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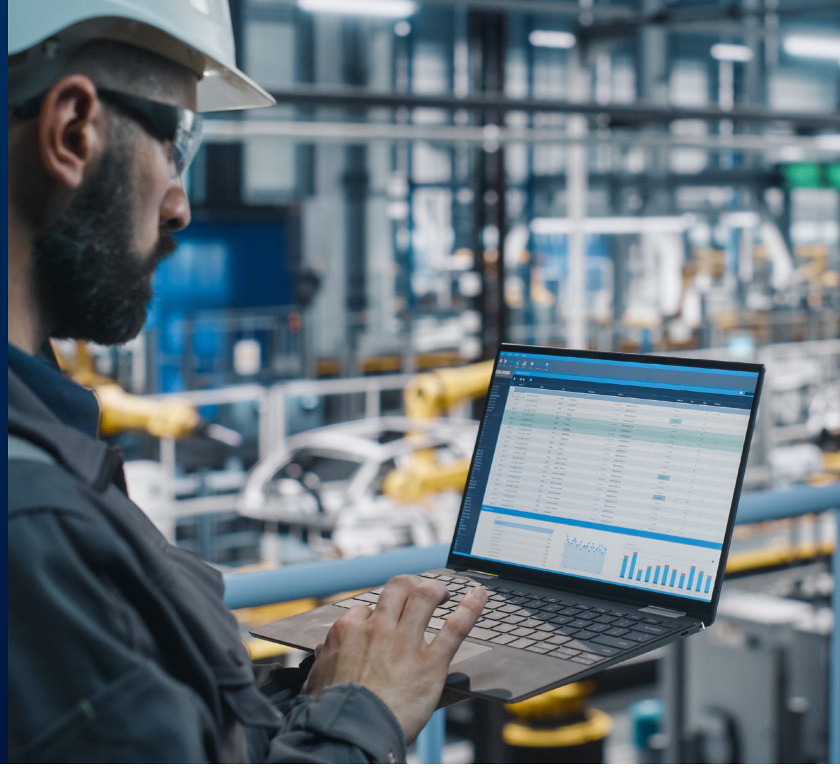
Supply Chain Challenges for the Energy Transition

An Overview



Many technologies will help comprise the energy transition. Clean energy in the form of wind, solar, batteries, nuclear, hydrogen, etc., all face challenges, stunting their implementation. We will need to utilize many of them, and others, to achieve a net-zero world. The following identifies and discusses supply chain challenges associated with these technologies.

This research is not intended to fully describe these supply chain challenges nor suggest favor for one technology versus another; it solely provides an overview of some of these challenges so that customers can take appropriate steps to mitigate these risks where possible.

Introduction

In 1977, many thought the world was running out of natural gas[1], and others believed that as early as 1919, oil supplies were nearly depleted[2]. Ingenuity led to more oil discoveries and, more recently, to hydraulic fracturing (i.e., "fracking") of natural gas trapped in rock formations, the latter of which helped the U.S. gain energy independence. However, climate change, not supply issues, drives the world to find means to source energy without carbon emissions. There are supply constraints to much of what is needed in the future, but history has demonstrated that humans find ways to obtain what is required and develop new technologies beyond those known now. Still, reliance on fossil fuels will continue for some time while these alternative technologies develop and grow. Renewables currently represent only a small but growing fraction of overall energy use.

Global sourcing is cost-effective but carries geopolitical risks, as seen with oil and renewables. China is the leader in sourcing, processing and manufacturing materials vital for the energy transition. As renewables gain market share in energy use, the U.S. becomes increasingly dependent on these materials. Given uncertain trade relations with China and expected renewables growth, the U.S. has taken steps to onshore manufacturing and reduce dependence on a single country. The Inflation Reduction Act (IRA) promotes renewable development and onshore manufacturing. Most believe the IRA will help diversify rather than fully domesticate supply chains. Global sourcing will continue, albeit relying less on individual countries, improving energy security over time.

