Deloitte.

CPRM
Serviço Geológico do Brasil

GOVERNMENT OF BRAZIL MINING SECTOR TECHNICAL SUPPORT AND COOPERATION

Renewable Energy and the Use of Critical Minerals

Prepared for:
Office of Energy Programs
Bureau of Energy Resources
U.S. Department of State

Prepared by:
Deloitte & Touche LLP
1919 N. Lynn Street
Arlington, VA 22209

January 16, 2022

This work was funded by the U.S. Department of State, Bureau of Energy Resources, Energy and Mineral Governance Program (EMGP)

DEPARTMENT OF STATE · UNITED STATES OF AMERICA

DISCLAIMER

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms

ASSBs	All-Solid-State-Batteries
BECCS	Bioenergy With Carbon Capture and Storage
BESS	Battery Energy Storage Systems
bp	British Petroleum
CAES	Compressed Air Energy Storage
CCS	Carbon Capture Storage
CCUS	Carbon Capture Utilization Storage
CIGS	Copper Indium Gallium Selenide
CH_4	Methane
CO_2	Carbon Dioxide
CPRM	Geological Survey of Brazil
CSP	Concentrating Solar Power
DERA	German Mineral Resources Agency
DLE	Direct Lithium Extraction
DOS	Department of State
DRC	Democratic Republic of Congo
EMGP	Energy and Mineral Governance Program
ENR	Bureau of Energy Resources
ESG	Environment, Social, and Governance
EV	Electric Vehicles
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWEC	Global Wind Energy Council
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISP	Institute for the Sustainable Futures
LCOE	Levelized Cost of Energy
LDES	Long-Duration Energy Storage
LFP	Lithium-iron-phosphate
LMO	Lithium Manganese Oxide
MME	Ministry Of Mines and Energy
NCA	Nickel Cobalt Aluminum
NCM	Nickel-Cobalt-Manganese
NMC	Nickel Manganese Cobalt
PNM	National Plan for the Brazilian Mineral Sector

PV	Photovoltaics
REE	Rare Earth Elements
SDG	Sustainable Development Goals
SDS	Sustainable Development Scenario
STEPS	Stated Policies Scenario
T&D	Transmission & Distribution Network
USGS	U.S. Geological Survey
VRE	Variable Renewable Energy
VRFBs	Vanadium Redox Flow Batteries

EXECUTIVE SUMMARY

Deloitte is implementing the *Government of Brazil Mining Sector Technical Support and Cooperation* Task Order (the Project) under Deloitte's Blanket Purchase Agreement (BPA) with the U.S. Department of State (DOS) in support of the Bureau of Energy Resources' (ENR), Energy and Minerals Governance Program (EMGP). The Deloitte team is providing technical assistance to support the Government of Brazil's Ministry of Mines and Energy (MME) and the Geological Survey of Brazil (CPRM) as they seek to improve their ability to:

- Develop safe, sustainable, and effective mine closure procedures and use of tailings, including methods of tailings sampling and characterization, based on international leading practices, to protect and improve the legacy of ongoing and future projects, thereby realizing sustainable benefits from the extractives industry;
- Manage a growing mineral sector and compete effectively in the global market, given a growing market and accelerated demand for critical minerals that are essential to the development of innovative technologies to advance the global clean energy transition (electric vehicles, batteries, and battery storage systems, etc.); and
- Streamline the structure of Brazil's nickel-cobalt data inventory, so Brazil can improve its understanding and increase development of critical minerals.

Under *Task 2A: Economic Viability and Global Market Competitiveness of Specific Minerals*, the Deloitte team developed a series of reports focused on nine minerals including, graphite, lithium, nickel, cobalt, rare earth elements (REEs), titanium, vanadium, tantalum, and copper. The purpose of these reports was to provide recommendations to the Government of Brazil on where and how Brazil could compete most effectively and inform their long-term strategic planning for commercialization of minerals based on global market trends and challenges to mineral resource development that may inhibit Brazil's overall market competitiveness. The Deloitte team's recommendations will also inform the National Plan for the Brazilian Mineral Sector 2050 and future policy actions for the Government of Brazil.

In addition to the market and competitiveness analysis for the nine critical minerals noted above, the Deloitte team is also preparing two appendices to support Task 2A. *Appendix 1: Renewable Energy and the Use of Critical Minerals* (this Report) will discuss the growing impact of climate change on the commodity markets (including the market for the critical minerals noted above), as countries around the world (including Brazil), implement plans to accelerate their clean energy transition. *Appendix 2: Leading Practice Critical Mineral Policy Initiatives* will focus on specific measures Western Australia and Canada have implemented to effectively compete in the market. These leading practices provide lessons learned for MME, CPRM, and other government entities in Brazil involved in the mining sector.

Key Highlights

- The global levelized cost of energy (LCOE) for renewables has decreased over the past 15 years, and in many places, wind and solar are cheaper than thermal power generation (natural gas and coal).[1] According to Lazard, between 2009-2018, the price of solar dropped by 86 percent.[2] This drop in cost has catalyzed the adoption of utility-scale renewable energy and shifted planned new generation capacity towards wind and solar, and away from gas and coal.

---

1 Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022 (eia.gov)

2 Solar Power Cost Rapidly Decreasing, Chart Shows (businessinsider.com)

- The most important technologies expected to dominate the clean energy market are wind, solar, hydrogen, and smart electric grids [transmission and distribution (T&D) networks]. Lithium-ion batteries for both electric vehicles (EVs) and battery energy storage systems (BESS) are also a key technology. Building out these technologies and industries will require a substantial increase in the supply of certain commodities (some of them critical minerals, such as REE, lithium, cobalt, nickel, platinum, and others) over the coming decades[3]. Lithium, nickel, cobalt, manganese, and graphite are currently crucial to lithium-ion batteries; REEs are essential for permanent magnets in wind turbines and EV motors; non-critical minerals, such as copper, silicon, and silver, are used in solar panel applications; vanadium is used in renewable energy technology for stationary energy storage in vanadium redox flow batteries; titanium (and tantalum, although in smaller amounts) are inputs to wind turbines; and T&D networks need a large amount of copper and aluminum.
- The Russian invasion of Ukraine has increased global uncertainty around the availability and price of oil and natural gas. Many governments, especially in Europe, which has been particularly impacted by fuel shortages and price increases, are reconsidering their energy policies and implementing plans to accelerate the clean energy transition. In addition, Russia is a major producer of a number of critical minerals and metals including aluminum, nickel, palladium, and vanadium. The Russian invasion of Ukraine has increased global uncertainty and triggered supply constraints and price spikes for multiple commodities. The price of aluminum and nickel reached 10-year highs in February 2022; similarly, the price of palladium and vanadium have seen rapid spikes since January 2022. This type of volatility in commodity prices can cause problems for producers and consumers; it could, for example, encourage buyers to take a more conservative, risk-averse approach, which means a preference towards longer-term contracts with less spot trade. Some primary consumers may also consider expanding vertical integrating their supply chains once the uncertainty subsides.
- The acceleration of the pace of renewable energy deployment, will be dependent on robust and transparent critical mineral supply chains. Key risks to such supply chains will include: the geological availability of specific critical minerals; the time required to develop mines and processing plants to recover commodities; the geopolitical energy landscape (with focus on China's market dominance in the processing and refining of critical minerals); and the social and environmental impacts of mining projects. As countries focus on expanding their domestic mining, production, processing, and recycling[4] of critical minerals, they will also have to address the growing issues of labor standards, environmental justice, and community engagement.

Figure 1 below summarizes market trends and green uses for the nine critical minerals analyzed under Task 2A.

---

[3] Critical Minerals & Materials | Department of Energy.

[4] According to the Institute for Sustainable Futures (ISF), recycling of metals from end-of-life batteries has the greatest opportunity to reduce primary demand for battery metals, including demand for cobalt, lithium, nickel, and manganese.

Figure 1: Green Uses for Select Mineral Commodities Analyzed Under Task 2A

Group	Clean Technology Applications/Green Uses	Market Overview and Potential
Graphite	• Key input for batteries and electrodes (anodes for lithium-ion battery), in the development of EVs. • Fuel-cell applications utilizing graphite plates in battery storage may require increased graphite demand.	• Growing, long-term demand for EVs and energy storage continues to drive the demand for graphite • Drawbacks include middlemen and the need for long-term offtake agreements. China dominates the production and processing of graphite.
Lithium	• Key component on all traction batteries currently used in EVs as well as consumer electronics (mobile phones, laptops, and portable tools). • Lithium-ion batteries are widely used in many other applications as well, from energy storage to air mobility.	• It will be challenging for lithium supply to keep up with demand growth over the next decade. Current forecasts all suggest that the lithium market will remain in deficit, even with timely financing and the development of new capacity. • Attempts to accelerate demand are becoming visible with some planned mining projects and new chemical plants increasing in size. Consequently, the market will need to develop new types of lithium sources such as clays and evaporites to meet demand.
REEs	• Key roles as inputs to green energy generation, storage, and control systems, magnets in motors and generators, and the IC chips in control systems from cell phones to EVs.	• Positive market demand and outlook to 2030 and beyond. • Supply is limited, and few mines operate at scale outside China.
Cobalt, Nickel, Copper	• Key inputs to wind power, solar cells, and EV battery production. • Nickel and cobalt hold roles in the next wave of EV battery and battery storage development, often substituting for each other in various types of technologies.	• Predicted near-term demand (and price) for copper, nickel, and cobalt expected to increase through 2040. • Increased EV demand and over-dependence on the Democratic Republic of Congo (DRC) causing a surge in exploration for new deposits or sources of cobalt.
Titanium and Vanadium	• Key input to wind power turbines, geothermal piping, catalytic converters for EVs and grid energy storage capabilities. • New redox battery technology may support increased use of vanadium.	• Long-term, steady demand for titanium due to China's increase in imports. Competitive market, with over eight major producers. • Vanadium demand likely to grow, tied to steel production and energy storage technology.
Tantalum	• Though small amounts needed, tantalum are inputs to wind turbines and solar arrays.	• Projected steady growth for tantalum; new opportunities with 5G technologies may absorb current over-capacity.

1. INTRODUCTION

1.1. Purpose of this Report

The demand for battery materials could mean a paradigm shift for the mining sector. Strengthening the critical mineral supply chain is necessary to manufacture several clean energy technologies, from EV batteries. to wind turbines, and solar panels. The purpose of this Report is to discuss the growing impact of climate change on the commodity markets as countries around the world (including Brazil), implement plans to accelerate their clean energy transition.

1.2. Organization of this Report

This Report is organized into five main sections, and one annex:

- **Section 1: Introduction** – Presents the purpose of this Report, background and context on the role of renewables and associated commodities, and a summary of market trends and outlook for renewables.
- **Section 2: Climate Change Strategies** – Provides background information on challenges associated with the shift to renewable energy and energy transition.
- **Section 3: Metal Demand in Key Technologies** – Examines different renewable technologies and the associated metals required for such technologies.
- **Section 4: Demand Outlooks for Renewable Commodities** – Examines a series of reports that have published demand forecasts for renewable commodities.
- **Section 5: Risks for Renewable Commodities** – Explains some of the risks associated with energy transitions, including the geopolitical landscape, geological availability of specific critical minerals, social and environmental impacts of the mining projects, and technology risks.
- **Annex 1 – Battery Technologies** - Provides a description of battery technologies.

1.3. Background and Context

Climate change is one of the biggest challenges facing the world today with widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere. Rising greenhouse gas (GHG) emissions are believed to be the dominant driver of climate change and global warming, and much of the increase has been human induced. In 2015, the Paris Climate Agreement committed 195 countries to limit global warming to below 2.0 degrees Celsius by 2050 through the reduction of GHG emissions. Around 75 percent of the world's GHG emissions are caused by the energy sector and the consumption of fossil fuels. Mitigating GHG emissions involves the replacement of fossil fuel energy sources with low or zero carbon renewable energy sources. Although the United Nations reports on climate change state that while there are positive steps towards the climate finance flows and the development of nationally determined contributions (NDCs), far more ambitious plans and accelerated actions are needed on mitigation and adaptation. In addition, LCOE for renewables has decreased significantly over the past 15 years that in many places, wind and solar are cheaper than thermal power generation (natural gas and coal).[5] For example, according to Lazard, between 2009-2018, the price of solar dropped by 86 percent.[6]

---

[5] Levelized Costs of New Generation Resources in the Annual Energy Outlook 2022 (eia.gov)

[6] Solar Power Cost Rapidly Decreasing, Chart Shows (businessinsider.com)

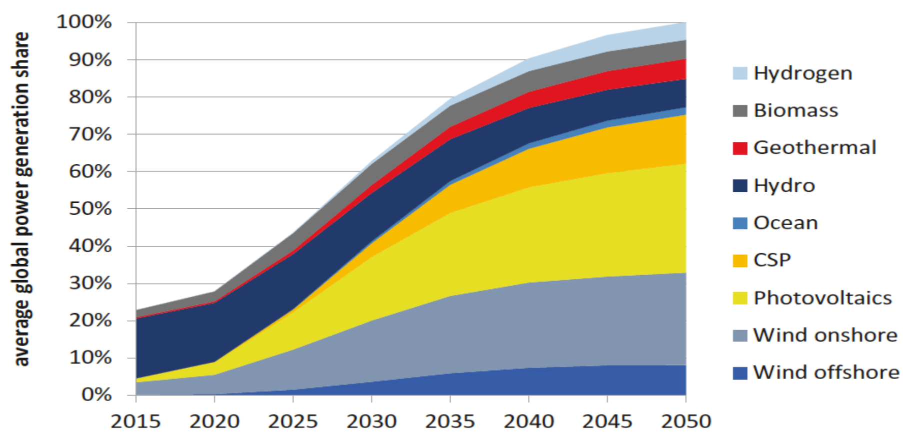
The International Energy Agency (IEA) highlights that global installed capacity of wind power has nearly quadrupled over the past decade. This growth was spurred by falling costs, which have declined by about 40 percent on average globally, and policy support in more than 130 countries. According to the IEA, worldwide solar photovoltaics (PV) capacity has increased by almost 20 times over the past decade, similarly spurred by declining costs plus strong policy support in key regions. In addition, a report by British Petroleum (bp) estimates that the price of solar could decrease another 55 percent by 2030,[7] which would accelerate the pace of solar installations globally. This decline in costs has catalyzed the adoption of utility-scale renewable energy and shifted planned new power generation plants heavily towards wind, and solar and away from gas and coal.

The Russian invasion of Ukraine has increased global uncertainty around the availability and price of oil and natural gas. The resulting increase in global energy prices caused many governments – in Europe and beyond - to reconsider their energy policies. Now, more than ever, countries understand the importance of increasing domestic energy production from renewable energy as a critical component to achieving energy security.

1.4. Summary of Market Trends and Outlook for Renewable Energy

As illustrated in Figure 2, below, the most important technologies expected to dominate the clean energy market are wind, solar, hydrogen, and ”smart“ upgrades to the T&D network to accommodate increased variable renewable energy (VRE) sources. Building out these technologies and industries will require a significant increase in the supply of associated commodities (some of them critical minerals). Within these renewable energy technologies, a large part of the demand for these commodities will also come from clean energy applications, like EVs and stationary energy storage using batteries.

Figure 2: Development of the Average Global Renewable Energy Sources (2.0 degrees C)



Source: Achieving the Paris Climate Agreement Goals. T. Pregger et al[8].

[7] Global solar LCOE could fall 40 – 55% by 2030, bp report says - PV Tech (pv-tech.org)

[8] https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwj1wc2q9O35AhXON8AKHdDnAtEQFnoECBAQAQ&url=https%3A%2F%2Flibrary.oapen.org%2Fbitstream%2Fid%2Fece42b8a-6fc7-43f4-aa27-01918ae680e1%2F1007262.pdf&usg=AOvVaw2B-r7IdYonnhP6duotne88

The types of mineral resources used vary by application and technology. Lithium, nickel, cobalt, manganese, and graphite are currently crucial to battery performance, longevity, and energy density, although formulations are slowly changing. REE are essential for permanent magnets that are extensively used in wind turbines and EV motors. Copper, silicon, and silver are used in solar panel applications. Electricity networks need a large amount of aluminum and copper, which are commodity cornerstones for all electricity-related technologies. Vanadium is used in stationary energy storage via vanadium redox flow batteries. Titanium is a key input to wind turbines, geothermal piping, catalytic converters for EVs, and grid energy storage. Tantalum, in smaller amounts, is an input to wind turbines and solar arrays.

