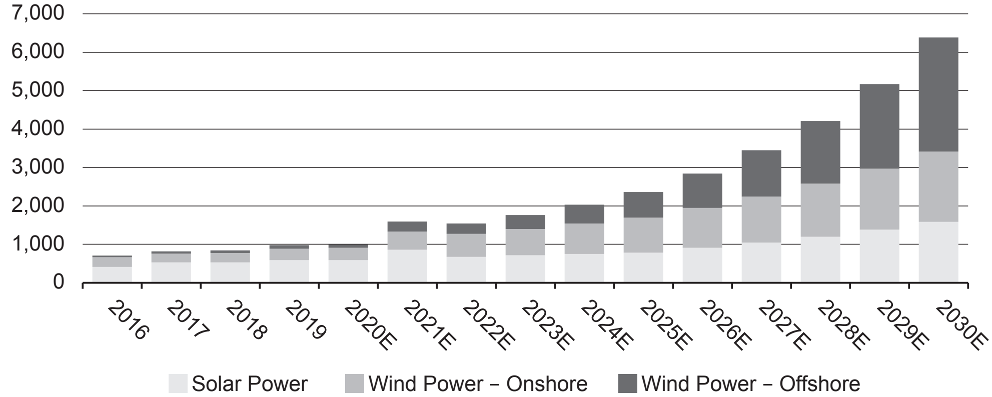
69) Branco W. Schipper, et al., "Estimating global copper demand until 2100 with regression and stock dynamics," *Resources, Conservation and Recycling*, Vol.132, May 2018: https://www.sciencedirect.com/science/article/pii/S0921344918300041!

70) See p. 27 "Is there Enough Copper for the Green Wave," Jefferies Equity Research, November 23, 2020.



Source: Jefferies, 2020 [71]

Figure 11 Copper intensity of power sources, grams/kWh



Source: Jefferies, 2020 [72]

Figure 12 Global copper demand for solar and wind, 2020–2030

perience. [73] On top of this under-examined set of issues, the depletion of existing mining projects is striking. Ore grades are seeing a striking decline, and therefore "without new capital investments, the Commodities Research Unit (CRU) predicts global copper mined pro-

71) Ibid.

72) Ibid.

73) On these data, see the summary of comments by Saad Rahim, Chief Economist and Global Head of Research, Trafigura, in "JEF U: Commodity Market Perspectives from Trafigura's Chief Economist," Jefferies University, December 16, 2020.

duction will drop from the current 20 million tonnes [Mt] to below 12Mt by 2034, leading to a supply shortfall of more than 15Mt. Over 200 copper mines are expected to run out of ore before 2035, with not enough new mines in the pipeline to take their place." [74] It is thus nearly certain that the looming structural deficit in copper will be worse than portrayed by the Jefferies Equity Research analysts, barring unimaginable and coordinated counter-measures by the global community.

Another factor to consider is input costs. This was warned of in United Nations Environmental Programmes's International Resource Panel (UNEP) 2014 study "Decoupling 2: Technologies, Opportunities and Policy Options." The UNEP conceded that technological innovation can help locate new resources as well as make some additional amount economically recoverable. But they argued that "this very rarely avoids the need for more energy, water and resource inputs to extract the same quantity of a natural resource. The tendency to process lower grades of ore to meet increasing demand is leading to a higher energy requirement per kilogram of metals, and consequently to increased production costs." [75] And indeed, recent data for copper suggest that required energy inputs per unit of output have increased significantly in recent years. [76] One 2017 study of Chilean copper production warned that "electricity demand for Chile's copper production is expected to increase by 53.5 % between 2015 and 2026, although the planned increase in copper production over that period is only 7.5%." [77]

Labour and Human Rights

The implications of these trends for human rights are profound, as supply constraints are likely to increase the pressure to relax worker and environmental safeguards in order to ramp up extraction from existing mines. The Industriall Global Union – representing 50 mil-

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74) Rick Mills, "Copper, the most critical metal," Mining.com, December 6, 2020: https://www.mining.com/web/copper-the-most-critical-metal/