The supply chain is not limited to equipment and materials, as there needs to be sufficient trained labor, including trade

1. https://www.americanactionforum.org/research/fuel-for-thought-fracking-and-the-natural-gas-boom/

2. https://en.wikipedia.org/wiki/Peak_oil

(electricians, plumbers, etc.), interconnections and a grid that can handle the increased load necessary for a more electrified world. While these issues impede the energy transition, this research focuses on supply chains associated with the technologies rather than other concerns.

Photovoltaic / Solar

Solar projects are mainly comprised of widely available materials, but processing these materials to make panels is only conducted in a few places. Some rare earth materials are used, including silver.

Solar modules are mostly made of silicon, which is derived from sand, the most abundant solid material on the planet[3]. Glass protects photovoltaic cells from damage by vapors, water and dirt. Silicon dioxide is converted into pure metallurgical grade silicone (MGS) to make polycrystalline cells. MGS is made from high-grade quartz, a product of silicon and oxygen. Other materials used are glass, resins for making plastic sheets (encapsulant and backsheet) and aluminum[4]. Though none of the materials used in this process are supply-constrained, China accounts for nearly 80% of solar polysilicon manufacturing capacity worldwide[5]. China's Xinjiang region, an area alleged to utilize forced labor, produces nearly 50% of the world's polysilicon supply chain alone. Even with significant IRA incentives available to onshore polysilicon manufacturing in the U.S., it will take some time for the U.S. to develop its own polysilicon supply chain. Cutting off supplies from China before that happens would, again, cripple the solar industry, which is how the Auxin Solar petition brought U.S. solar to a standstill in 2022[6]. Further, some believe that even with incentives, it will be challenging to manufacture polycrystalline panels at a competitive cost against those made in China for the foreseeable future[7]. As of late November 2023, there was a glut of supply of solar panels in Europe[8], and some see a decline in solar panel production approaching[9].

China: Country concentration as shares of global manufacturing capacity[10]

Thin-film panels, such as those made by First Solar and Toledo Solar, utilize cadmium and tellurium, which are not used in polycrystalline panels. These panels are mainly made by U.S. companies and require less reliance on materials from other countries. Cadmium and tellurium are byproducts from mining waste streams. While thin-film panels represent only about 5% of the global market, they comprise 40% of the utility-scale U.S. market[11].

Ultimately, the U.S. relies heavily on China for polycrystalline (not thin-film[12]) solar panels and other important materials used in renewable energy. Given an uncertain trade relationship with China, the U.S. has taken steps toward onshore manufacturing, thus diversifying its supply chain and reducing its dependence on China for essential materials.

Silver comprises 6% of the cost of a solar panel. Silver powder is an important conduction component for solar panels, and the solar industry could exhaust 85-98% of global silver reserves by 2050[13]. This is 10% more than the current percentage of the world's silver used for solar panels[14]. Solar companies are actively exploring alternative conductors, such as electroplated copper.

3. https://atlasgeographica.com/sand-the-most-important-natural-resource

4. https://www.energy.gov/eere/solar/solar-photovoltaics-supply-chain-review-report#:~:text=The%20primary%20inputs%20to%20the,and%20backsheet)%2C%20and%20aluminum.

5. https://www.statista.com/statistics/1334952/solar-polysilicon-manufacturing-capacity-share-by-country-or-region/#:~:text=In%202021%2C%20China%20accounted%20for,the%20global%20manufacturing%20capacity%2C%20respectively.

6. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/glut-of-inexpensive-solar-panels-in-europe-boosts-project-economics-77068399

7. https://www.powerengineeringint.com/solar/china-to-dominate-global-solar-manufacturing-to-2026-says-wood-mackenzie/

8. https://www.canarymedia.com/articles/solar/thin-film-solar-sparks-a-manufacturing-boom-in-the-midwest

9. https://www.bloomberg.com/news/articles/2023-07-03/the-world-s-appetite-for-solar-panels-is-pushing-up-silver-prices?embedded-checkout=true

10. https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary

11. https://www.canarymedia.com/articles/solar/thin-film-solar-sparks-a-manufacturing-boom-in-the-midwest

12. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/avoiding-china-supply-chain-risks-first-solar-soars-60949212

13. https://www.bloomberg.com/news/articles/2023-07-03/the-world-s-appetite-for-solar-panels-is-pushing-up-silver-prices?embedded-checkout=true

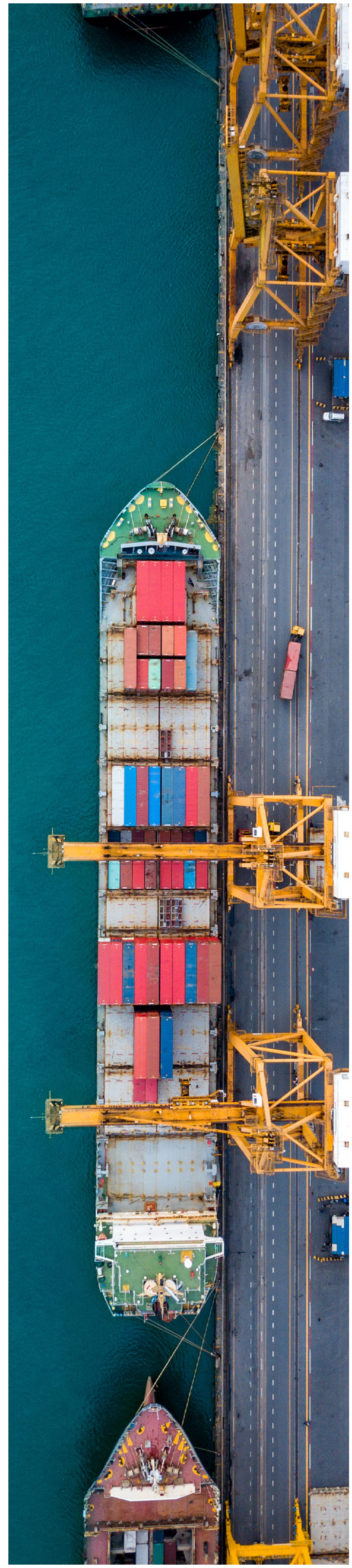
14. https://blog.ucsusa.org/charlie-hoffs/mining-raw-materials-for-solar-panels-problems-and-solutions

Other roadblocks to solar farm development include long interconnection queues[15] and a transformer shortage[16]. At least 3000 GW of renewable power projects are waiting in grid connect queues[17]. Solar farms cannot deliver power without an interconnection or a transformer. Delivery time for transformers and associated equipment has increased from 50 weeks a year ago to 150 weeks or longer. This is, in part, driven by factory shutdowns in China, export restrictions imposed on Russia, expense-driven unwillingness to expand U.S. transformer production and short supplies of specialty steels[18], all during a rapid scale-up of wind, solar and storage projects.[19,20] There is hesitancy to build factories in the U.S., partially due to the lack of qualified individuals[21]. Utilities are working with government officials to mitigate this problem, and the June 2022 Defense Production Act authorized the Energy Department to rapidly expand American manufacturing for transformers and other equipment.

While this discussion focuses on the supply chain for new projects, replacement equipment is needed when an existing project is damaged. Contractors building new solar projects do not specialize in replacing damaged equipment, which can add to replacement time. Because solar technology changes quickly, the solar panels and racking installed a few years ago may no longer be available or easily replaced by current equipment. Even if the panels needed are still current, acquiring the needed replacement panels is not always possible, as some OEMs are sold out for several years with projects continuously planned[22]. Consequently, the project may need to pay more for the replacement panels or buy from a different supplier. Projects can strive to contract with vendors with pre-agreed costs and replacement panel availability timing as part of their contingency planning program. Contingency planning is also important with respect to sourcing or sparing replacement transformers and other electrical equipment; wait times when ordering specific equipment are currently three to five years[23].

Wind

Wind projects are subject to the same transformer and grid issues as solar projects. Additionally, wind turbine generators are 40-50% steel (used for towers, structure, and mechanical components), copper (generator winding and cables), and aluminum (nacelle), all of which have constrained supplies that will only worsen as more projects are built. Steel, copper and aluminum prices have nearly tripled in recent years, impacting OEM profitability and slowing progress for onshore and offshore wind projects.