Many organizations have developed theoretical commodity-demand-shift scenarios, quantifying the impact on commodity demand by 2030 and 2050. Although these scenarios are useful for long-term planning, the actual increase in demand that certain metals will experience is still unclear and challenging to predict, because the technologies are constantly evolving. Other important factors, often not addressed, are the impacts of improving material efficiency, increased levels of recycling mineral resources, and expected demand for renewable energy commodities. Specifically, increased levels of recycling mineral resources could have important bearings on the required supply of new material, because for some commodities, the current stocks of materials will not be sufficient to fill the demand gap predicted by economic growth. Also, given the demand expectations for renewable energy commodities, the available supply of these commodities introduces risk factors, such as the geological availability of mineral resources; the time required to develop mines and process plants to recover these commodities; the geopolitical landscape; and the associated social and environmental impacts of the mining projects.

One of the most pressing concerns of several governments is the high geographical concentration of supply for many critical commodities (either through mining, processing, or both) as well as the long lead times required to bring new production to stream. These factors, in combination, raise concerns around the reliability and sustainability of critical mineral supplies, especially given the elevated quantities of such minerals that will be required to support the expected increase in renewables demand associated with the climate goals outlined in the Paris Climate Agreement.

Finally, incremental changes and improvements in renewable energy and lithium-ion battery technology will take place over the coming years; however, the current technology is unlikely to change significantly within the next 10 years. This is because of the conservative nature of end-user industries, the long qualification times of materials and processes, and the existing and planned investments in capacity. Nevertheless, in the long- term, it will be important to monitor the development of new technology and corresponding evolving mineral requirements against current and planned future metal production, to support a balanced outcome of supply and demand for each individual commodity.

2. CLIMATE CHANGE STRATEGIES

Most national climate change strategies are generally centered around the 2015 Paris Agreement. The Paris Agreement's climate change goals require a significant reduction in GHG emissions between 2010 and 2050: a 41 to 72 percent decrease for a 2.0 degrees Celsius scenario and a 78 to 89 percent decrease for a 1.5 degrees Celsius scenario, according to data from the Intergovernmental Panel on Climate Change (IPCC)[9].

2.1. The Challenges to Achieve Climate Change Goals

2.1.1. Increased Climate Change Pressure

The pressure on the world was raised when the United Nations Sustainable Development Goal 13 (*SDG13 - take urgent action to combat climate change and its impacts*) progress report for 2019[10] stated that with rising GHG emissions, climate change is occurring at rates much faster than anticipated. Although there have been positive steps made towards mitigating the effects of climate change, better planning and actions are needed to reach global climate goals.

The Sixth Assessment Report (AR6), which is the most recent climate change assessment report by the IPCC (August 2021), stated that human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Since the Fifth Assessment Report (AR5) in 2014, there has been an increase in observed changes in extreme weather conditions with more regions of the world having heatwaves, heavy precipitation, droughts, and tropical cyclones. According the AR6, these extreme weather changes can be attributed to human influence.

McKinsey reported in its Global Energy Perspective 2022 that global emissions remain far from a 1.5-degree pathway. To meet the requirements for a 1.5-degree pathway, mature economies would likely need to accelerate their annual emissions' decline, on average, by a factor of 8 to 9 times compared to efforts in the last 10 years. Emissions from emerging economies are projected to continue to grow over the next decade; these countries may need to move to lower-carbon growth paths sooner and reach their emissions peaks earlier than their current commitments.

2.1.2. Corporate Strategies

In its attempt to improve corporate initiatives, the IPCC pointed out that now more than ever it is critical for companies to consider the impact of climate change and associated mitigation and adaptation efforts on their strategies and operations and disclose related material information. Companies that invest in activities that may not be environmentally viable in the longer term may be less resilient to risks associated with climate change; and their investors may experience lower financial returns.

The strategies for the reduction in GHG and Carbon Dioxide (CO_2) footprints are mainly centered around the management of energy use, in particular the decarbonization of energy sources and the improvement in energy efficiency using new technologies. Also important is the reduction in fugitive emissions and carbon capture. These new strategies are resulting in demand for new clean energy technologies which in turn are driving unprecedented demand for a series of commodities and critical minerals.

---

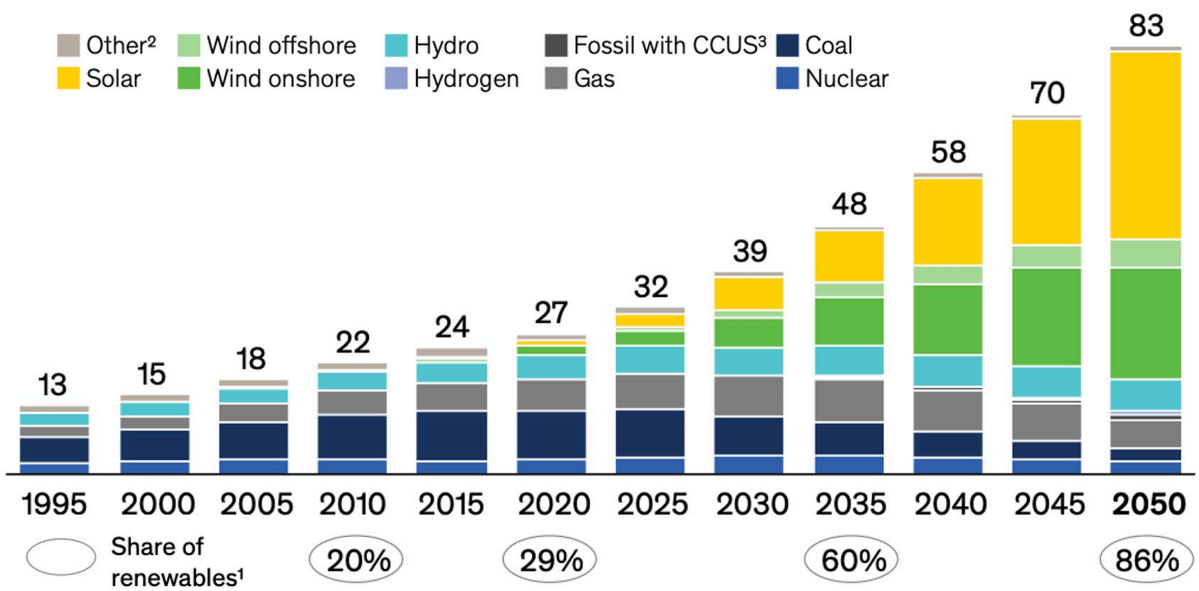
[9] The Intergovernmental Panel on Climate Change - Assessing the Science Related to Climate Change. https://www.ipcc.ch.

[10] United Nations - Progress on sustainable development goal 13. https://sustainabledevelopment.un.org/sdg13.

2.1.3. Renewables the New Baseload

Figure 3 shows a global power generation mix forecast to 2050. Renewables are expected to become the new baseload, accounting for 60 percent of the power mix by 2035 and 86 percent by 2050. Solar and wind construction already come at a lower cost than existing fossil fuels in most countries and are projected to become increasingly cost competitive globally. Thermal generation is projected to shift to a role of back-up flexibility provider to support grid stability. There are expected regional differences in the decarbonization paths for the power mix, driven by active policies, political preferences, economic factors, and the availability of land and resources.

Figure 3: Global Power Generation Mix Forecast to 2050 (Thousand TWh)



Source: McKinsey - Global Energy Perspective 2022. 1. Includes solar, wind, hydro, biomass, bioenergy with carbon capture and storage (BECCS), geothermal, and marine and hydrogen-fired gas turbines. 2. Other includes bioenergy (with and without carbon capture utilization and storage [CCUS]), geothermal, marine, and oil. 3. Includes gas and coal plants with CCUS.

COVID-19 triggered a drop in global CO_2 emissions of around 5 percent, however, emissions showed a strong rebound in 2021, almost returning to 2019 levels. In 2021, both coal and natural gas emissions were higher than 2019 levels. The primary driver in the surge of coal emissions was power, supported by strong industrial growth in China and high gas prices globally. Gas emissions only marginally declined in 2020 and then increased beyond 2019 levels in 2021. Oil emissions only partially rebounded in 2021, largely due to the slow recovery in aviation.

Many countries updated their decarbonization plans in 2021 to have more aggressive reduction targets. Around 91 percent of global CO_2 emissions are now covered by net-zero targets. In late 2021, as a precursor to COP26, some of the world's largest emitters recognized that GHG methane (CH_4) is a prominent contributor to global warming. They committed to a 30 to 50 percent reduction in methane emissions by 2030. Although these pledges would reduce global methane emissions by around 13 percent by 2030, they remain far from the 34 percent that is required to achieve a 1.5-degree pathway. Some large emitters, such as Russia, India, and China have not yet made commitments to reduce methane emissions.

McKinsey notes that should roadblocks arise that limit the deployment of renewables, low-carbon technologies such as CCUS, nuclear, and long-duration energy storage (LDES) could help meet emission goals. Moreover, nuclear uptake could be significant in land-constrained regions, while CCUS could cover 8 to 17 percent of the remaining fossil fuel generation by 2050, if growing CO_2 prices make it attractive in regions with low-cost fuels.

2.1.4. Russian Invasion of Ukraine and Europe's Energy Policy

The Russian invasion of Ukraine has increased global uncertainty around the availability and price of oil and natural gas. Before the conflict began, the rebound in energy demand following COVID-19 had already triggered supply constraints and price spikes for multiple commodities; Russia's aggression, and the subsequent sanctions imposed, have only caused further energy price volatility; energy costs as a percentage of world gross domestic product (GDP) are now near the highs of 2008 at around 14 percent. In Europe, this figure is currently closer to 19 percent of GDP. In contrast, over the past 20 years, energy prices have averaged about 7 percent of GDP. From 2015 to 2021 they traded at around 5 percent.

This increase in global energy prices has caused many governments – in Europe and beyond - to reconsider their energy policies. Now, more than ever, countries understand the importance of increasing domestic energy production from renewable energy as a critical component to achieving energy security. Nuclear power is also increasingly accepted as a key part of the energy security and decarbonization process.

2.2. Renewables Investment Requirements

In 2020, the share of renewables in world electricity generation reached 29 percent, according to IEA[11]. This is expected to increase to 32 percent by 2025. BloombergNEF reports[12] that in 2021, global investment in the low-carbon energy transition totaled $755 billion, up from $595 billion in 2020 and just $264 billion in 2011, as shown in Figure 4 below. This figure includes investment in projects such as renewables, storage, charging infrastructure, hydrogen production, nuclear, recycling, and carbon capture storage (CCS) projects, as well as end-user purchases of low-carbon energy devices, such as small-scale solar systems, heat pumps, and zero-emission vehicles.

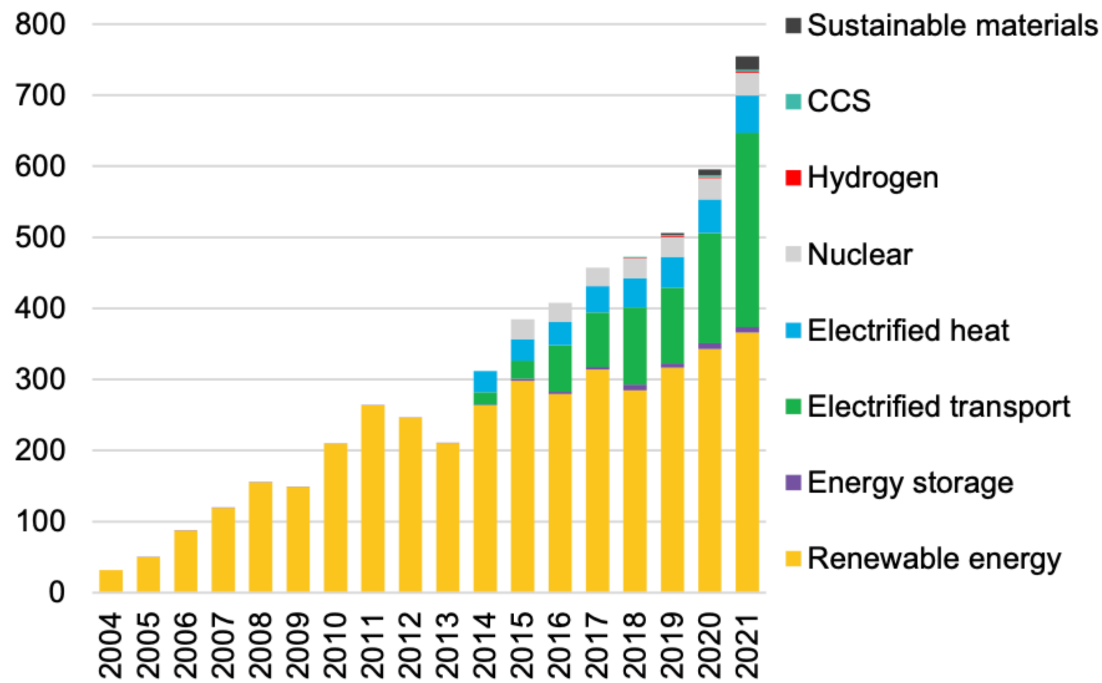
The sector that attracted the largest investment in 2021 was renewable energy, some $366 billion was invested for new projects and small-scale systems; however, the electrified transport sector grew the fastest and investment totaled $273 billion, an increase of 77 percent. The next largest sectors of spending were electrified heat, at $53 billion, and nuclear energy, at $31 billion. The Asia Pacific region attracted the most investment, at $368 billion, and recorded the highest growth, at 38 percent.

---

[11] International Energy Association (IEA) - The Role of Critical Minerals in Clean Energy Transitions. https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf.

[12] BloombergNEF - Energy Transition Investment Trends 2022. https://assets.bbhub.io/professional/sites/24/Energy-Transition-Investment-Trends-Exec-Summary-2022.pdf.

Figure 4: Global Investment in the Energy Transition Sector ($ Billion)



Source: BloomberNEF

According to BloombergNEF's 2021 energy report[13], emissions still need to fall 30 percent below 2019 levels by 2030, and to drop 75 percent by 2040 to reach zero in 2050. This means adding up to 505 GW of new wind, 455 GW of new solar, and 245 GWh new battery storage on average every year to 2030 under its 'Green Scenario' – a clean-electricity and green-hydrogen net-zero pathway. This is over 5.2 times the amount of wind capacity added in 2020, 3.2 times the amount of solar and 26 times the amount of battery storage. By 2030, that adds up to a total of 5.8 TW of installed wind, 5.3 TW of installed PV, and 2.5 TWh of batteries. These totals are up eightfold, ninefold and 176-fold from 2020 levels, respectively.

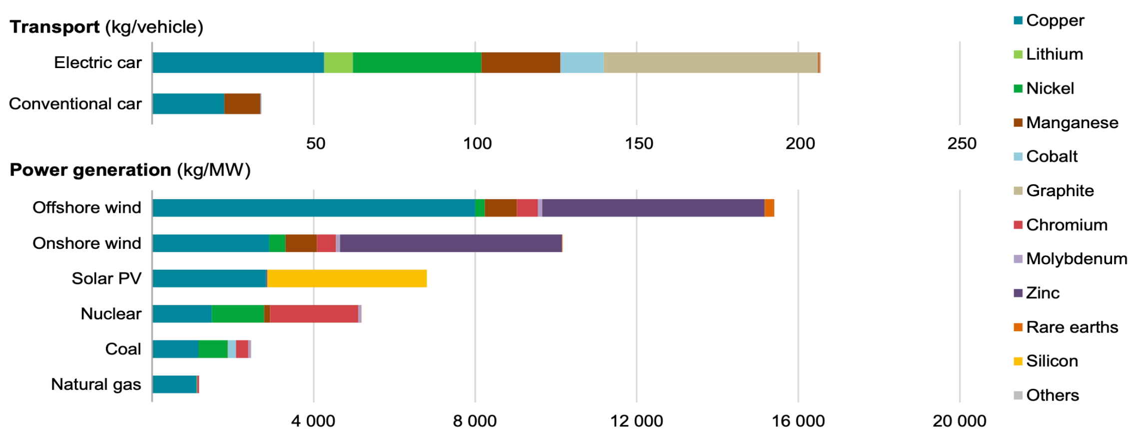
Meanwhile, the IEA notes that decarbonizing electricity production is a key step, but there is also an urgent need to transform 'hard to abate' sectors including transport, buildings, and energy-intensive industries (iron, steel, and cement).