75) See p. 31 "Decoupling 2: Technologies, Opportunities and Policy Options," United Nations Environmental Programme/International Resource Panel, 2014: https://www.resourcepanel.org/sites/default/files/documents/document/media/-decoupling_2_technologies_opportunities_and_policy_options-2014irp_decoupling_2_report-1.pdf

76) For example, see Palacios Joe-Luis, et al., "The energy needed to concentrate minerals from common rocks: The case of copper ore," *Energy*, August 15, 2019: https://www.sciencedirect.com/science/article/abs/pii/S0360544219310278

77) See "Energy intensity in copper and gold mining," AT Mineral Processing, October 2017: https://www.at-minerals.com/en/artikel/at__3001684.html

lion workers in 140 countries – warned about in these challenges in a November 20, 2020 report. They examined the global battery supply chain's reliance on copper, cobalt, nickel and lithium, together with the implied acceleration of electric vehicle sales. Their expert consultation warned that

> "[t]he demand for critical raw materials for the low carbon energy transition batteries, cobalt, lithium, copper and nickel, etc. will likely follow the same upstream demand side (mining) narrative of human rights' violations and unacceptable environmental consequences: child labour, destruction of the living environment of indigenous peoples, ecological destruction, water shortage etc." [78]

One of the experts Industriall Global Union consulted with was Andy Leyland, head of Supply Chain Strategy at Benchmark Mineral Intelligence. Leyland noted that battery makers and electric vehicle manufacturers are all pressing for cost reductions, at all points of the supply chain, including mining. For this reason, he warned that working conditions and other factors at existing mines are likely to degrade significantly in a "race to the bottom." He also forecast that prices for batteries will increase, even though virtually all expectations are for declining prices. Indeed, as we have seen earlier, nearly every "green recovery" and 100% renewable energy scenario rests on the assumption of continued price declines in generation, transmission, storage (including batteries) and other aspects of power systems. These scenarios have even increased the call on CRM by simplistic modeling of the economics of scaling "green hydrogen" to 100 GW in a decade. They assume that learning-curve dynamics will drive the price of renewable-produced hydrogen below the "blue hydrogen" produced by fossil fuels by 2030. [79] Yet Leyland highlights the patent fact that "demand for the required raw materials will grow faster than new mining capacities can be created." [80]

It is important to add that protecting labour and human rights necessarily increase the cost of CRM and other materials. Worker safety and environmental protections are not free. And hence one basis on which the Chinese gained dominance in rare earth supply

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78) See "Developing an global trade union battery supply chain strategy," Industriall Global Union, November 20, 2020: http://www.industriall-union.org/developing-a-global-trade-union-battery-supply-chain-strategy

79) On this scenario, see "Making Green Hydrogen a Cost-Competitive Climate Solution," International Renewable Energy Agency, December 17, 2020: https://www.irena.org/newsroom/pressreleases/2020/Dec/Making-Green-Hydrogen-a-Cost-Competitive-Climate-Solution

80) Ibid.

chains – which we reviewed above – is the fact that, compared to its competitors, it is “less burdened with environmental or labor regulatory requirements that can greatly increase costs incurred in mining and manufacturing rare-earth products.” [81)]

Highlighting this fact of the cost of safeguards is not an argument against them. Rather, it simply to point out that they present additional drivers for price increases in CRM. That assertion underlies a call to rethink 100% renewable and related scenarios, and craft decarbonization roadmaps that better integrate the cost of achieving justice.

Price Increases Across the CRM

The above has shown that prices for copper are increasing, and that prices for CRM such as nickel, cobalt, and lithium are likely to rise as well. As for rare earths, the data indicate that in November 2020 the prices of all major Chinese-sourced rare earths increased. BMO Capital Markets analysts pointed out in a December 4, 2020 research note that the price increases were especially notable for rare earths used in magnets. Research noted that neodymium – the most common rare earth used in making magnets – had risen by 27% since early November, 2020, leading to a 50% price increase within 2020.

BMO Capital Markets analysts also highlighted geopolitics, particularly China’s new Export Control Law. The law came into effect on December 1, giving the Chinese government greater regulatory control over rare earths exports and other technologies and materials.