15. https://www.washingtonpost.com/climate-environment/2022/12/20/clean-energy-bottleneck-transmission-lines/

16. https://www.reuters.com/business/energy/us-renewable-grid-battery-projects-battle-transformer-shortage-2023-11-15/

17. https://www.linkedin.com/posts/alessandro-blasi-6579a66_renewables-energy-production-activity-7125395873227780096-0ieB

18. https://www.route-fifty.com/infrastructure/2022/08/electric-utilities-around-us-are-running-out-transformers/375934/

19. https://www.reuters.com/business/energy/us-renewable-grid-battery-projects-battle-transformer-shortage-2023-11-15/

20. https://www.pv-magazine.com/2023/10/31/transformer-shortages-new-bottleneck-of-the-energy-storage-supply-chain/

21. https://news.bloomberglaw.com/environment-and-energy/grid-transformer-supply-crunch-threatens-us-clean-energy-plans

22. https://www.cnbc.com/2023/07/27/first-solar-announces-fifth-us-factory-as-climate-deal-fuels-domestic-manufacturing.html

23. https://www.conference-board.org/publications/US-electric-transformer-shortage-is-impeding-grid-expansion-transformation

Additionally, neodymium and praseodymium, rare earth metals, are needed as high-power magnets in both wind turbine generators and electric vehicles. McKinsey estimates these materials will face a 50-60% shortage in 2030[24]. Recycling will play an increasingly important role but is expected to meet only 10% of total demand.

Acquiring replacement parts for wind turbines can become challenging as technology changes quickly and older models become obsolete. Sometimes, if a turbine or its blades need to be replaced, "like kind and quality" is no longer available, and the site needs to use a larger turbine. The larger turbine may also require foundation upgrades to support it.

In recent years, wind turbine (WTG) manufacturers and offshore wind developers have struggled financially. Leading WTG producers Siemens-Gamesa, Vestas and GE Vernova have taken significant losses[25]. Increased steel prices and inflation have made some planned projects no longer viable, and some offshore wind projects have recently been canceled. While this trend alone does not represent a supply constraint, some worry about the future viability of these companies and their long-term commitment to wind projects moving forward, which could impact supplies for key spares and replacement equipment.

One crucial supply chain issue concerning offshore wind is vessel availability. Offshore wind projects can only receive equipment from ships flagged and built in the U.S. to comply with the Jones Act. There are currently no such vessels here, and one that is being built was expected to be ready by the end of 2023 and has now been delayed at least a year, resulting in a >20% cost increase. This development contributed to the cancellation of several large offshore wind projects off the New Jersey shoreline. Other domestic shipyards engaged in commercial vessel construction are booked for several years. This issue significantly impedes the construction of new offshore wind projects.[26]

Batteries / Energy Storage

China controls a significant portion of the battery supply chain. There are several technologies and different materials used for each technology. Furthermore, batteries are not only used for energy storage but also for cell phones, laptops, watches, electric vehicles and more.

Lithium-Ion

Lithium-ion batteries are the leading technology for batteries and energy storage. Two main types of Lithium-ion technology are nickel manganese cobalt (NMC) and lithium iron phosphate (LFP). Both technologies have a high energy density, allowing them to store a lot of energy in a relatively small and lightweight package. NMC batteries have a higher energy density than LFP batteries, while LFP batteries have a longer cycle life (thousands of cycles vs. hundreds of cycles). Both LFP and NMC batteries are used in automobiles. LFP batteries are considered safer, as they are less prone to thermal runaway and are said to have a lower risk of catching fire or exploding.[27, 28]

Research is underway to develop Solid State Batteries and lithium-ion technology that can solve some of the following issues prominent in NMC and LFP batteries:

- Flammability
- Limited voltage
- Unstable solid-electrolyte interphase formation
- Poor cycling performance and strength

Other Energy Storage Technologies

Given that both technologies are favored for electric vehicles and other consumer uses, other technologies are being sought to ease supply concerns. Some of these technologies include:

- **Lead Acid Batteries** – inexpensive, safe, reliable, and provide high power; however, low specific energy, poor cold-temperature performance, and short calendar and lifecycle impede their use.
- **Iron Air (form energy, "reversible rusting")[29]** – utilizes materials that are safe, inexpensive, accessible and can provide multi-day duration.

24. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/renewable-energy-development-in-a-net-zero-world-disrupted-supply-chains

25. https://stopthesethings.com/2023/05/03/wind-industrys-major-meltdown-in-2022-ge-vestas-siemens-energy-lost-4-6-billion/

26. https://www.cato.org/blog/jones-act-helps-sink-new-jersey-offshore-wind-project?utm_source=social&utm_medium=linkedin&utm_campaign=Cato%20Social%20Share

27. https://www.linkedin.com/pulse/nmc-vs-lfp-which-best-energy-storage-rahul-jalthar/

28. https://afdc.energy.gov/vehicles/electric_batteries.html

29. https://formenergy.com/technology/battery-technology

- **Sodium Ion** – replace lithium with sodium as cathode. They have better safety characteristics than lithium-ion batteries, have no thermal runaway exposure and cost less. However, they have a lower energy density even with similar power delivery characteristics. These batteries are now being used for small vehicles by BYD in China, with a shorter range than cars using Lithium-ion batteries.
- **Flow Batteries** – modular and scalable, with energy durations of many hours or even days. They are made of low-cost and readily available materials, many of which can be recycled[30].
- **Zinc-Based Batteries** – longer lasting than lithium-ion batteries with aqueous-based non-flammable systems[31]. They can work in a wide temperature range but require more space than other technologies.
- **Nickel-Metal Hydride Batteries** – high cost, high self-discharge, heat generation at high temperatures and the need to control hydrogen loss.
- **Hydrogen Energy Storage** – while relatively expensive, hydrogen can be stored and burned as a fuel to generate clean power for extended periods. This is useful if power is needed for days or weeks instead of hours.
- Other technologies, including Pumped Hydro, Compressed-Air Energy Storage (CAES) and more.

Battery Supply Chain challenges

NMC Lithium-Ion batteries use five critical minerals: lithium, nickel, cobalt, manganese and graphite. Critical minerals are found worldwide, but most economically viable deposits are found in only a few places. While demand for these minerals is already high and expected to grow significantly, there are sufficient supplies to meet our current and future needs. Even with sufficient minerals available, there are not enough operating mines with their own environmental and labor challenges.

In Henry Sanderson's book, "Volt Rush,"[32] he details the challenges and supply chain issues associated with rare earth metals. Some of the problems Sanderson identified are as follows:

Lithium

The world has abundant supplies of lithium available. However, like other rare earth metals, lithium is often found at very low concentrations. As a result, mining for lithium involves energy, work and environmental implications. Currently, there are insufficient active lithium mines, though companies, including Exxon-Mobil[33], are investing in lithium extraction. Additionally, lithium-rich polymetallic nodules filled with metals are used to make lithium-ion batteries in parts of the Pacific Ocean. Still, scientists are unsure whether removing these nodules could damage the ocean's ecosystem[34]. Over time, the recycling of lithium-ion batteries is expected to contribute significantly to future lithium needs[35].