[13] BloombergNEF - New Energy Outlook 2021. https://assets.bbhub.io/professional/sites/24/NEO-Executive-Summary-2021.pdf.

3. METAL DEMAND IN KEY TECHNOLOGIES

The first step to analyzing future critical mineral demand is to examine which renewable technologies are being / are likely to be broadly adopted and determine their associated commodity profiles. Figure 5 illustrates the relative role of 12 critical minerals across multiple clean energy technologies, including transportation and power generation. Six of the nine minerals listed are covered in the Deloitte team reports developed under Task 2A.

Figure 5: IEA - The Role of Critical Minerals in Clean Energy Transitions



Source: IEA

3.1. Metal Demand for Solar Technologies

Solar PVs transform light energy into electrical energy using semiconductor materials. Advances in technology and increased manufacturing scale have improved the reliability and the efficiency of photovoltaic installations, which has resulted in marked price reductions in solar PV costs in recent years. In addition, a report by bp estimates that the price of solar could decrease another 55 percent by 2030,[14] which would accelerate the pace of solar additions globally.

Crystalline silicon cells make up about 95 percent of the solar PV market and are made from silicon wafers and can either be manufactured as single crystalline, polycrystalline, or amorphous silicon. A solar PV panel contains about 76 percent glass (panel surface), 10 percent polymer (encapsulant and back-sheet foil), 8 percent aluminum (frame), 5 percent silicon (solar cells), 1 percent copper (interconnectors), and less than 0.1 percent silver (contact lines) and other metals[15]. The metal with the potential largest demand impact is silver. Solar PV currently consumes approximately 9 percent of end-use silver. The balance of demand for solar PV is thin film technology, which mainly uses copper indium gallium selenide (CIGS) cells. Figure 6 shows an overview of the key metals used in the solar PV supply chain.

Innovation in the manufacturing and design of solar panels over the past decade has supported remarkable advances in efficiency and has contributed to large reductions in materials intensity. Since 2008, silicon intensity has more than halved as wafer thickness diminished substantially, while silver intensity has fallen by 80 percent due to more efficient and less silver-intensive metallization pastes. Reductions in material intensity are expected to continue.

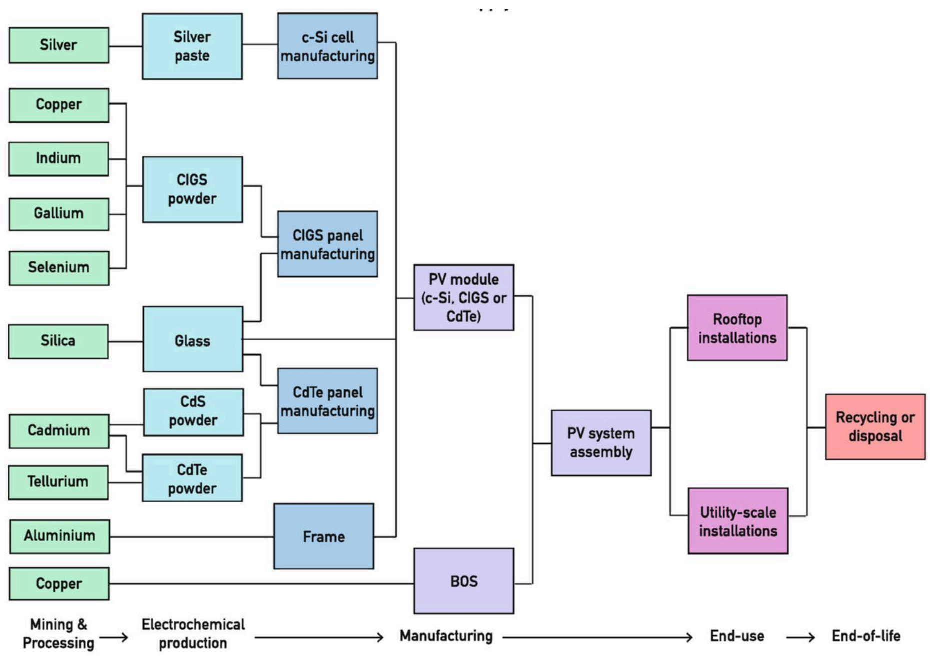
---

[14] Global solar LCOE could fall 40 – 55% by 2030, bp report says - PV Tech (pv-tech.org)

[15] IEA. Renewables 2019. https://www.iea.org/reports/renewables-2019.

Future metal demand in the solar industry will depend on both the total amount of solar PV installed, and choices between competing solar technologies. The demand for silver is also critically a function of the impact of improving material efficiency and potential recycling rates.

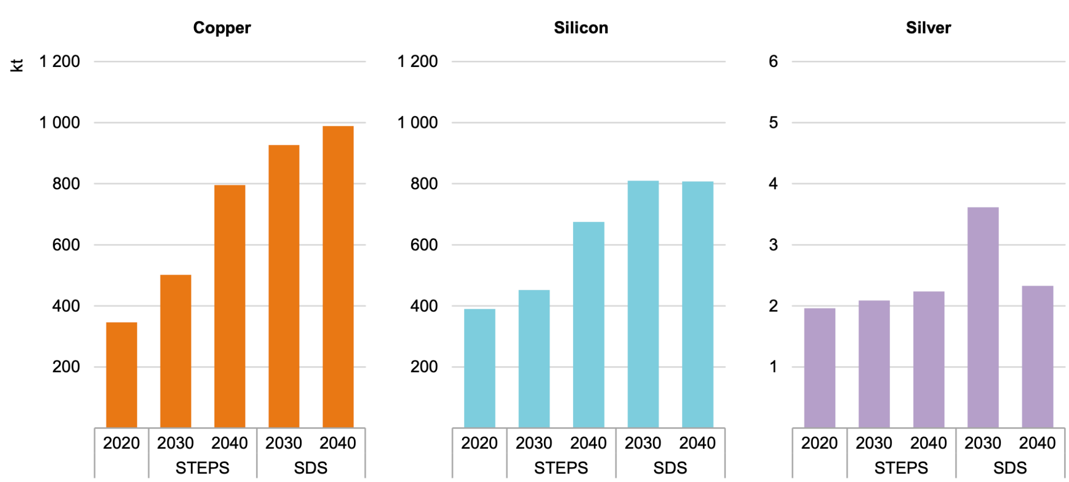
Figure 6: Overview of Key Metals in Solar PV Supply Chain



Source: Achieving the Paris Climate Agreement Goals. T. Pregger et al.

According to the IEA, worldwide solar PV capacity has increased by almost 20 times over the past decade, spurred by declining costs and strong policy support in key regions. With sharp cost reductions over the past decade, solar PV now offers some of the lowest electricity costs in most countries, cheaper than new coal- or gas-fired power plants. Figure 7 shows the demand for three of the key commodities used in solar PV.

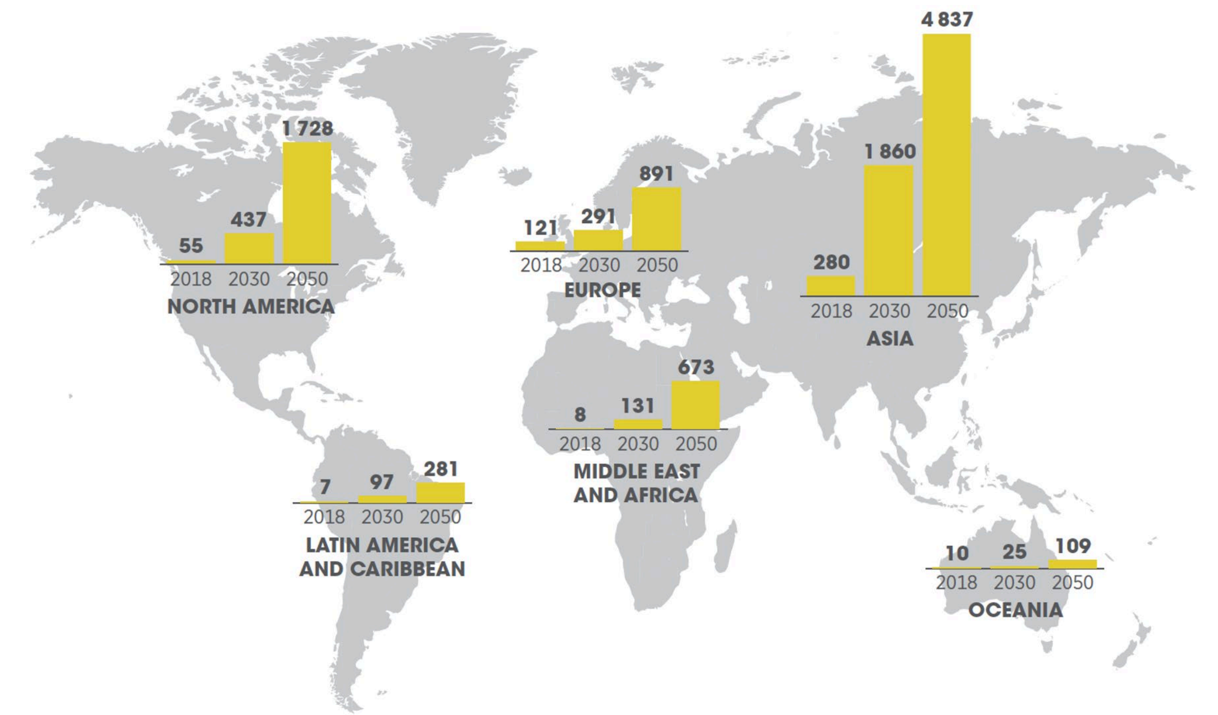
Figure 7: Demand for Copper, Silicon, and Silver for Solar PV by Scenario



Source: IEA Note: STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario. (See p.25)

The International Renewable Energy Agency (IRENA) forecasts an increase in global solar capacity from 480 GW in 2018 to 2,840 GW by 2030, and 8,519 GW by 2050[16]. In annual growth terms, a doubling in annual solar PV capacity additions is needed by 2030 (to 270 GW per year) and near tripling by 2050 (to 372 GW per year), compared with 134 GW added in 2020. The IEA forecasts that capacity additions of around 320 GW per annum are required out to 2040. Asia (mostly China) is expected to continue dominating installed solar PV power capacity, with a share exceeding 50 percent by 2050, followed by North America (20 percent), and Europe (10 percent), as shown in Figure 8.

Figure 8: Forecast of Solar PV Installed Capacities (GW)



Source: IRENA

3.2. Metal Demand for Wind Technologies

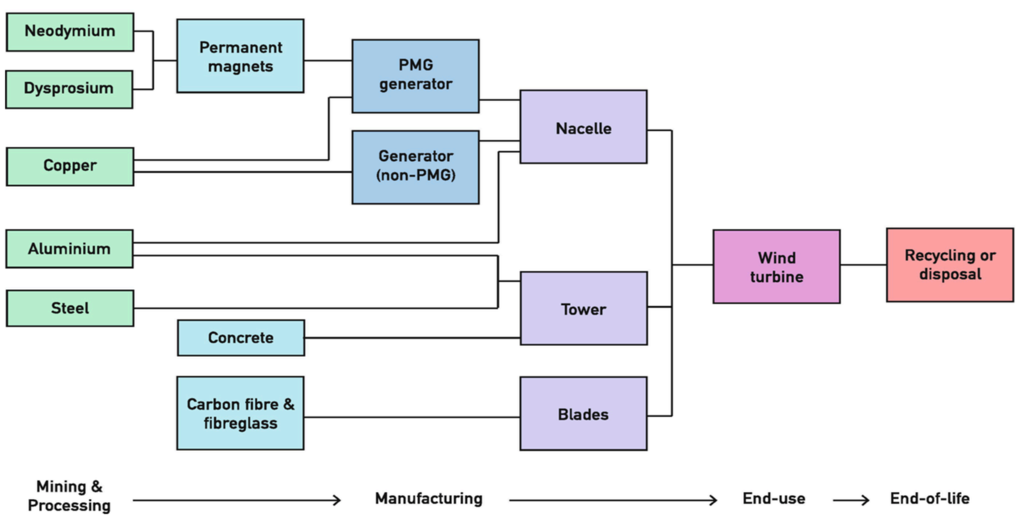
The technology options for wind are numerous and are related to the size of the turbine and whether it rotates vertically or horizontally. To minimize cost, the industry has converged on large, horizontally rotating turbines. There are two main designs, geared turbines and direct-drive turbines. Onshore geared turbines currently make up around 70 percent of the installed base.

Geared turbines use a system of gears to convert the relatively low rotation speed of the turbine to a much higher speed (thousands of revolutions per minute) for the generator. Geared turbines use coil-driven generators that require significant amounts of copper, but do not often use permanent magnets. Direct-drive wind turbines do not have a gearbox but use a more complicated and expensive low-speed generator, which is generally constructed with permanent magnets containing REEs.

[16] IRENA – Future of Solar Photovoltaic November 2019. https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic

Geared turbines have traditionally had a cost advantage over direct-drive turbines, because of the lower cost generator, however, the reliability of geared turbines has traditionally been worse because of the complicated gearbox, especially in places where higher wind speeds put more stress on the gearboxes. As a result of the higher reliability, direct-drive turbines are usually installed more in offshore locations with higher wind and areas with more difficult access, while geared turbines have been installed in onshore locations with lower wind speeds and easier access. Innovations on the horizon include floating turbines. Figure 9 gives an overview of the key metals used in the wind power supply chain.

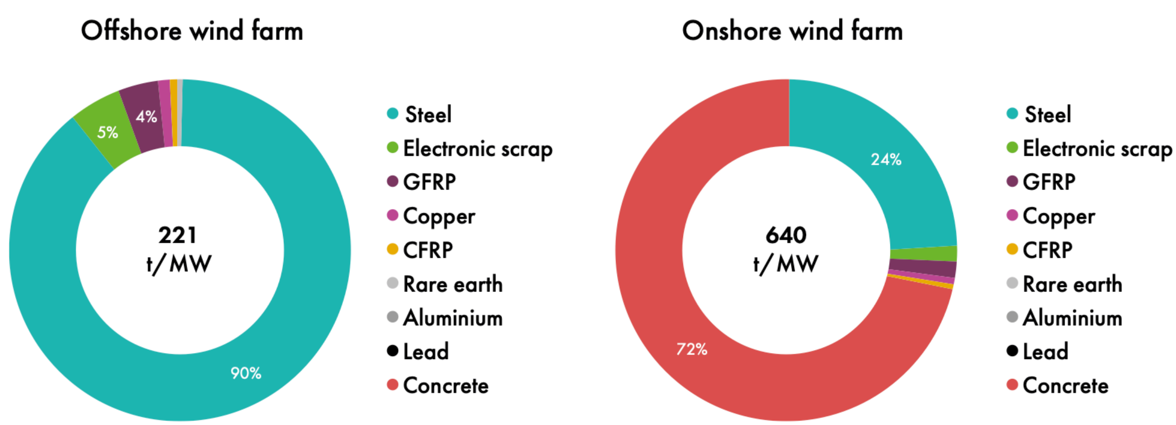
Figure 9: Overview of Key Metals in Wind Power Supply Chain



Source: Achieving the Paris Climate Agreement Goals. T. Pregger et al.

The major raw materials required for the manufacture of wind turbine components are bulk commodities: iron ore, copper, aluminum, limestone, and carbon (fiberglass). Wind turbines use steel for the towers, nacelle structural components, and the drivetrain, accounting for about 80 percent of the total weight. Figure 10 gives a breakdown of materials used for onshore and offshore wind farms.