Colin Hamilton, Managing Director and commodities analyst for BMO Capital Markets, warned that “the introduction of the new law will lead to a restriction of rare earth-based exports from China to key partners including the U.S., on the pretext that it is safeguarding its national security.” He indicated that this law would further increase upward pressure on prices. [82)]

Further price increases in rare earths and other CRM seem quite likely, for all the reasons noted above. Thus there is good reason to be dubious about claims that renewable energy costs are destined to continue declining. Here again, items from the Bloomberg News group began to express caution in early December of 2020. Referring to undue confidence in

81) Noted in Russell Parman, “An elemental issue,” *Army AL&T Magazine*, No. 92, Fall, 2019: https://asc.army.mil/armyalt/Fall2019/html/htmlArticles/articles/92_article.html

82) See the comments in “Chinese rare earth metals surge in price,” Mining News, December 4, 2020: http://www.miningnewspro.com/News/609601/Chinese-rare-earth-metals-surge-in-price

continued cheapening because of more learning via increased diffusion, Bloomberg News warned:

> "The learning-rate hypothesis is treated as certain now, but just 15 years ago it was viewed with more doubt. The prices of raw materials can derail cost reductions for long periods — as we saw during the 2000s, when solar prices stood still for a decade thanks to a shortage of the polysilicon needed to make photovoltaic wafers. Comparable shortages of cobalt may yet derail projected price reductions for lithium-ion batteries. Current designs of PEM electrolyzers — one of the most promising technologies for producing green hydrogen — are highly exposed to the prices of platinum-group metals and Nafion, a synthetic membrane made by Chemours Co."[83)]

The general response to this kind of information is to argue for substitution of the supply-constrained CRM. But there are limits to that, as we saw in copper's role in offshore wind. Another example is seen in the effort to use nickel to reduce reliance on cobalt in electric vehicle batteries. In collaboration with Panasonic, the US automaker Tesla has been at the forefront of this initiative. Indeed, Tesla's goal is to entirely eliminate the role of cobalt in electric-vehicle (EV) batteries, and it is achieving notable success in this objective. However, the initiative has encountered something of a "whack a mole" phenomenon. This is because supplies of nickel are increasingly constrained, posing a challenge to large-scale substitution of cobalt in the high energy-density batteries required for electrified transport. Global demand for nickel in EV batteries is projected to increase from 3% of all sources of demand (such as stainless steel, non-ferrous alloys, and other products) in 2018 to 12% by 2023, as global automakers are expected to introduce over 200 new EV models. But the volatility of prices for nickel have been a drag on investment in increased mining capacity. In consequence, metals analysts warn that "[t]here is no new nickel in the pipeline" even as other specialists highlight the time required to find alternatives.[84)]

The limits on substitution and poor investment into new CRM supply risk significant

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83) David Fickling, "Hydrogen is a trillion dollar bet on the future," *Bloomberg News*, December 2, 2020: https://www.bloomberg.com/graphics/2020-opinion-hydrogen-green-energy-revolution-challenges-risks-advantages/index.html

84) Rhiannon Hoyle, "Electric-Car Dreams Could Fall a Nickel Short," *The Wall Street Journal*, September 29, 2029: https://www.wsj.com/articles/electric-car-dreams-could-fall-a-nickel-short-11569780257

price increases. This risk of price increases all along the supply chain for green hydrogen has led to comparative analyses of using renewable energy and nuclear power as the key source of electricity. A December 16, 2020 analysis by the New Nuclear Watch Institute, titled "On the Role of Nuclear Power in the Development of a European Hydrogen Economy," [85] compared costs. The report showed that the German plans for green hydrogen rely heavily on imports, whereas the French plans (whose power sector is over 70% nuclear) imply significant use of nuclear. The report noted that nuclear is 5 times more efficient than solar and 2.2 times more efficient than wind in producing hydrogen, using far less land area to generate the power for electrolyzing hydrogen. The report does not point out that the CRM-intensity of hydrogen production would be lowered by adding nuclear to the mix. But it is certainly an important implication, based on the comparative CRM-intensities reviewed earlier.

We next turn to Japan's actions in building collaborative industrial policy that may help address CRM constraints in pursuing decarbonization.