Nickel, Cobalt, Copper, Phosphorus/Phosphate, Manganese and Graphite

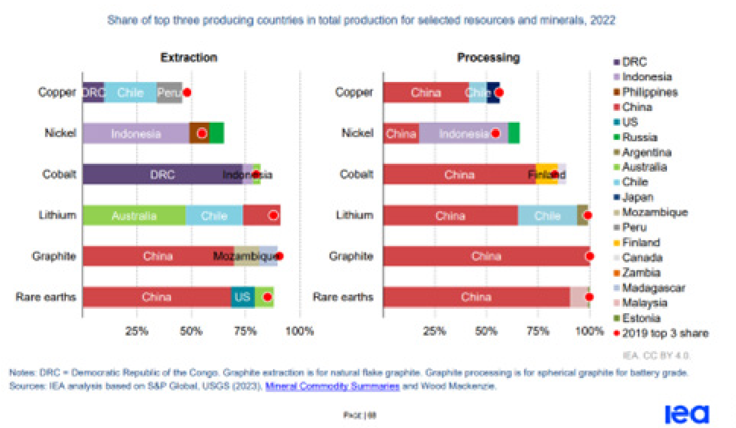
Nickel, heavily concentrated in Indonesia, has its own labor issues. Mining nickel involves safety concerns associated with hexavalent chromium, which could cause cancer.[36] Cobalt production is dominated by the Democratic Republic of the Congo (DRC), which has significant labor and environmental concerns. Copper is mainly sourced in Africa and South America, and supplies are notably constrained[37]. The largest sedimentary phosphate deposits are found in Northern Africa, China, the Middle East and the United States, with significant igneous occurrences found in Brazil, Canada, Finland, Russia and South Africa[38]. Around 70% of known phosphate rock resources are geographically concentrated in Morocco and the Western Sahara region.

Regarding processing, high-purity phosphorus needed for LFP batteries is currently produced by only one method, and refining capacities exist in only four countries: China, the United States, Kazakhstan, and Vietnam[39]. LFP batteries contain phosphorous, also used in large volumes

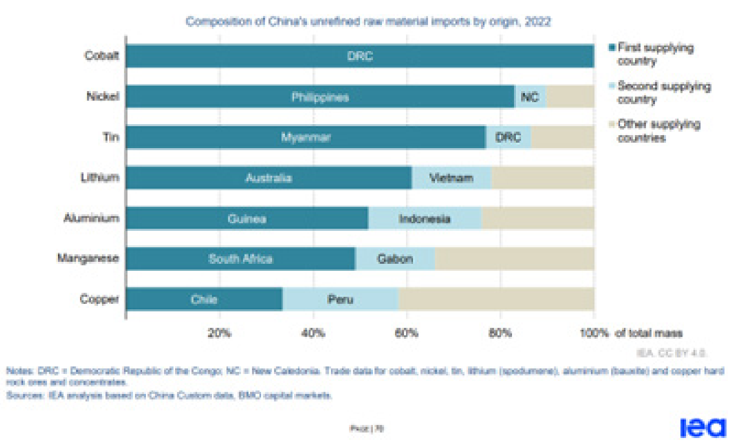
30. https://flowbatteryforum.com/what-is-a-flow-battery/
31. https://www.utilitydive.com/news/energy-storage-long-duration-hydrogen-iron-air-zinc-gravity/698158/
32. Sanderson, Henry, Volt Rush, OneWorld Publications, 2022
33. https://lowcarbon.exxonmobil.com/lower-carbon-technology/mobil-lithium s
34. https://www.reuters.com/graphics/MINING-DEEPSEA/CLIMATE/zjpqezqzlpx/
35. https://www.epa.gov/hw/lithium-ion-battery-recycling#recycled
36. Sanderson, Henry, Volt Rush, OneWorld Publications, 2022
37. https://www.cnbc.com/2023/02/07/there-isnt-enough-copper-in-the-world-shortage-could-last-until-2030.html
38. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-phosphate.pdf
39. https://iea.blob.core.windows.net/assets/afc35261-41b2-47d4-86d6-d5d77fc259be/CriticalMineralsMarketReview2023.pdf

for fertilizer production.[40] South Africa supplies 80% of the manganese we use, with China, Australia, India, Ukraine, Brazil and Gabon also contributing. About 70% of the graphite we use comes from China, and graphite represents 50% of material needed in lithium-ion batteries.

While the sourcing of rare earth metals is concentrated in various countries, the processing of these materials is mainly done in China, as shown in the graphs below.