Figure 10: Materials Breakdown for Onshore and Offshore Wind Farms



Source: GWEC – Global Wind Energy Report 2022.

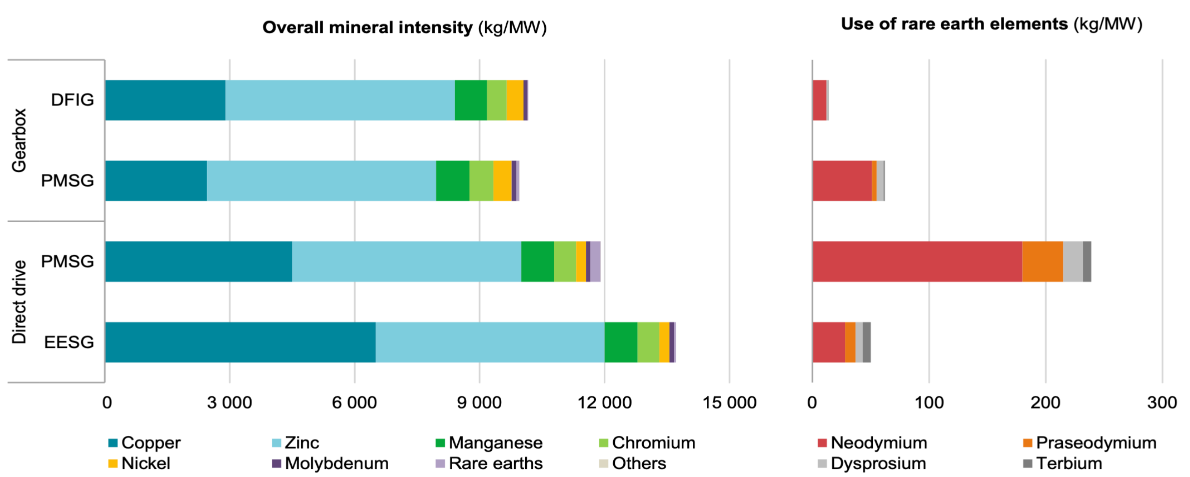
The IEA highlights that global installed capacity of wind power has nearly quadrupled over the past decade, spurred by falling costs, which have declined by about 40 percent on average globally, and policy support in more than 130 countries. The Global Wind Energy Council (GWEC) reports in its latest study[17] that in 2021 there was 94 GW of new wind power installations bringing global cumulative wind power capacity up to 837 GW, an annual increase of 12 percent.

The growth in the onshore market in 2021 was negative due to a slowdown in China and the United States, the world's two largest wind markets, however, there was record-high growth in Europe, Latin America, and Africa and the Middle East, where new onshore installations increased. The world's total offshore capacity increased by 21 GW to a cumulative 57 GW in 2021, which is 7 percent of global installations. China contributed 80 percent of that offshore growth.

In 2021, Brazil achieved a record year of new wind additions with nearly 4 GW in new installations for a total of 21.6 GW. Three factors were decisive for this growth: first, the regulatory framework for auctions facilitated procurement of wind energy at competitive prices; and second, financing designed to focus on national content provided Brazil with a solid wind industrial base, with capacity to produce enough turbines to install around 5 GW per year. The third factor is external: caused by changing weather patterns and drops in reservoir levels and output for hydropower generation. 2021 was also a milestone for the beginning of offshore wind implementation in Brazil.

Figure 11 gives the mineral intensity for wind power by turbine type including REE intensity. Some geared turbines and many direct-drive wind turbines use permanent magnet generators which contain the REE neodymium, praseodymium, and dysprosium. About 23 percent of all installed wind turbines currently use rare earth magnets.

Figure 11: IEA - Mineral Intensity for Wind Power by Turbine Type

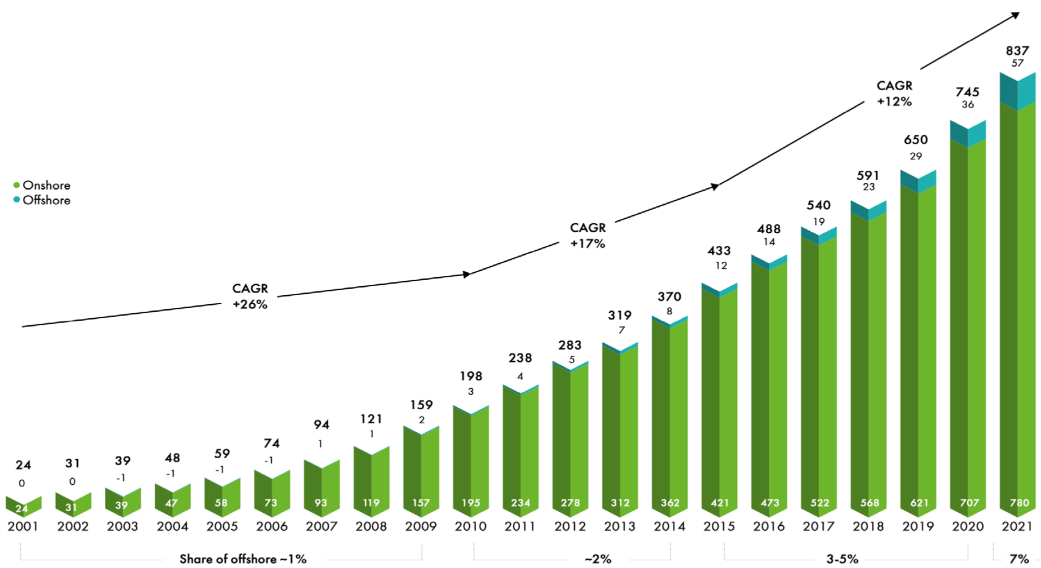


Source: IEA Note: DFIG = double-fed induction generators; PMSG = permanent-magnet synchronous generator; EESG = electrically excited synchronous generator.

[17] GWEC – Global Wind Energy Report 2022. https://gwec.net/wp-content/uploads/2022/04/Annual-Wind-Report-2022_screen_final_April.pdf.

Figure 12 shows the historic development of total wind capacity installations. Some 78 percent of the installed capacity in 2021 was onshore.

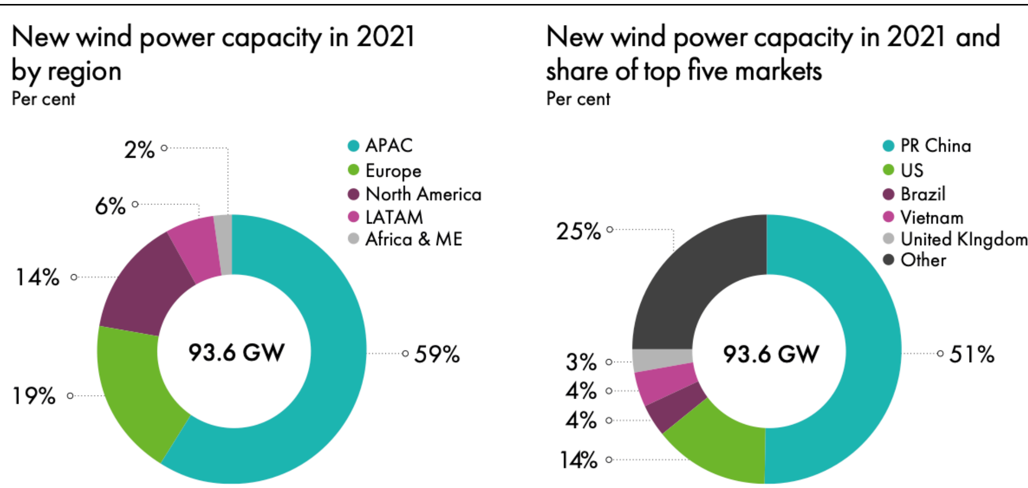
Figure 12: Historic Development of Total Wind Capacity Installations



Source: GWEC – Global Wind Energy Report 2022.

Going forward, the IEA expects annual global capacity installations for wind to increase to 160 GW by 2040. GWEC highlights that to have a chance of meeting the Paris Net Zero target by 2050, annual run rates for wind need to be even steeper, reaching 160 GW by 2025 and then 280 GW by 2030; however, GWEC expects that only 557 GW of new capacity (equivalent to only about 110 GW per annum) will be added in the next five years under current policies. An account of decommissioned capacity is also considered in the forecasts by GWEC, with a loss of about 34 GW in global capacity from 2026-2030 based on 25-year turbine lifetime. Figure 13 shows the new wind capacity installation in 2021 by region and the top five individual markets. These five markets combined made up 75 percent of global installations.

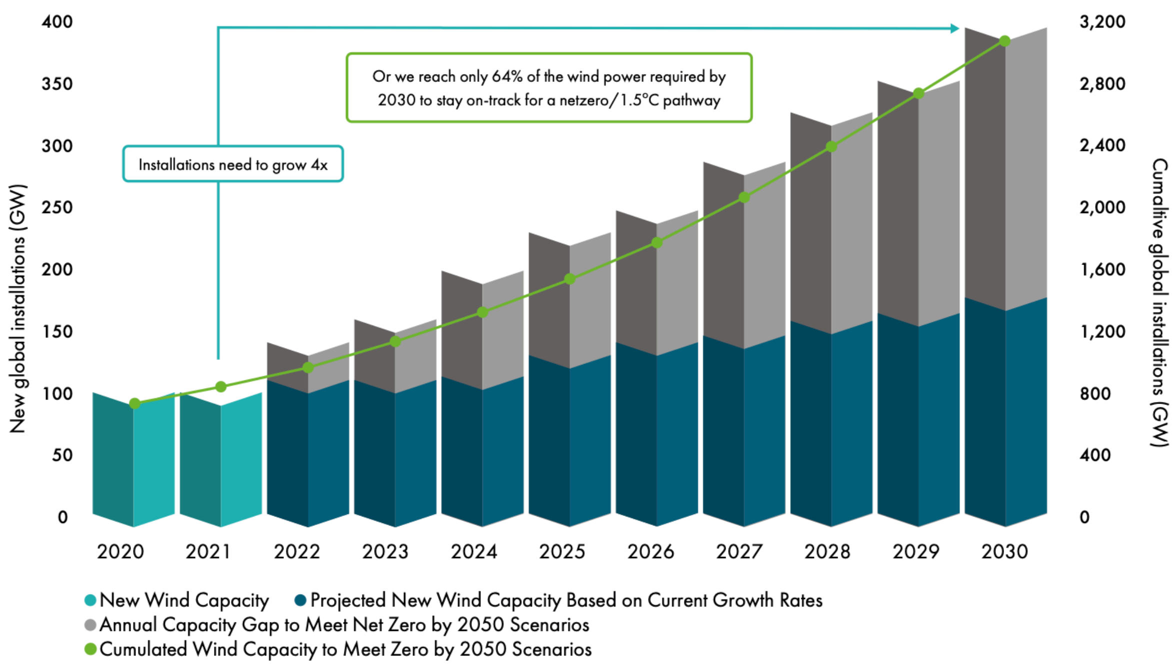
Figure 13: New Wind Capacity Installations 2021



Source: GWEC – Global Wind Energy Report 2022.

In total, GWEC suggests that 466 GW of onshore wind capacity and 91 GW of offshore capacity is likely to be built in 2022-2026. GWEC concludes that wind energy is not growing nearly fast or widely enough to realize a secure and resilient global energy transition. At current rates of installation, GWEC forecasts that by 2030 the world will have less than two-thirds of the wind energy capacity required for a 1.5 degrees Celsius (and net zero) pathway, as shown in Figure 14.

Figure 14: Forecast New Wind Capacity Installations to 2030 versus Required Installations



Source: GWEC – Global Wind Energy Report 2022.

3.3. Metal Demand for Energy Storage Batteries and EV Motors

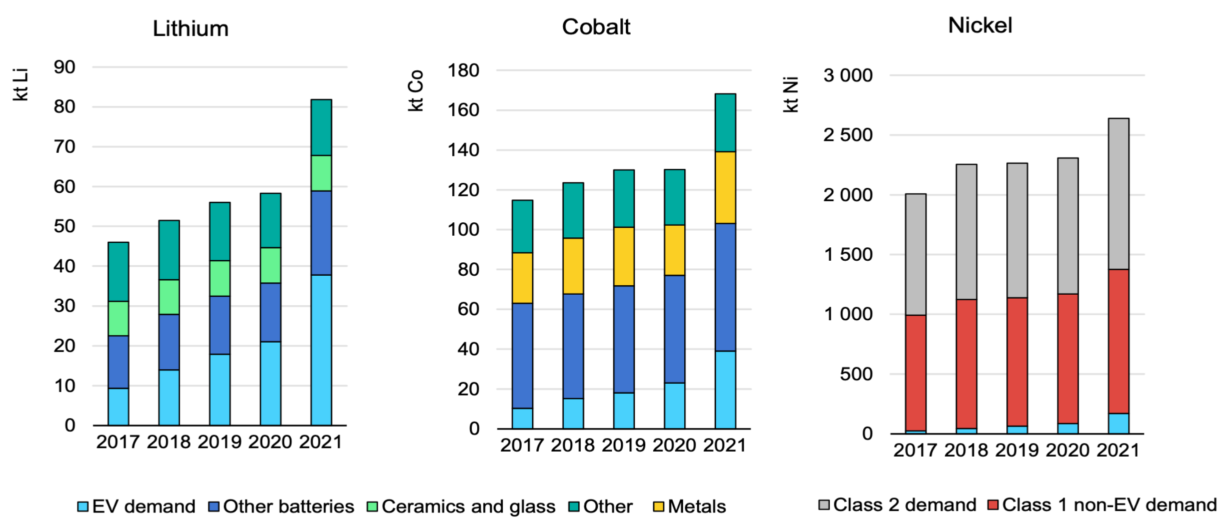
There are multiple battery chemistries but the most dominant current technology for transportation and many non-utility applications is lithium-ion batteries. The fundamental advantage of lithium-ion batteries over alternatives like lead acid or nickel cadmium batteries is their higher energy density. The average cost of lithium-ion batteries has declined by almost 90 percent over the past decade, falling to $137/kWh in 2020 according to BloombergNEF. These rapid cost reductions have been driven by the use of lithium-ion batteries in EVs and the strong growth in EV sales over the past decade, as well as improvements in technology.

A variety of different types of hybrids and EVs are expected to become dominant in future transportation systems. These vehicles can use a range of battery technologies, with lithium- or nickel- based batteries providing propulsion functionality in full hybrids, plug-in hybrids, and full electric vehicles. Lithium-ion batteries for EVs and their demand will be strongly influenced by the rate of growth of electric vehicle fleet sizes. EV sales are surging due to a combination of policy support, improvements in battery technology, the increased availability of charging infrastructure, and new compelling models from automakers. Electrification is also spreading to new segments of road transport, setting the stage for huge changes ahead.

3.3.1. Lithium-ion Batteries

Lithium-ion batteries are made of two electrodes (anode and cathode), current collectors, a separator, electrolyte, a container, and sealing parts. The anode is typically made of graphite, with a copper foil current collector. The cathode is typically a layered transition metal oxide, with an aluminum foil current collector. In between the electrodes is a porous separator and electrolyte. All these components are typically housed in an aluminum container. Figure 15 shows the change in demand of the three key metals in lithium-ion batteries from 2017 to 2021.

Figure 15: Battery Metals Demand for Lithium, Cobalt, and Nickel 2017 to 2021[18]



Source: IEA – Global Supply Chains of EV Batteries July 2022.