Broad-Based Decarbonization Industrial Policy in Japan

Japan is quite vulnerable to CRM supply constraints. In 2020, Japanese policymakers undertook several initiatives to secure more autonomous access to CRM, in addition to increasing strategic stockpiles.[86] The Japanese authorities will also ramp up "industry-academia-government collaboration to address various challenges including technological development and securing human resources." [87] These measures seem unlikely to be enough given the global emphasis on renewable energy in decarbonization.

At the same time, Japan has also been evolving an integrated, platform style of industrial policy that may help maximize CRM and other material efficiencies in the pursuit of decarbonization. For one thing, Japan's decarbonization measures are expanding within a larger

85) The report is available at New Nuclear Watch Institute, "Study Confirms Benefits of Using Nuclear Power for Robust Hydrogen Economy 'clear case made for technology-neutral policies'," New Nuclear Watch Institute, December 16, 2020: https://www.newnuclearwatchinstitute.org/report-nuclear-produced-hydrogen

86) On this, see "Japan to strengthen control over rare metal reserves," Mining, July 12, 2020: https://www.mining.com/japan-to-strengthen-control-over-rare-metal-reserves/

87) See "Japan's new international resource strategy to secure rare metals," Japan Agency for Natural Resources and Energy, July 31, 2020: https://www.enecho.meti.go.jp/en/category/special/article/detail_158.html

paradigm of collaborative industrial policy that has produced strong material efficiencies. One clear example of Japan's "whole of government" collaborative capacity dates back to the 2005 legislative change in the structure and objectives of the National Spatial Plan (NSS). Organizational restructuring and other factors led to a more inclusive planning process that shifted its focus from growth to sustainability. Policymakers explicitly recognized growing resource constraints, and sought to address them. The changes thus deliberately incorporated environmental issues into planning, and created autonomous regional planning. Within this nexus, the regional NSS plans are under the authority of the major subnational governments.[88)]

The fruits of collaboration were seen in Japan's National Spatial Strategy (NSS), adopted in August 2015. As the OECD emphasized in its *Territorial Review of Japan, 2016*, the NSS "is the most important of a number of key planning documents." Unlike prior spatial plans, the NSS was a "truly horizontal initiative." It was built on the basis of "an intensive exercise in inter-ministerial co-ordination and consultations extending beyond the government itself under the aegis of the National Land Council, which brings together parliamentarians, academic experts, representatives of the private sector, elected officials from the cities and regions, and others." Reflecting trends in industrial and other policymaking, the NSS was thus distinctive from Japan's previous top-down planning strategies. The NSS was composed in a "whole of government" approach that brought together the MLIT and the other central agencies as well as the subnational governments. In addition, the consultation with civil society was also unprecedented in its breath. This degree of consultation gave the NSS a legitimacy that transcended its predecessor documents. On top of that legitimacy was legal authority: at least 20 other national laws are obligated to refer to the NSS.

This collaboration builds on a legacy of material-efficiency. We saw earlier that Japanese per-capita waste streams are lower than peer countries. Indeed, among megacities, Tokyo's per-capita energy, water and waste flows are considerable below the average of such peers as Shanghai, New York City, London, Paris, and others. Tokyo also adopted Japan – and the world's – first urban cap and trade scheme that includes the commercial and industrial sector, "including office buildings, which are often concentrated in megacities." More generally, Japanese cities are built in a compact manner that fosters efficient resource use. This was recognized in the UNEP's International Resource Panel (IRP) 2018 report on "The

88) On this, see (in Japanese) Yada Toshifumi "The National Spatial Planning System's Objectives and Issues," *Economic Geography*, Vol 62, 2016: https://www.jstage.jst.go.jp/article/jaeg/62/4/62_360/_pdf

Weight of Cities: Resource Requirements of Future Urbanization." The IRP report noted that "Japanese cities have the densest and most connected street patterns," with Tokyo's "level of transit connectivity and intensity of use" being the highest in the world. The material-efficiency of the Tokyo Metro transit network (primarily subway) reflects this. Tokyo Metro's 382 kilometer length is far less than Shanghai's 639 kilometers, and even New York's 401 kilometers; but in 2018 its annual ridership of 3.463 billion was the world's largest, dwarfing that of second-ranked Moscow (2.369 billion), 3 rd-ranked Shanghai (2.044 billion), and 6 th-ranked New York City (1.806 billion).[89] These structural factors result in Japan having "the highest world energy productivity (ratio of energy consumption to added value), close to three times the global average."[90] That efficiency means that effective and efficient CRM use is maximized.