Where does China get its raw materials? [43]



Global Mining of Rare Earth Elements (REEs) vs. Fossil Fuels [45, 46]

Though there are challenges in mining rare earth elements, the quantities needed are dwarfed by the current mining quantities for fossil fuels. The mining materials used to build projects can be recycled, whereas fossil fuels are burned as a fuel. The rare earth materials needed to supply batteries are available if they can be mined. It should be noted that mining these materials requires considerable energy, usually provided by fossil fuels.

Nuclear

Russia's war in Ukraine has many countries concerned about reliance on Russian energy. According to the Energy Information Administration, 14% of the United States' uranium imports in 2021 came from Russia (and 43% from Kazakhstan and Uzbekistan). Russia is the only commercial supplier of small modular reactors (SMRs), the type of uranium needed to fuel new reactor designs to reduce costs and safety concerns.

While not part of the traditional supply chain, the cost and time associated with securing approval for SMRs from the Nuclear Regulatory Commission (NRC) is an important impediment to nuclear projects. NuScale canceled plans to develop a small nuclear reactor project in Utah in November 2023 and now hopes to build SMRs in Romania, Kazakhstan, Poland and Ukraine.[47]

Russia dominates uranium processing and is the world's only commercial supplier of high-assay,

40. https://iea.blob.core.windows.net/assets/afc35261-41b2-47d4-86d6-d5d77fc259be/CriticalMineralsMarketReview2023.pdf

41. https://www.generalkinematics.com/blog/manganese-mining-processing-everything-need-know

42. https://elements.visualcapitalist.com/graphite-essential-material-in-battery-supply-chain

43. https://iea.blob.core.windows.net/assets/afc35261-41b2-47d4-86d6-d5d77fc259be/CriticalMineralsMarketReview2023.pdf

44. https://www.nature.com/articles/d41586-023-02153-z

45. https://media4.manhattan-institute.org/sites/default/files/mines-minerals-green-energy-reality-checkMM.pdf

46. https://www.linkedin.com/posts/gwagner_fossil-fuels-500x-the-material-impact-activity-7083049346572640257-rW_n/

47. https://www.reuters.com/business/energy/nuscale-power-uamps-agree-terminate-nuclear-project-2023-11-08/

low-enriched uranium (HALEU).[48,49,50] Nuclear firms are justifiably concerned about this situation, and the U.S. has begun taking steps to supply its own fuels, which will take years.

Uranium itself is available in limited amounts, mainly from rocks. Extracting uranium from seawater may provide another source of nuclear fuel, reducing supply chain pressures.[51]

Hydrogen

Water is a key raw material to make hydrogen through electrolysis. Water is plentiful, and desalination's cost and energy use represent a tiny fraction of the overall energy demand.[52] The most significant supply source for making hydrogen is the renewable energy needed to power the electrolyzers, particularly where new green energy sources are required.

Summary

While significant supply chain challenges are associated with all new clean energy technologies, there are ample supplies of the materials needed to power the energy transition. Onshoring of manufacturing may improve energy security concerns, but significant challenges lie ahead to build competitive manufacturing, not only while IRA subsidies are available but also after the subsidies end. It may be more effective to spread the energy supply chain across the world than to attempt to fully domesticate it. Diversifying countries supplying and processing critical materials would be prudent to promote energy security.

Companies building projects should understand the supply chain issues associated with their projects. Where possible, develop contingency plans to source necessary equipment and materials to help limit the impact of any event that interrupts the site's operation. This means sparing key equipment and developing contingency plans for equipment and replacement equipment, such as solar panels and wind turbine blades, at predetermined costs and timeframes from OEMs as part of contractual agreements. Pre-arranging recycling protocols is similarly recommended.

Consider taking measures to minimize the likelihood of an event impacting projects, such as using the most resilient design available in areas subject to weather risk and testing mitigation procedures to ensure they work when required.

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51. https://www.acs.org/pressroom/presspacs/2023/december/extracting-uranium-from-seawater-as-another-source-of-nuclear-fuel.html

52. https://www.linkedin.com/posts/paul-martin-195763b_folks-i-keep-seeing-it-again-and-again-activity-7080171845680840706-VpLj/

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