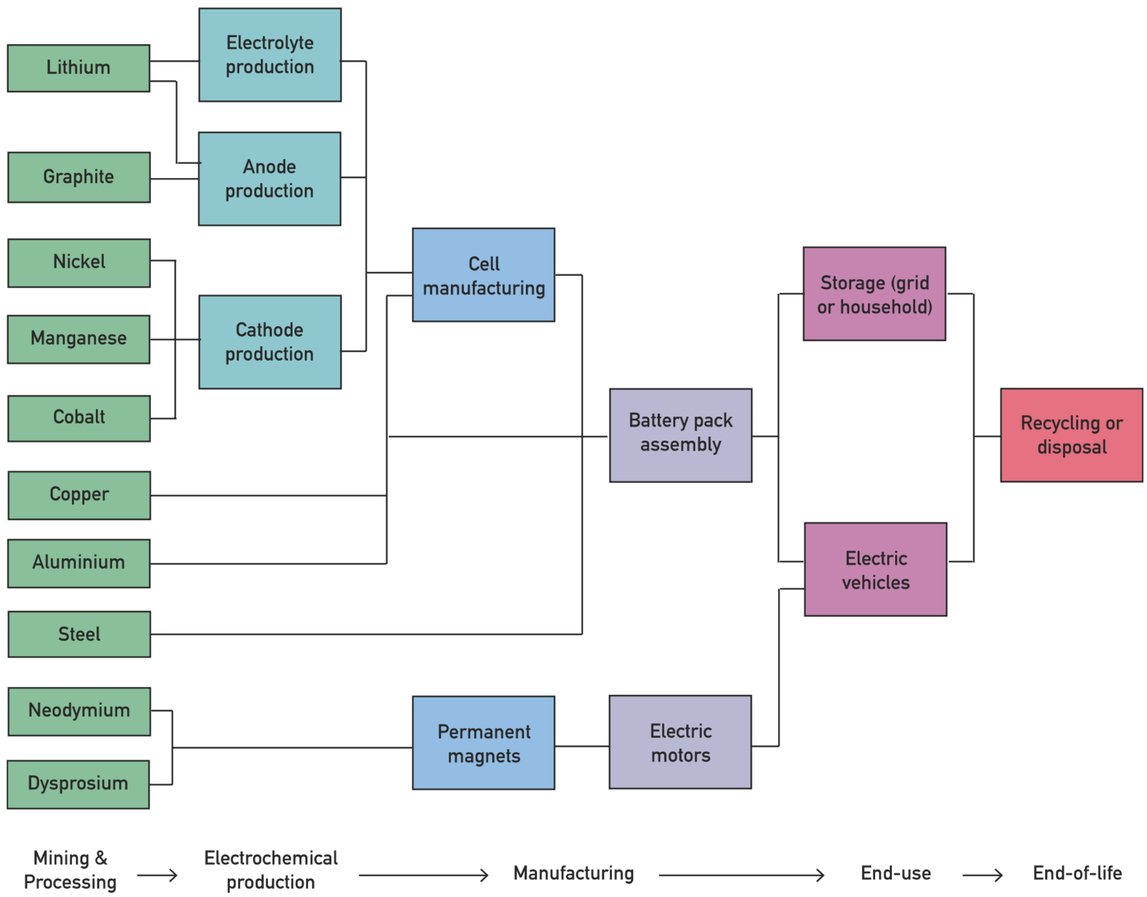
Figure 16 gives an overview of the key metals in the lithium-ion battery supply chain through to EVs and stationary battery energy storage. Lithium-ion batteries are often categorized by the chemistry of their cathodes. The most common lithium-ion battery types for EV applications are nickel manganese cobalt (NMC), lithium iron phosphate (LFP), nickel cobalt aluminum (NCA), and lithium manganese oxide (LMO). For mobile phones, laptops, and other handheld equipment, lithium cobalt oxide (CBO) batteries are generally used for their high specific energy. Figure 17 shows the mineral composition of different battery cathodes and market shares of sales.

Lithium hydroxide and lithium carbonate are both used in lithium-ion batteries. Manufacturers favor lithium hydroxide over cathode technologies and high nickel chemistry batteries such as NCM811 (nickel-cobalt-manganese or NCM), which have a higher energy density. NCM622 cathodes can use either lithium hydroxide or carbonate, while lower nickel-bearing NCM cathodes require lithium carbonate. Other lithium batteries such as LFP, which have a lower energy density but are lower cost, also use lithium carbonate. Lithium salts produced for batteries require a higher purity of product and are usually designated as 'battery-grade'.

Further discussion on the different battery technologies can be found in Annex 1.

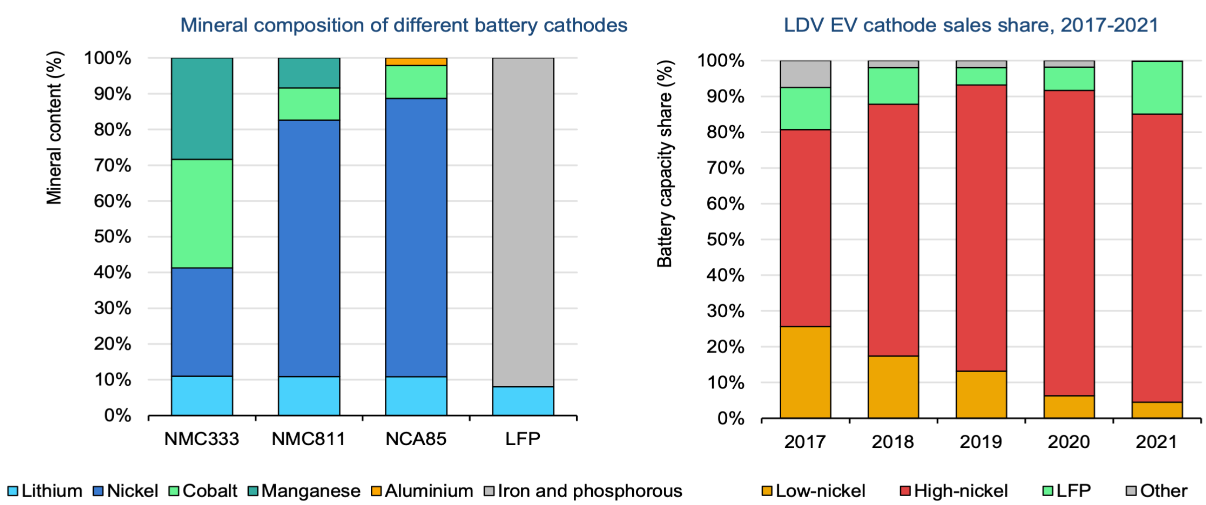
[18] Typically, there are two types of nickel produced Class 1 (high grade) and Class 2 (low grade). Class 1 is used to produce metal and nickel sulphate for batteries and Class 2 is used in stainless steel. For additional information on the types of nickel produced, please refer to the *Nickel Market Competitiveness Report*.

Figure 16: Overview of Key Metals in Lithium-ion Battery Supply Chain



Source: Achieving the Paris Climate Agreement Goals. T. Pregger et al.

Figure 17: Mineral Composition of Different Battery Cathodes and Market Shares of Sales

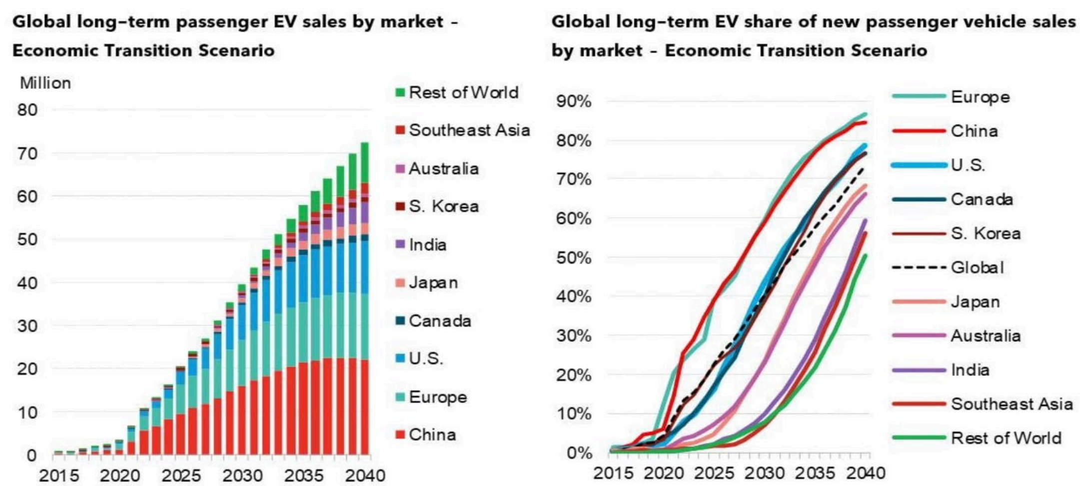


Source: IEA – Global Supply Chains of EV Batteries July 2022.

The momentum of strong EV demand (battery electric and plug-in hybrid vehicles combined) continued in 2021 with market penetration rising in all of the major markets. Western Europe's EV market share was the highest of all regions at 26 percent at the end of 2021, up from an average of 11 percent in 2020. China followed at 19 percent, up from 6 percent in 2020. The United States lagged the two other major markets at just 5 percent at the end of 2021, albeit up from 2 percent in 2020. The lithium-ion battery market has grown from 70 GWh in 2015 to a 614 GWh market in 2022.

The future demand for lithium-ion batteries will be strongly influenced by the rate of growth of EV fleet sizes. This rate of growth is difficult to forecast and there are a range of estimates made by government agencies, economists, research analysts, and industry. Historically, the market has been overly optimistic in its projection for EVs. Nevertheless, most people are projecting strong growth for EVs over the coming decades and consequently strong demand growth for lithium-ion batteries. Figure 18 shows the global long-term passenger EV sales forecast by market from BloombergNEF.

Figure 18: Global long-term Passenger EV Sales Forecast



Source: BloombergNEF - Electric Vehicle Outlook 2022. https://about.bnef.com/electric-vehicle-outlook/

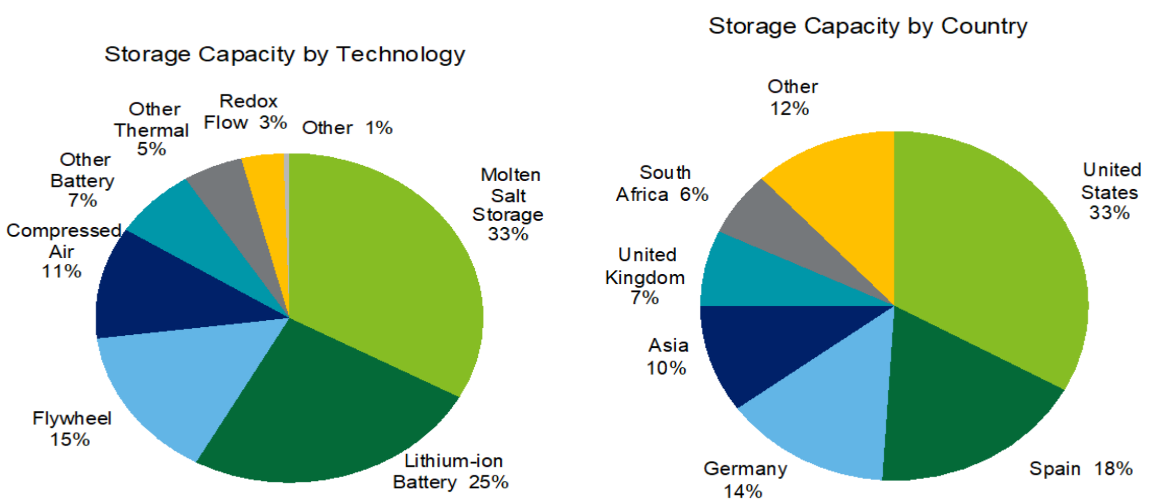
This demand is prompting plans for huge investment around the world in new battery manufacturing facilities. The result is the megafactory and the gigafactory, terms coined by Benchmark Minerals Intelligence (BMI) as a way to describe the facilities that produce vast amounts of battery cells to meet that demand. As of May 2022, the number of gigafactories in the pipeline totaled 304 globally, equivalent to 6,388 GWh of capacity. China continues to dominate gigafactory announcements, but North America and Europe have seen significant growth over the past two years due in part to automaker and battery manufacturer joint ventures. BMI calculates that $200 billion needs to be invested into building gigafactories by 2028 to meet the growing demand for electric vehicles and energy storage by 2030[19]; however, automakers including Tesla and Rivian have warned of an impending shortage of batteries.

[19] Benchmark Mineral Intelligence. https://www.benchmarkminerals.com/membership/global-gigafactory-pipeline-hits-300-china-maintains-lead-but-west-gathers-pace/?mc_cid=d8d9a89beb&mc_eid=6dae4eeb78

3.3.2. Stationary Battery Energy Storage

A stationary energy storage system can store energy and release it in the form of electricity when it is needed. In most cases, a stationary energy storage system will include an array of batteries, an electronic control system, inverter, and thermal management system within an enclosure. The primary commercially available technologies capable of long duration energy storage include lithium-ion batteries, compressed air energy storage (CAES), flow batteries, sodium sulfur batteries, and molten salt batteries. The two main flow battery technologies are vanadium redox flow and zinc bromine flow. Figure 19 shows the energy storage power capacity by technology and by country.

Figure 19: Energy Storage Power Capacity (2020)



Source: On Location, US DOE Global Energy Storage Database. Excludes pumped hydro storage.

IRENA[20] forecasts that total electricity storage capacity could triple by 2030. The growth in the electricity storage market to 2030 is not likely to be confined to just one type of battery energy storage. The very different requirements of the range of services that electricity storage can provide, and the varying performance characteristics of each group of electricity storage technologies means that a diverse group of storage technologies will be developed and implemented. IRENA believes that it is therefore likely that a range of technologies will find different market segments where they can compete on performance and cost. The electricity storage market in stationary applications will therefore remain a diverse one to 2030 and beyond.

Vanadium redox flow batteries (VRFBs) are the only redox flow batteries that have been used in large-scale applications around the world for extended periods of time. VRFBs are expected to take a significant share of the stationary energy storage market owing to unique advantages for long-duration stationary energy storage applications. These include long lifespan cycles, full discharge without material performance degradation, and operation close to ambient temperatures with no fire or smoke risk from thermal runaway. There are some 113 VRFBs installed worldwide, with 17 installed in China (15.8 MW, 48.0 MWh), 17 in the United States (7.4 MW, 33.2 MWh), and 15 installed in Germany (1.5 MW, 86.2 MWh).

[20] IRENA, Electricity Storage and Renewables: Costs and Markets to 2030, October 2017, https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

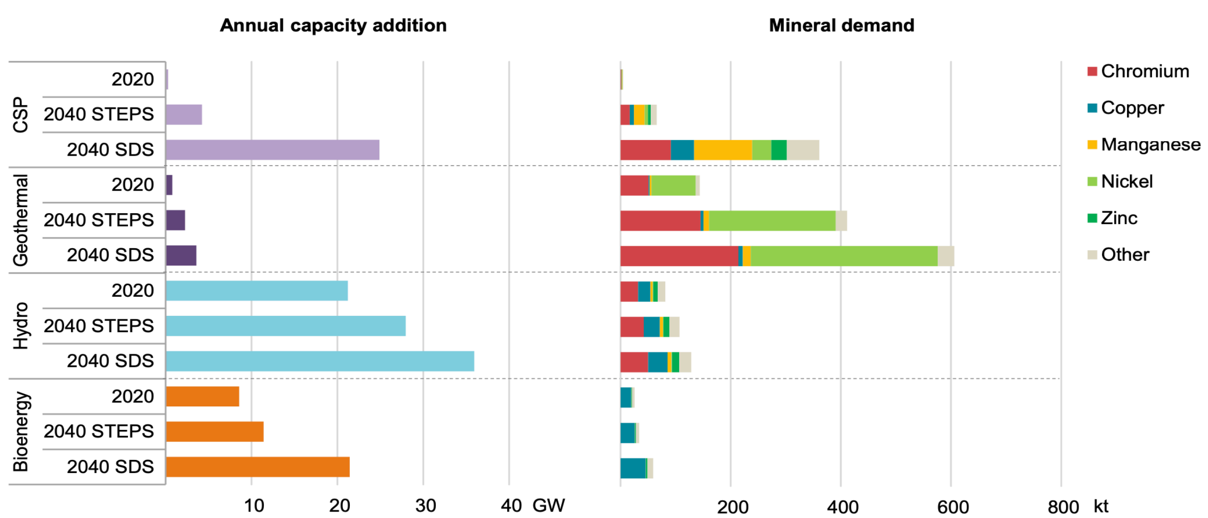
3.3.3. EV Motors

The two most common electric motor technologies for plug-in EVs are permanent-magnet synchronous motors and asynchronous induction motors. Permanent-magnet motors have the highest efficiency and power density, but their use of REEs make them expensive compared to other technologies. In addition to neodymium (0.25 to 0.50 kg/vehicle) and other REEs (0.06 to 0.35 kg/vehicle), permanent-magnet motors also require copper (3 to 6 kg/vehicle), iron (0.9 to 2 kg/vehicle), and boron (0.01 to 0.03 kg/vehicle). Induction motors have the advantage of lower costs but only have moderate efficiencies due to electrical losses in copper windings. While induction motors do not require REE, they require a substantial amount of copper (11 to 24 kg/vehicle) for the rotor cage and copper stator.