Building on this, Japan's "Society 5.0" industrial policy includes a number of initiatives that are likely to aid in reducing material-intensity. These includes digitalization and 3 D mapping, as what can be monitored can also be managed.[91] In Japan, and particularly in Tokyo, such smart technology is used in the development and deployment of advanced radars for bolstering meteorological data against extreme weather. These next-generation radars give rapid and pinpoint advance warning of impending rainfall. That situational awareness allows water managers to adjust dams, river protections, sewerage systems and other critical infrastructures to cope with the hydrological challenges. 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 4.48 million cubic metres of waste-water per day through 13 treatment centres.[92]

At the same time, Tokyo maximizes the deployment of renewable energy in the system, the efficiency of pumps and other equipment, and the recovery of such valuable resources as phosphorous (crucial to agriculture). The radar networks also afford valuable infor-

89) The data are compiled by the International Association of Public Transport, and published as "World Metro Figures 2018": https://www.uitp.org/sites/default/files/cck-focus-papers-files/Statistics%20Brief%20-%20World%20metro%20figures%202018V 4 _WEB.pdf

90) See p. 109 "The Weight of Cities: Resource Requirements of Future Urbanization," International Resource Panel, 2018, available at the following URL: http://www.resourcepanel.org/reports/weight-cities

91) 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

92) The data are available (in Japanese) in "Tokyo's Sewerages, 2018," Tokyo Metropolitan Government, December, 2018: https://www.gesui.metro.tokyo.lg.jp/business/pdf/seweragei ntokyo2018.pdf

mation in other areas of the economy, such as energy management, agriculture, retail, tourism, and the myriad other domains where reliable weather data is useful. And Tokyo publicizes its use of advanced radars and other technologies, regularly producing quite readable pamphlets as well as very professional videos for the public. This effort at public education helps to reinforce the link between resource-efficient adaptation and mitigation.

Japan also has a long policy background on the circular economy, or "circular society" (*junkangata shakai*) in Japanese. The policy is very relevant to CRM. The policy's underpinnings in administrative law date back to the August 1994 implementation of the "Environmental Basic Law" (*kankyou kihon hou*) followed by the January, 2001 enactment of the Law for the Promotion of the Circular Society (Fundamental Framework Law) (*junkangata shakai keisei suishin kihonhou [kihonteki wakugumihou]*). This legal framework has since served as the basis for integrating various regulatory policies on recycling cars, construction materials, household appliances and other items into full-fledged circular economy plans. These plans are developed under the aegis of the Japanese Ministry of the Environment (MoE). The first of these "Plans for the Promotion of the Circular Society" (*junkangata shakai keisei suishin keikaku*) was adopted by the Japanese Cabinet on March 14, 2003. Each plan covers a 5-year period, and has regularized follow-up on progress made in achieving such targets as increased rates of recycling. The most recent plan is the fourth, which was enacted on June 19, 2018 by the Japanese Cabinet.[93)]

Japan's 4th plan is integrated with multiple challenges the country confronts, such as the need for CRM and other material efficiency, international collaboration, regional economic sustainability, the implementation of Society 5.0, and the like. The plan's 5 pillars address regional circularity, international resource circulation, lifecycle resource circularity, proper waste management, and disaster waste management. The plan notes that Japan's resource-productivity (or volume of resources used for generating wealth) has increased over the decades. It warns that this rate of increase is slowing down. Hence the plan aims are 4 key goals by 2025. The first is to generate JPY490,000/ton of value from resource inputs. This target is an increase on the JPY 380,000/ton goal for 2015, and would represent a doubling of the 2000 target. The second major goal concerns the cyclical use rate in the resource base. This metric measures the fraction of recycled material in the overall volume of resource inputs. The 2025 target is 18%, up from the 16% target in 2015 and roughly an 80% increase over the 2000 level.

93) Each plan and its follow-up studies is outlined (in Japanese) at the following Japanese Ministry of the Environment website: https://www.env.go.jp/recycle/circul/keikaku.html

The third goal concerns the cyclical use rate as a percent of the overall waste volume. This metric calculates the rate of recycling within the waste stream from the overall economy. The 2025 goal is 47%, up from the 44% target in 2015 and an approximate 30% increase over the year 2000.

The fourth target is the final disposal amount, which measures the material volume that goes to landfill. The 2025 target is 13 million tons, a marginal increase on the 14 million ton goal of 2015, but a 77% reduction in landfill waste volumes back in 2000.

Within these overall goals and data are numerous other important metrics. One is the size of the circular economy as a business. The Japanese plan aims to double the JPY 40 trillion size of the circular economy in 2000 by 2025, after having achieved an increase to JPY 47 trillion as of 2014. Other targets include a further reduction in average daily per-capita household waste from 653 grams in 2000 to 440 grams in 2025, having achieved a level of 507 grams as of 2016. Another important goal is reduction of average per capita daily municipal waste volumes, which incorporates material outside of the household waste stream. The 2025 goal is 850 grams per-capita/day by 2025, significantly down from the 1,185 gram average in 2000. The average achieved in 2016 was 925 grams. And we saw earlier in this paper that Japan's performance is much better than its peer countries in Europe and North America.

These initiatives underpin the ongoing amplification of collaboration. As we see in Table 4, Japan has a broadly inclusive Local Revitalization SDGs Public-Private Collaborative Platform. The table lists the platform's members by category and then by the total members per category. As of November 1, 2020, the platform's membership includes 825 of Japan's prefectural and local governments in addition to most of the national government's central agencies. In addition, civil society was represented by 3,023 research institutions, business firms, NPOs and other organizations. The total membership of 3,861 was more than triple the April 2020 total of 1,235 members. This rapid increase in the platform's total membership reflects the accelerating integration of industrial policy platforms.

Table 5 shows the ongoing results of the Japanese Cabinet Office's efforts to disseminate best practice. Since 2018, the Cabinet Office has opened a competition for subnational governments to be designated as SDG Future Cities and for particularly well-integrated initiatives to be designated as Model Cases. As of September of 2020, there are 93 SDG Future Cities and 30 Model Cases. The increasing numbers are indicative of the prioritization of the program and its widespread impact.

Japanese collaborative action is also unfolding in its Smart City Public-Private Collaborative Platform, whose total organizational membership is itemized in table 6. Of

Table 4 Japan's Local Revitalization SDGs Public-Private Collaborative Platform

Member Category	Number of Members
Subnational Governments	825
Central Agencies	13
Private Firms and others	3,023
Total Membership (as of October 31, 2020)	3,861

Source: Future City, 2020 [94]

Table 5 Japan's Local SDGs Communities and Model Cases (as of April, 2020)

Category and Year	Number
2018 SDG Future Cities	29
2018 SDG Model Cases	10
2019 SDG Future Cities	31
2019 SDG Model Cases	10
2020 SDG Future Cities	33
2020 SDG Model Cases	10
Total Cities and Cases	Cities: 93, Model Cases: 30

Source: Kantei, 2020 [95]

particular note is the growing number of local governments, 134 as of November 5, 2020. This number is a significant increase over the 114 recorded in April of the same year. This platform is yet another venue via which Japan is undertaking decarbonization while building materially efficient resilience.

A more recent platform is Japan's Green Infrastructure Public-Private Collaborative Platform. Table 7 shows that its membership as of March 2020 exceeds 400 local governments, central agencies and other stakeholders. The local government membership includes Sendai City (the host city for the Disaster Risk Reduction program), Tokyo, and other influential cases. Moreover, the important role of central agencies is coupled with the participation of business, academe, NPOs and other stakeholders whose collective expertise encompasses water, energy, construction, and other areas crucial to designing and

94) See (in Japanese) "November 30, 2020 list of local revitalization SDGs public-private platform members," Future City, Japan, November 30: https://future-city.go.jp/data/pdf/platform/20201130_member.pdf

95) See (in Japanese) "Local Revitalization SDGs and Environmental Future City," Japanese Cabinet Office, 2020: https://www.kantei.go.jp/jp/singi/tiiki/kankyo/index.html