3.4. Metal Demand for Other Areas of Renewable Technology

There are a number of other areas in the shift to renewable energy supplies that are responsible for increased consumption of some commodities. These include the increased adoption of other renewable technologies including concentrating solar power, geothermal, hydropower, and bioenergy. In addition, the grid hardening necessary to integrate large amounts of intermittent solar PV and wind generation in addition to the growth of EV chargers are other sources of mineral demand. Figure 20 shows the annual capacity additions and mineral demand from other renewable technologies by scenario.

Figure 20: Annual Capacity Additions and Mineral Demand from Other Renewable Technologies



Source: IEA Note: CSP = concentrating solar power (See p.25). STEPS = Stated Policies Scenario; SDS = Sustainable Development Scenario.

3.4.1. Concentrating Solar Power

Concentrating solar power (CSP) systems use mirrors to direct solar radiance to a central receiver where energy is transmitted to a heat-exchange fluid used to generate electricity. Two main types of CSP technology (parabolic troughs and central towers) account for most of the installed, planned, and projected additions. The overall installed capacity of CSP remains low at around 7.0 GW in 2020, owing to limited suitable geographies, high project costs, and long distances to demand centers, however, it has more than doubled since 2010 due to policy and financing initiatives in Spain, the United States, and the United Arab Emirates.

In addition, as countries look to add more storage to support renewable energy additions, governments, especially across the Middle East, are increasingly considering CSP to meet both renewable energy and storage needs. The expansion of CSP, driven by material-intensive central tower systems, comes with substantial demand growth for chromium, copper, manganese, and nickel.

3.4.2. Geothermal Energy

Around 16 GW of geothermal capacity is currently installed globally, providing low-carbon baseload power in geo-hotspots such as Kenya, Iceland, Indonesia, the Philippines, Turkey, and the United States. The IEA forecasts installed capacity to grow fivefold to 82 GW by 2040; however, geothermal is a more expensive technology and is restricted by location so it is not expected to grow significantly beyond this forecast. Geothermal power plants generate electricity by powering turbines using underground hydrothermal resources (steam or hot water) piped to the surface. The very high temperatures and potentially corrosive nature of geothermal reservoirs require the use of specialized steel (high in chromium, molybdenum, nickel, and titanium) to withstand the harsh operating environment.

3.4.3. Hydropower

Hydropower is the largest renewable source of electricity, accounting for 17 percent of global electricity generation in 2020. While it plays an important role in providing flexibility to the power system as it operates as a baseload power source, its share of total power capacity additions is expected to continue to decline through to 2040, as high capital costs and geographic constraints limit further growth. Between 2020 and 2040, nearly 60 percent of cumulative capacity additions occur in Asia Pacific, with China alone accounting for 25 percent of the global total. While hydropower uses substantially more cement and concrete than any other generation technology, it has a relatively low mineral intensity compared to other sources of low-carbon power.

3.4.4. EV Chargers

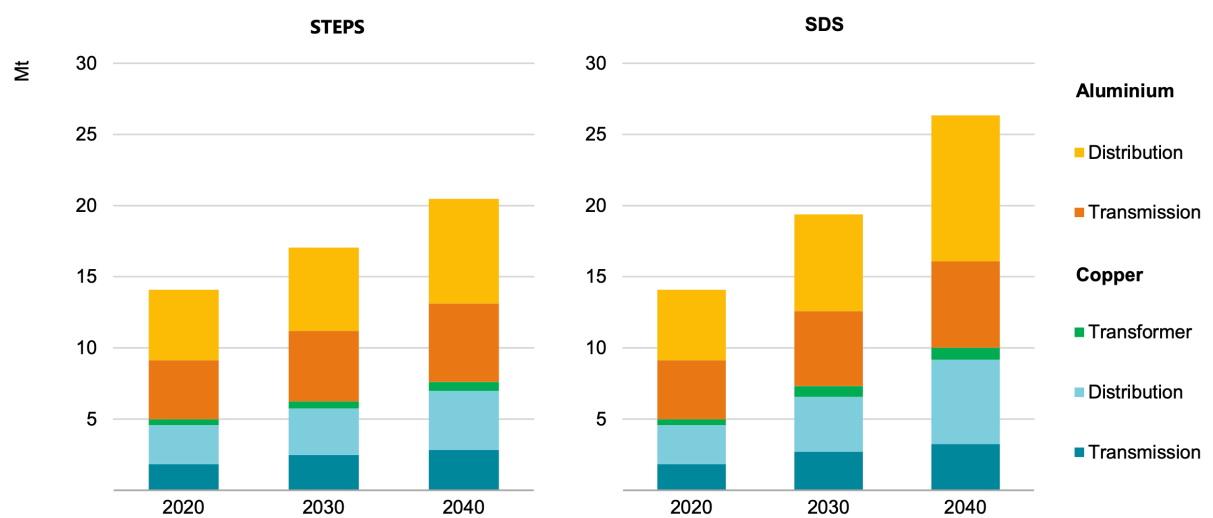
Installations of public chargers along highways, in grocery store parking lots, or at fleet depots continue at pace. Installations increased by 30 percent in 2020 to bring the global total to 1.36 million nozzles. Copper is an important component, and a public electric vehicle charger typically needs 25 kg of copper, while a smaller charger to use at home needs around 2 kg of copper, according to BloombergNEF estimates. Charger installations are set to increase rapidly to reach 309 million connectors by 2040, when the sector's annual investment will top $590 billion.

3.4.5. Electricity Grids

The IEA points out that distribution systems currently account for over 90 percent of total line length and play an increasing role in supporting the integration of residential solar PV and onshore wind capacity, in addition to their traditional role of delivering electricity to regional end users. The growth in electrical transmission systems is supported by the rise of high-voltage direct current (HVDC) technologies. HVDC technology offers the most efficient means of transmitting large amount of power over long distances, helps connect green power to the grid, and stabilizes three-phase-grids. HVDC systems have been used since the 1950s, but over two-third of total installed HVDC transmission capacity has been added in the past 10 years. Today, HVDC systems represent around 7 percent of newly installed transmission systems, and their share is expected to rise further given the considerable technological progress made over the past decade. An HVDC cable has a copper or aluminum compact or compressed conducting core.

Figure 21 shows the IEA forecast for aluminum and copper for the Sustainable Development Scenario (SDS) and Stated Policies Scenario (STEPS). Around 50 percent of the increase in transmission lines and 35 percent of the increase in distribution network lines are attributable to the increase in renewables. In addition to more lines, there is scope to refurbish grids to strengthen the resiliency of electricity systems to climate change and extreme weather events. Refurbishment of electricity grids is also strongly linked to digitalization, given the rising need for smart and flexible grids. Investment in digitalization and grid flexibility helps increase reliability and can reduce the cost of generating, transmitting, and distributing electricity. In the SDS, some 55 percent of the expansion to 2030 in advanced economies such as the European Union and the United States, are attributable to refurbishment and digitalization.

Figure 21: Demand for Copper and Aluminum for Electricity Grids by Scenario



Source: IEA (See p.25).

4. DEMAND OUTLOOKS FOR RENEWABLE COMMODITIES

This section broadly examines the approach and conclusions of some of the key reports developed over the past few years that have analyzed the future demand for renewable energy and commodities. The commodities required for the decarbonization of energy are reasonably defined within today's parameters of expected technology out to 2050. The mining industry is expected to provide most of the raw materials needed for these technologies, however, the path is likely to be uneven and driven by the usual cyclicality of supply and demand of such commodities.

The reports summarized in this section include:

- **IEA Analysis on the Role of Critical Minerals in Clean Energy Transition**: This report analyzes the role of critical minerals in clean energy transitions.[21] The report states that the following: (i) an essential step in the clean energy transition is for policymakers to provide clear signals about their climate ambitions, and provides recommendations on how policymakers can turn their targets into action; (ii) long-term visibility is important to provide the confidence investors need to commit to new projects; and (iii) efforts to scale up investment should complement a strategy that encompasses technological innovation, recycling, supply chain resilience, and sustainability.
- **The World Bank Commodities Study**: In June 2017, the World Bank developed a set of commodities demand projections up to 2050.[22] It did so by providing best estimates on the level of uptake of three discrete climate-friendly technologies; wind, solar, and energy storage batteries, required to help meet three different global warming scenarios. The report examined which metals will likely see a rise in demand in a carbon-constrained future, and mapped production and reserve levels of relevant metals globally, focusing on implications for resource-rich developing countries.
- **BloombergNEF New Energy Outlook**: BloombergNEF publishes an annual outlook focused on long-term scenario analysis on the future of the energy economy. Their 2021 Outlook highlights that getting on track for net-zero emissions in 2050, means deploying commercially available abatement technologies in each sector this decade.[23]
- **McKinsey Raw Materials Challenge**: In 2022, McKinsey published a report looking at how the mining and metals sector will be at the core of supporting the energy transition. Among other things, the report notes that the transition to a net-zero economy will be metal-intensive.[24]

---

[21] IEA – The Role of Minerals in Clean Energy Transitions. https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

[22] World Bank. The Growing Role of Minerals and Metals for a Low Carbon Future. https://www.extractiveshub.org/servefile/getFile/id/4563.

[23] BloombergNEF. New Energy Outlook. https://about.bnef.com/new-energy-outlook/.

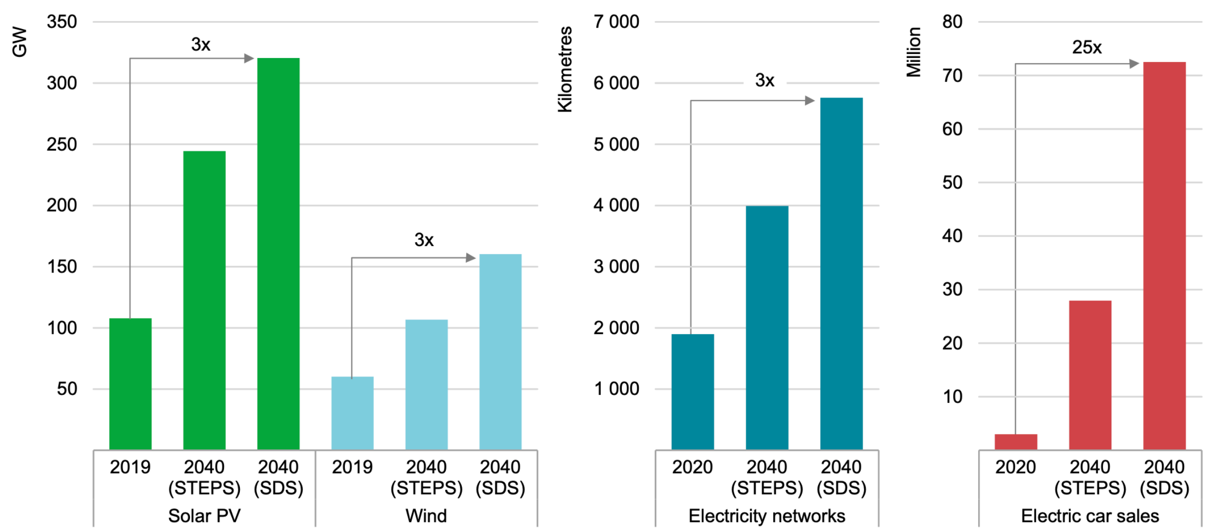
[24] McKinsey - The Raw Materials Challenge. https://www.mckinsey.com/industries/metals-and-mining/our-insights/the-raw-materials-challenge-how-the-metals-and-mining-sector-will-be-at-the-core-of-enabling-the-energy-transition

- **Institute for Sustainable Future (ISF) Responsible Minerals Sourcing**: The ISF, an interdisciplinary research and consulting organization at the University of Technology Sydney published a report on responsible minerals sourcing for renewable energy in 2020.[25] This report concludes that under a 100 percent renewable energy scenario, demand for some metals could rise dramatically, such as copper (+29 percent), cobalt (+1,788 percent), nickel (+313 percent), REE (+592 percent), lithium (+8,845 percent, and silver (40 percent).

4.1. IEA Analysis - The Role of Critical Minerals in Clean Energy Transitions

In May 2021, the IEA published a special report on the role of critical minerals in clean energy transitions. The report identifies risks to key minerals and metals that could significantly impact global progress towards a clean energy future, and therefore hamper international efforts to tackle climate change. Figure 22 shows the annual deployment of clean energy technologies. While demand trajectories are subject to large technology and policy uncertainties, it concludes from a bottom-up assessment that a concerted effort to reach the goals of the Paris Agreement would mean a quadrupling of mineral requirements for clean energy technologies by 2040. An even faster transition, to hit net-zero globally by 2050, would require six times more mineral inputs in 2040 than today.

Figure 22: Annual Deployment of Clean Energy Technologies by Scenario



Source: IEA.

The IEA report analyses two main scenarios:

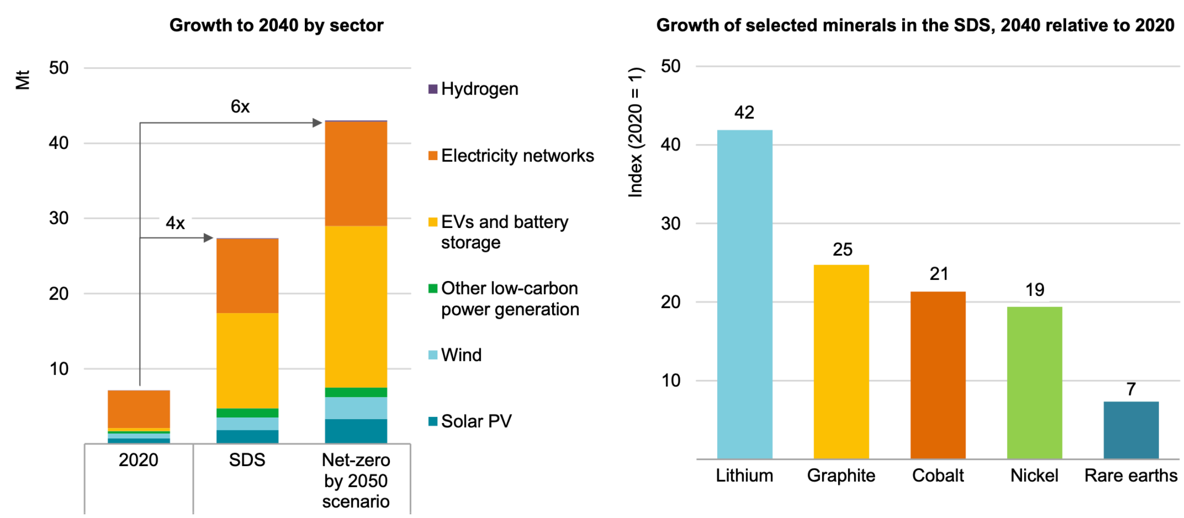
- The Sustainable Development Scenario (SDS) charts a pathway that meets in full the world's goals to tackle climate change in line with the Paris Agreement, improve air quality, and provide access to modern energy.

[25] Institute for Sustainable Futures. Responsible Minerals Sourcing for Renewable Energy. https://www.uts.edu.au/sites/default/files/2019-04/ISFEarthworks_Responsible%20minerals%20sourcing%20for%20renewable%20energy_Report.pdf.