Table 6 Japan's Smart City Public-Private Collaborative Platform

Member Category	Number of Members
Subnational Governments	134
Central Agencies	11
Businesses, Research Centres, and others	410
Business Associations	2
Total Membership (as of November 5, 2020)	544

Source: MLIT, 2020 [96)]

Table 7 Japan's Green Infrastructure Public-Private Collaborative Platform (as of March, 19, 2020)

Member Class	Number
Subnational Governments	43
Central Agencies	4
Businesses, Research Centres, and others	200
Individual Memberships	232
Total Membership	439

Source: MLIT, 2020 [97)]

implementing comprehensive and CRM-efficient green-infrastructure solutions. This emphasis on green-infrastructure not only helps achieve mitigation and adaptation and inclusive sustainability; it also reduces CRM footprints and the burden of future costs to maintain such traditional "grey infrastructure" as levees.

One of Japan's key governance platforms for designing, implementing and revising integrated policy is National Resilience. National Resilience predates the 2030 Agenda's SFDRR, formally adopted in 2015, and closely parallels the latter's content by emphasizing all-hazard disaster preparation, building back better, and "whole of government" inclusive collaboration. National Resilience also encompasses smart communications, sustainable energy systems, resilient water networks, and the other critical infrastructures that are essential to holistic resilience and CRM-efficiency in the modern city.

National Resilience is also Japan's program for closely linking national and subnational

96) See (in Japanese) "Smart City Public-Private Collaboration Platform," Ministry of Land, Infrastructure, Transport and Tourism: https://www.mlit.go.jp/scpf/about/index.html

97) See (in Japanese) "Green Infrastructure Public-Private Collaboration Platform," Ministry of Land, Infrastructure, Transport and Tourism: https://www.mlit.go.jp/scpf/about/index.html

Table 8 Increase in Japan's Local National Resilience Plans (NRPs)

Administrative Level	April 1, 2019	December 1, 2020
Local Government	190	1,705

Source: National Resilience, 2020 [98)]

governments in a rapidly expanding portfolio of national and subnational NRPs that have legal precedence over other plans. NRPs are aimed at bolstering the country's resilience to natural disasters and other hazards, before they happen, as well as fostering the capacity to recover from such disasters when they occur. Since 2014, there have been 2 iterations (2014, 2019) of the NRP Basic Plan as well as 6 annual action plans that decide and then monitor the planning cycle and the achievement of Key Performance Indicators (KPI). These KPIs include hard measures, such as monitoring hazards via smart sensors, strengthening back-up power for hospitals and other facilities, reinforcing flood-control systems, and hardening critical communications infrastructure. The KPIs also include soft measures, such as skill-building, risk communication, and measures to break down governance silos. In the 2019 revision of the original 5-year NRP Basic Plan, the number of KPIs had increased to 179. The 2020 update of the NRP action plan is slated to raise the number of KPIs to 268. Moreover, Japanese National Resilience has been made a core aspect of the recovery from COVID-19.

This approach has diffused extensively and rapidly. By December 1 of 2020, all of Japan's 47 prefectures had adopted their own regional versions of the NRP. Moreover, as table 8 shows, 1,705 of Japan's 1741 cities, special wards, and towns had either adopted their own local versions of the NRP or were formulating plans. Japan's subnational governments now routinely request increased regular budget and special fiscal stimulus spending on NRP, SDGs, Society 5.0 projects and their integration in the smart city. These fiscal and related requests are articulated collectively through such subnational representative organizations as the National Governors' Association, the National Mayors' Association and others. Indeed, Japanese local governments have become very strong proponents of integrated, disaster-resilient structural change.[99)]

98) See (in Japanese) "Map of Local Government National Resilience Plan Rate of Adoption," Cabinet Office of National Resilience Promotion, December 1, 2020: https://www.cas.go.jp/jp/seisaku/kokudo_kyoujinka/pdf/201201_keikakumap.pdf

99) See for example (in Japanese) "Recommendations Towards Realizing Revitalized Regions," Japanese National Governors' Association, November 20, 2020: http://www.nga.gr.jp/ikkrwebBrowse/

Conclusion

We have seen that many CRM are used at far greater density, per unit of energy consumption or production, in green technologies as compared to conventional power systems, automobiles, and the like. Supplies of these materials have other competing sources of demand, including smart phones, jet engines, health care, and multiple other areas. Advocates of decarbonization by 100% renewable energy do not adequately discuss supply constraints, geostrategic risks, human rights concerns, environmental damage (from harvesting and processing critical materials), and other issues. But we have also seen that many counties and regions, such as the Canadian province of Quebec, are implementing CRM industrial policies. These projects are unlikely to satisfy demand requirements for a global decarbonization led by renewable energy. The emerging facts suggest that decarbonization will require a significant role for nuclear power, carbon capture and other innovations. It will also require prioritizing the use of constrained CRM. Doing that will almost certainly require Japanese-style comprehensive governance.