- The Stated Policies Scenario (STEPS) provides an indication of where today's policy measures and plans might lead the energy sector. These outcomes fall far short of the world's shared sustainability goals.

In climate-driven scenarios, mineral demand for use in EVs and battery storage is a major force, growing at least 30 times to 2040. Figure 23 shows the mineral demand for clean energy technologies for five key commodities. Lithium sees the fastest growth, with demand growing by over 40 times by 2040, followed by graphite, cobalt and nickel (around 20-25 times). The expansion of electricity networks means that copper demand for power lines more than doubles over the same period.

Figure 23: Mineral Demand for Clean Energy Technologies by Scenario



Source: IEA Note: SDS = Sustainable Development Scenario.

The IEA analysis of the near-term outlook for supply presents a mixed picture. Some minerals such as mined lithium and cobalt are expected to be in surplus in the near term, while lithium chemical products, battery-grade nickel, and key rare earth elements might face tight supply until 2030. Looking further ahead in a scenario consistent with climate goals, however, expected supply from existing mines and projects under construction is estimated to meet only half of projected lithium and cobalt requirements and 80 percent of copper needs by 2030.

The IEA notes that the largest source of demand variability comes from uncertainty around the stringency of climate policies. The big question for suppliers is whether the world is really heading for a scenario consistent with the Paris Agreement. Policy makers have a crucial role in narrowing this uncertainty by making their ambitions clear and turning targets into actions. This will be vital to reduce investment risks and promote adequate flow of capital to new projects.

4.2. World Bank Commodities Study

The 2017 World Bank Commodities Report developed a set of commodities demand projections up to 2050 by providing best estimates on the level of uptake of three discrete climate-friendly technologies; wind, solar, and energy storage batteries, required to help meet three different global warming scenarios. The report examined which metals will likely see a rise in demand in a carbon-constrained future. These include aluminum (including its key constituent, bauxite), cobalt, copper, iron ore, lead, lithium, nickel, manganese, platinum group metals, REE including cadmium, molybdenum, steel, titanium, and zinc. The report also mapped production and reserve levels of relevant metals globally, focusing on implications for resource-rich developing countries.

The report addressed what materials are required in the scaled-up production of these technologies. Precise estimates on the actual demand for metals is predicated by at least two independent variables: (i) the extent to which the global community succeeds in meeting its long-term Paris climate goals; and (ii) the nature of intra-technology choices. The report clearly shows that the technologies assumed to populate the clean energy shift (wind, solar, and T&D networks) are in fact significantly more material intensive in their composition than current traditional fossil-fuel-based energy supply systems.

The report concluded that key metals including copper, silver, aluminum (bauxite), nickel, zinc, and possibly platinum, among others, are likely to benefit from a low carbon energy shift. Key REE (for at least the three technologies analyzed in depth) are neodymium and indium, among others, however, the report notes that the actual metals that will experience dramatic increases in demand are unclear and difficult to predict.

4.3. BloombergNEF's New Energy Outlook

BloombergNEF publishes an annual outlook focused on long-term scenario analysis on the future of the energy economy. Electrification plays a large role. Across all scenarios, the use of electricity in industry, transport, and buildings raises its share of total final energy to just below 50 percent in 2050, from the current 19 precent. Their 2021 Outlook highlights that getting on track for net-zero emissions in 2050 means deploying commercially available abatement technologies in each sector this decade. More than three quarters of the effort to cut emissions out to 2030 falls to the power sector, and the faster deployment of wind and solar PV. Another 14 percent is achieved with greater use of electricity in transport, in heating for buildings, and in providing lower-temperature heat in industry.

While the first 1,000 GW of wind and PV took twenty years to deploy, getting to net-zero emissions in its Green Scenario will need about 1,400 GW of renewables to be deployed every year, on average, for the next three decades. The outlook estimates investment in energy supply and infrastructure of between $92 trillion and $173 trillion over the next thirty years. Annual investment will need to more than double to achieve this, rising from around $1.7 trillion per year today, to somewhere between $3.1 trillion and $5.8 trillion per year on average over the next three decades. BloomberNEF models increased recycling for steel, aluminum, and chemicals, as well as faster consumer uptake of rooftop solar PV systems and small batteries.

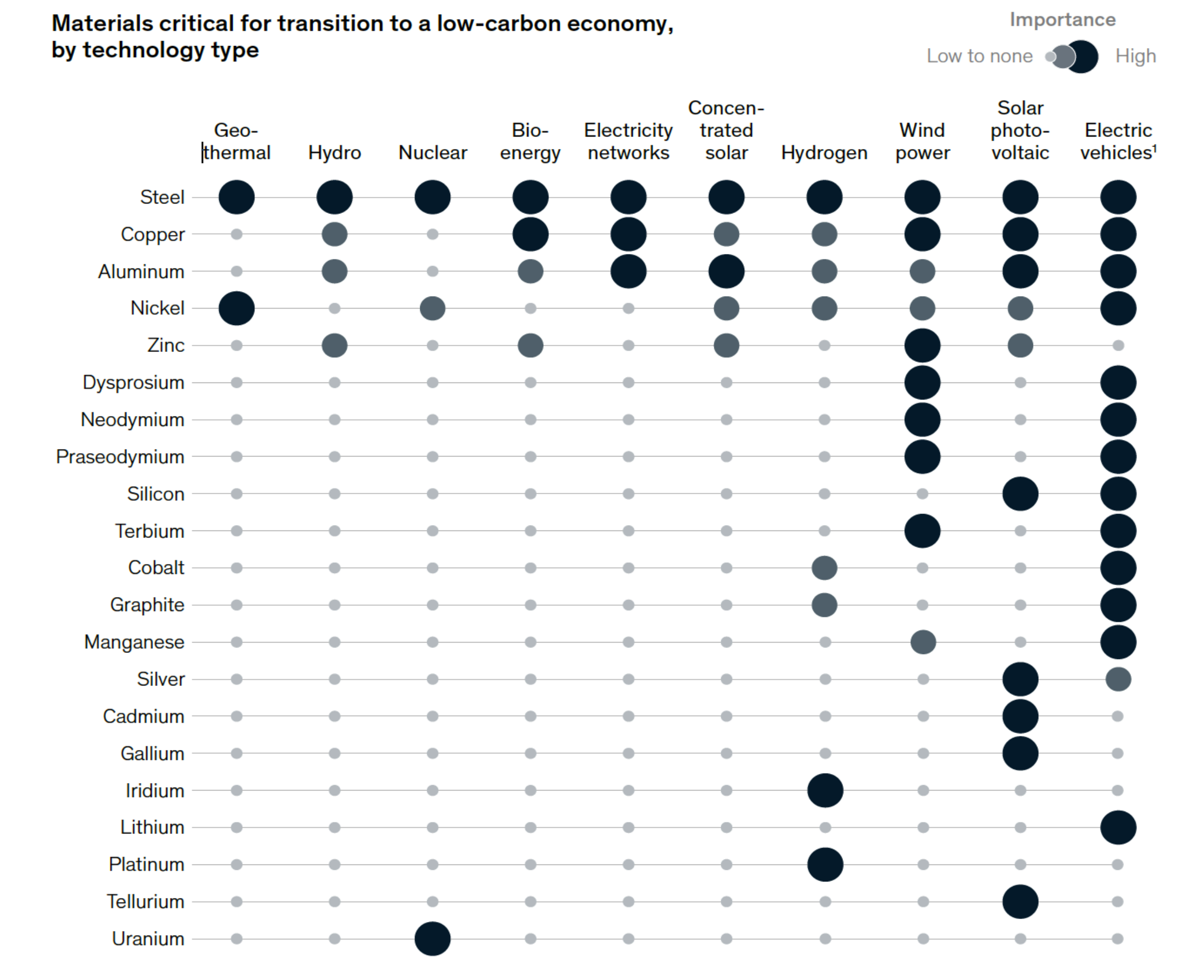
4.4. McKinsey and the Raw Materials Challenge

In 2022, McKinsey published a paper looking at how the metals and mining sector will be at the core of supporting the energy transition. It notes that the transition to a net-zero economy will be metal-intensive. As the move toward cleaner technologies progresses, the metals and mining sector will be put to the test and will need to provide the vast quantities of raw materials required for the energy transition, although producing growth in metal production has a long lead-time, is highly capital-intensive, is subject to price volatility, and may be filled with bottlenecks that will be unavoidable as demand outstrips supply. The volatility will also create uncertainty around the ongoing capital investments needed for production.

Requirements for additional supply will come not only from relatively large-volume raw materials such as copper for electrification and nickel for battery EVs, which are expected to see significant demand growth beyond their current application, but also from relatively niche commodities, such as lithium and cobalt for batteries, tellurium for solar panels, and neodymium for the permanent magnets used both in wind power generation and EVs. Some commodities, most notably, steel, will also play an enabling role across technologies requiring additional infrastructure. Figure 24 shows the materials critical for transition to a low-carbon economy.

Supply, demand, and pricing interplays will emerge across different commodities, leading to feedback loops followed by a combination of technology shifts, demand destruction, and materials substitution. Metals and mining companies will be expected to grow faster and more sustainably than ever before. At the same time, end-user sectors will need to factor potential resource constraints into technology development and growth plans.

Figure 24: Materials Critical for Transition to a Low-Carbon Economy



Source: McKinsey 2022

4.5. ISF's Responsible Minerals Sourcing

The ISF published a report on responsible minerals sourcing for renewable energy in 2020. It concludes that under a 100 percent renewable energy scenario demand for metals such as copper, cobalt, nickel, REE, lithium, and silver could rise dramatically. These metals are the most challenging to reduce total demand through substitution and efficiency and require new sources of primary and recycled metals. It is expected that renewable energy technologies will consume a growing share of these metals and in many cases may be the major driver of demand. The EV and battery industries have the most urgent need to avoid negative impacts in their supply chains. Cobalt, lithium, and rare earths are the metals of highest concern, considering their projected future demand and supply risks. Batteries for EVs are the main driver of demand for these metals, rather than stationary storage or wind power.

The report suggests that demand from renewable energy and storage technologies could exceed reserves for cobalt, lithium, and nickel, and reach 50 percent of reserves for indium, silver, tellurium. The demand, however, is based on current technologies as these results should be considered as a high-demand scenario, since over time new technologies may become more efficient or new technologies may emerge.

The report highlights that recycling can significantly reduce primary demand, especially for batteries, however it cannot meet all demand. There is also a time delay before recycled metals become available. The report compares incremental use of each commodity as a result of use in renewables and compares it to the level of world-wide resources available. Actual overall demand forecasts for each commodity are not provided in the report.

5. RISKS FOR RENEWABLE COMMODITIES

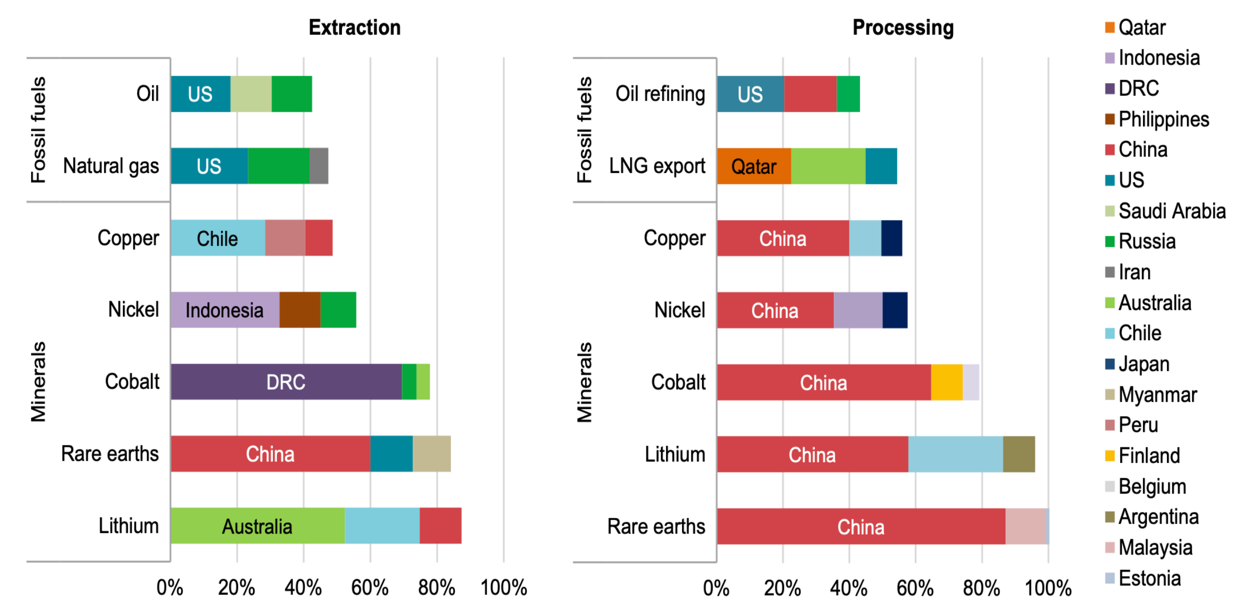
This section explores some of the challenges for producing renewable commodities and outlines key risks in the supply chain for critical minerals. These risks include: the available supply for critical minerals; the geopolitical energy landscape, given China's market dominance for processing and refining critical minerals; and the social and environmental impacts of mining projects. This section also discusses the role of recycling in alleviating critical mineral supply chain risks.

5.1. Concentration of Production and Reserves

The ISF examined the security risks in renewable energy supply chains; the geographical distribution of producers and reserves; and the renewable energy share of end-use. The concentration of supply in a single or very few countries is a risk for manufacturers to secure ongoing supply and makes metal more vulnerable to price fluctuations.

Figure 25 shows the top three producing countries for selected minerals and fossil fuels. The metals for which supply is highly concentrated are cobalt, REEs, and tellurium. Australia, Chile, DRC, and Indonesia have large shares of the production of metals for lithium-ion batteries, and China, Japan, and South Korea have significant production levels of metals for solar PV, although the majority of both lithium and cobalt mined products are shipped to China for processing. China further dominates the manufacturing of solar PV and lithium-ion batteries and is the largest market for these technologies.

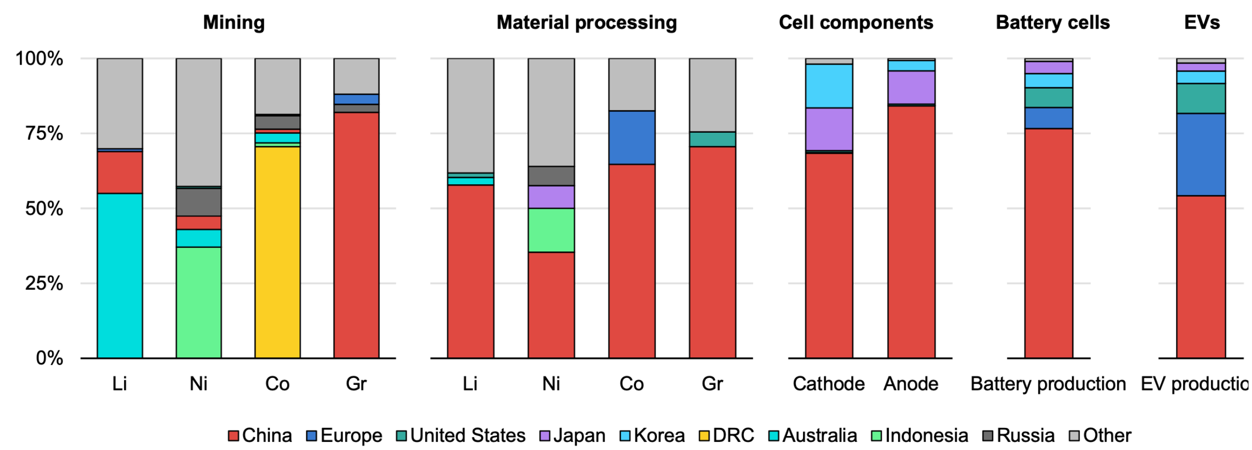
Figure 25: Share of Top Three Producing Countries for Selected Minerals and Fossil Fuels - 2019



Source: IEA

Chinese companies have significant control of supply chains. Figure 26 shows the geographical distribution of the global EV battery supply chain, highlighting the concentration of China.