The first imperative is to reduce undue reliance on any particular material via substitution. The Japanese did this in the wake of 2010, when rare earth prices rose and Chinese policies on rare earths indicated increased risks of export bans against Japan. In response, the Japanese invested heavily in alternatives. These strategic investments resulted in such innovations as new magnet technologies that greatly reduce the role of neodymium.[100)]

Yet as we saw with copper and nickel, substitution has its limits, because of the enormous projected increase in demand for nearly all CRM. Options for substituting CRM appear limited. Hence increased attention to strategic, spatially-smart use of these scarce materials is required.

We have also seen that compact and resource-efficient community has long been an element of National Spatial Planning and other policy regimes, and is incorporated in Japan's National Resilience and Society 5.0 industrial policies. Japan's comprehensive approach to circularity places the objective within multiple other goals, and matches that with integrated institutions and ample public finance. This approach seeks to maximize the co-benefits for a

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material/files/group/2/20201120katuryokuarutihounojitugenteigen.pdf

100) Cindy Hurst, "Japan's Approach to China's Control of Rare Earth Elements," *China Brief*, Volume 11, Issue 7, April 22, 2011: https://jamestown.org/program/japans-approach-to-chinas-control-of-rare-earth-elements/

very broad range of stakeholders, giving the paradigm enduring political legitimacy.

Covid-19 has led the global community to stress a green recovery. This paper has argued that the CRM required for a 100% renewable recovery are a fraught issue. Thus maximizing material-efficiency is clearly imperative. Emphasizing adaptation with mitigation can help further this goal of CRM efficiency. Indeed, the global specialist debate now recognizes the urgency of doing both mitigation and adaptation in addition to the fact that they often overlap.[101] Abundant evidence indicates the potentially decarbonizing impact of resilient adaptation, especially when coordinated at the national level to maximize public goods and positive externalities. For example, compact cities and green infrastructure are inherently mitigating as well as robust in the face of mounting risks of flood, fire and other disasters. The data also show that during Covid-19 Japan has been accelerating its policy integration. Myriad other examples could just as easily have been adduced to illustrate Japan's ongoing work to build more collaboration in a larger industrial policy of holistic and transformative resilience.

But Japan's main difficulty of poor CRM resource endowments remains. The emphasis on material-efficiency only alleviates the challenge; it does not solve it. What remains to be seen is whether Japanese initiatives for sea-bed mining and other alternative supplies bear fruit.[102] The country also faces difficult decisions on the role of nuclear energy in the power mix. It is very likely that these issues will become prominent in the Japanese debate over revising the triennial Strategic Energy Plan in 2021. Japanese policymakers have coordinated many of their most authoritative committees in order to assess decarbonization options in addition to revise the Strategic Energy Plan.[103] Their deliberations are an important area for future research, as the global community strives to decarbonize while rebuilding from a pandemic.

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101) On this point, see the critical comments of IPCC Working Group II on the "presumed tradeoff between mitigation and adaptation": http://www.ipcc.ch/ipccreports/tar/wg2/index.php?idp=62

102) "Japan Dives to Secure Cobalt and Nickel in the Ocean," BloombergNEF, September 10, 2020: https://about.bnef.com/blog/japan-dives-to-secure-cobalt-and-nickel-in-the-ocean/

103) These institutional developments are discussed in detail in by Yuri Invest Research's Japan NRG Weekly, in their "Net Zero Policy Directory: Part 1" and "Net Zero Policy Directory: Part 2." The details can be found, respectively, in Japan NRG Weekly, December 7, 2020 and Japan NRG Weekly December 14, 2020.