Figure 26: Geographical Distribution of the Global EV Battery Supply Chain



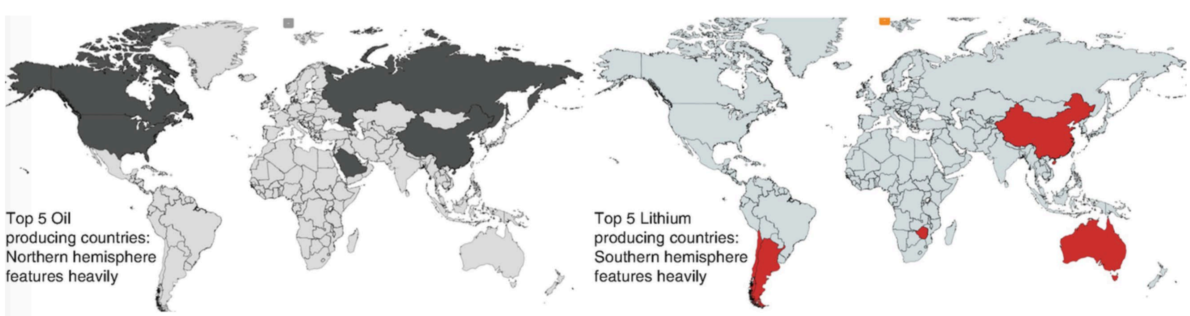
Source: IEA – Global Supply Chains of EV Batteries July 2022.

Cobalt has the highest concentration of potential supply, with nearly 50 percent of reserves in DRC. Most other metals are found in many regions across the globe, with Australia, Chile, Brazil, and China having significant shares of many metals. REEs are found in many countries but are not always economically viable to mine. Despite the fact that REE' production is highly concentrated in China, countries such as Brazil (17 percent), Vietnam (18 percent), and Russia (17 percent) have a significant share of global reserves, but currently only a very small share of production.

5.1.1. Geopolitical Shift Underway

The geopolitical shift underway in the supply of the resources required for the future energy mix is illustrated in Figure 27. Whereas the value of the lithium industry is much less than the value of the oil industry, this comparison highlights a distinct geographical shift in the energy commodities that society values. Oil's rate of use is projected to decline somewhat in the decade ahead. BP in its 2022 Energy Outlook[26] forecasts oil demand to decrease from approximately 98 million barrels per day (mb/d) in 2019 to 90 mb/d in 2030.

Figure 27: Top 5 Oil-Producing Countries versus Lithium-Producing Countries



Source: Achieving the Paris Climate Agreement Goals

[26] https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html

Meanwhile, the World Bank suggests that the shift to low carbon energy will also produce regional opportunities with respect to minerals. The Latin America region is in an excellent position to supply the global climate-friendly energy transition. The region has a key strategic advantage in copper, iron ore, silver, lithium, aluminum, nickel, manganese, and zinc. Africa, with its reserves in platinum, manganese, bauxite, and chromium, should also serve as a growing source for these resources.

5.2. Recycling to Reduce Primary Demand

Recycling has an important long-term role to play in reducing raw material consumption and driving the circular economy, because for some commodities the current stocks of materials will not be sufficient to fill the demand gap predicted by economic growth.

Recycling of metals from end-of-life batteries was found to have the greatest opportunity to reduce primary demand for battery metals, including cobalt, lithium, nickel, and manganese, according to the ISF. Increasing efficiency or shifting away from cobalt also has a significant impact (although this may increase demand for other metals including nickel and lithium). Many EVs and battery manufacturers have been proactive in establishing recycling initiatives and improving the efficiency of battery technologies; however, there is potential to improve recycling rates as not all types of metals are currently being recovered in the recycling process (including lithium and manganese), or are only being recovered at low rates.

The ISF also reported that improving the efficiency of material use was found to have the greatest potential to reduce primary demand for metals for solar PV, owing to the long life of these products. The industry has already made significant improvements to minimize the demand for materials, improve performance, and reduce costs, however, the solar PV industry also needs to engage further in recycling to avoid future waste streams and recover more metals from the process. Recycling remains a particular challenge for the solar PV industry as there is not always a strong business model.

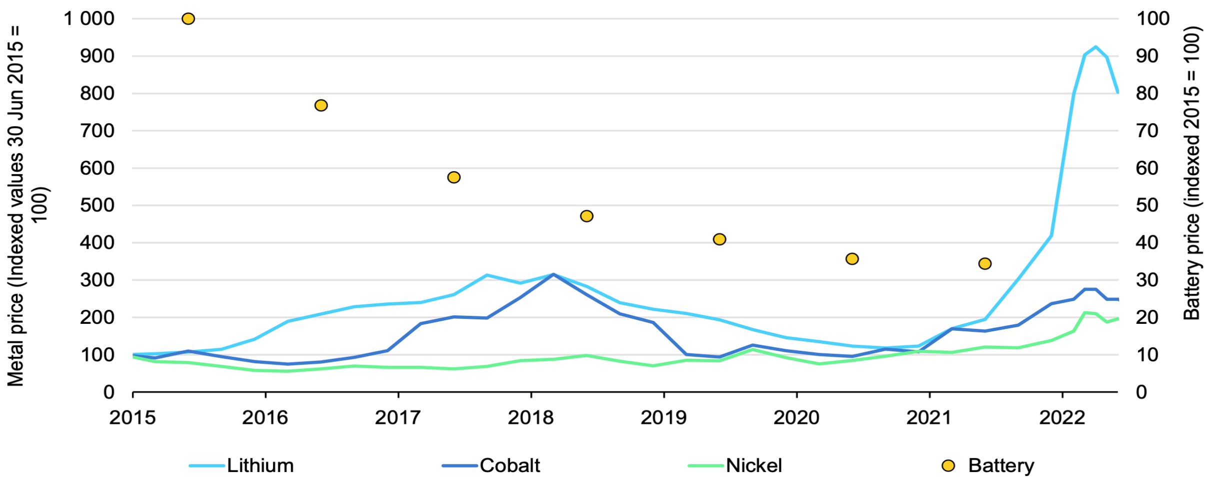
Overall recycling is the most important long-term strategy for the renewable energy and battery industries going forward, as the industry is already very focused on improving the efficiency of material use, which is expected to continue to improve over time. It is important to note, however, that recycling will be a long-term solution as the demand for minerals to manufacture batteries and other energy transition technology is so high in the short-term to meet quickly growing technology deployment needs. Once there is a significant stock of technology manufactured, recycling will play a key role in reducing raw material consumption overall.

5.3. Pricing of Commodities

The price path of commodities tends to be uneven and cyclical, as both supply and demand change and surge at different rates over time, both positively and negatively. From a supply perspective, the construction of new mines, downstream processing plants, new lithium-ion battery plants, and wind and solar production facilities tend to result in 'lumpy' changes in capacity. Figure 28 shows battery metals prices from 2015 to July 2022 and the recent surge in prices of lithium cobalt and nickel, which are expected to result in higher battery prices going forward.

Price volatility can have a number of important impacts. The uncertainty of pricing can have an important negative impact by discouraging investors from investing in new mining capacity, especially when current pricing is close to the trough of the cycle. High prices, while positive for the mining industry, are negative for the downstream manufacturing of products, causing either reduced profitability for manufacturers or higher costs for consumers, which may negatively impact end-use demand.

Figure 28: Battery Metals Prices 2015 to July 2022



Source: IEA – Global Supply Chains of EV Batteries July 2022.

5.4. Environmental and Social Challenges

There are always important social and environmental impacts that arise from the extraction of raw materials; however, it is how these impacts are mitigated that is important. The formal mining industry in developed economies is rarely willfully negligent, and usually operates with well-established environmental, social, and governance (ESG) principles that adhere to relevant government safety, social, and environmental regulations. Regulatory compliance is also heavily monitored, and standards are continually assessed and often raised; however, in some circumstances, the mining and supply chain for these metals can have adverse social and environmental consequences for workers, local communities, and the environment. One example is artisanal mining of cobalt in DRC, which has a history of human rights violations, child labor, and severe environmental pollution affecting health, although this is now being addressed to some degree.

Advancements in lithium-ion battery technology involves more than just the challenge of improving energy density, durability, safety, and cost. It also includes the effort to do so while minimizing the environmental, social, and political costs of acquiring their constituent materials. There are trade-offs associated with renewables because they compete for land, which could be used for agriculture and urbanization, or for conservation and leisure, and can cause local destruction of wildlife. Offshore wind turbines have an impact on marine ecosystems. Meanwhile, solar panels and wind turbine blades, which have a finite service life, are currently difficult to recycle and often end up in landfill sites. Similarly, reforestation, which is a proven means of carbon capture, is not always welcomed by local and Indigenous communities because it too may lead to some destruction of wildlife.

5.5. Technology Risks

Incremental changes and improvements in renewable energy and lithium-ion battery technology will take place over time, however, the current technology is unlikely to change significantly over the next ten years unless some unforeseen breakthrough takes place. This is because of the conservative nature of end-user industries, the long qualification times of materials and processes, and the existing and planned investment in capacity. Nevertheless, in the long-term, new technology must be continually monitored and referenced against current and future metal production to a balanced outcome of supply and demand for each individual commodity.

5.5.1. Lithium, Graphite, and Cobalt

One significant technology change that could take place in a lithium-ion battery is that the amount of lithium used may increase significantly with the advent of all-solid-state batteries (ASSBs). An ASSB uses solid electrodes and a solid electrolyte in lithium-ion batteries where the anode, electrolyte, and cathode would all potentially contain lithium, however, these batteries are currently expensive and present other technical problems.[27] Solid state lithium batteries are expected to take time to commercialize and will see limited mainstream uptake due to cost and manufacturing limitations at present.

The ASSB presents a longer-term risk to the demand for graphite with lithium as an alternate material for anodes. In the medium term, silicon is currently considered to be the most promising anode material to replace graphite due to its higher theoretical capacity. Nevertheless, silicon undergoes significant volume changes during the electrochemical cycles which results in rapid capacity degradation of the battery.[28]

More recently, battery makers have begun to use anodes made from carbon mixed with silicon which increases the specific capacity and energy density compared with pure graphite. This type of anode has already started to become more mainstream, and the outlook is for silicon to comprise around 7 percent of anode materials by 2030. Important EV manufacturers, material suppliers, and cell producers have recently announced that graphite-containing composites will mark the state-of-the-art for next-generation lithium-ion batteries, providing significantly enhanced energy densities compared to the current technology.[29]

Technology for the direct lithium extraction (DLE) from brines could be very important for the development of new lithium resources to meet the rising demand for lithium-dependent energy storage in the future. Geothermal brines in particular could become a major new source of lithium around the world. The most well-investigated and technologically advanced method for direct lithium extraction from brines is adsorption by metal oxides and hydroxides. It is apparent that lithium extraction and recovery from geothermal brines is becoming technically possible and 45 different DLE technology solutions are under development which may be incorporated into new lithium brine projects in development.[30] Many companies have developed their own proprietary extraction technologies, however, the economics of DLE are still uncertain and challenges remain in developing economically and environmentally sustainable DLE processes for mainstream production at commercial scale.

A risk for cobalt demand in the longer term is the continued reduction of cobalt in battery chemistries in favor of higher nickel content, as well as the use of cobalt-free batteries such as lithium-iron-phosphate (LFP) batteries. *For more discussion on LFP batteries, please see page 38 in Annex I.*

---

[27] IEA – The role of Critical Minerals in Clean Energy Transitions

[28] Energy Fuels 2021, American Chemical Society

[29] Sustainable Energy Fuels, The Royal Society of Chemistry Nov 2020.

[30] Jade Cove Partners

6. CONCLUSION

As of 2022, 194 parties have signed the Paris Agreement, agreeing to limit GHG and reduce CO_2 emissions by 2050.[31] The demand for battery materials could mean a paradigm shift for the mining sector. Strengthening the critical mineral supply chain is necessary to manufacture several clean energy technologies, from EV batteries, to wind turbines, and solar panels. This Report discussed the growing impact of climate change on the commodity markets, as countries around the world (including Brazil), implement plans to accelerate their clean energy transition.

The Report focused on the crucial role being played by commodities in the decarbonization of energy and how it is reshaping the demand for commodities. It examined recent research reports from various public, government, and private organizations discussing the requirements for minerals and commodities needed for the development of the renewables industry. In recent years, there has been an upsurge in studies of 'mineral criticality', covering the high penetration of renewable and storage technologies, and the potential constraints that certain minerals may impose. The Report has taken a brief look at each of the significant renewable technologies to examine which commodities are important in their production and development. While it is clear that the technologies assumed to populate the clean energy market (wind, solar, hydrogen, and electricity systems) are in fact significantly more material intensive in their composition than current traditional fossil-fuel-based energy supply systems, the actual increase in demand that certain metals will experience is unclear and difficult to predict. This is because it is difficult to forecast the uptake and rate of growth of the individual technologies and the level of relative penetration of each technology. Also, the technologies themselves are still evolving. Furthermore, important factors such as the impact of improving material efficiency and potential recycling rates remain uncertain.

Despite the difficulties, various organizations continue to make and update forecasts of how the world's energy markets will evolve out to 2050. The forecasts generally highlight those metals likely to benefit from a low carbon energy shift include copper, cobalt, silver, aluminum, nickel, zinc, lithium, graphite, and rare earth, among others. This Reports also noted that it is important to understand the changes in the available supply of these commodities, the geopolitical landscape, and the associated social and environmental impacts. These specific challenges are discussed in individual commodity reports developed under *Task 2A: Economic Viability and Global Market Competitiveness of Specific Minerals*.

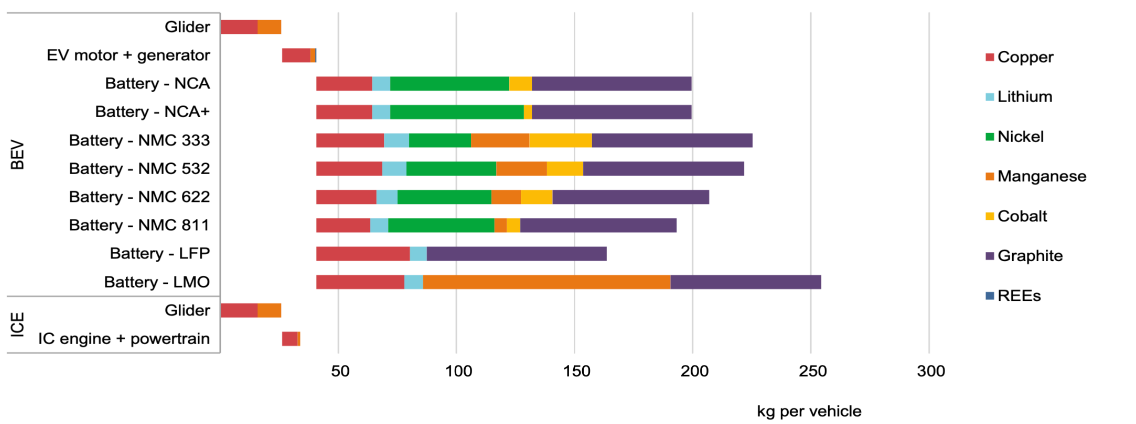
---

[31] The Paris Agreement | United Nations

ANNEX 1 – BATTERY TECHNOLOGIES

While there are a number of battery chemistries, the two main types of batteries currently are lead-acid and lithium-ion. Lead-acid batteries are the more mature technology but have poor power-to-weight and energy-to-weight ratios. Lead acid batteries have specific energies in the range of 35 to 40 watt-hours per kilogram (Wh/kg), while lithium-ion batteries have a range of around 90 to 260 Wh/kg. Consequently, Lithium-ion batteries are the preferred technology for most hand-held applications and are being used for almost all EVs on the market today and for the foreseeable future. The continued increase in volume has allowed battery prices to decrease significantly in the past decade. The four main components of a lithium-ion cell are the cathode, anode, liquid electrolyte and separator. Figure 29 shows the typical use of minerals in an internal combustion engine (ICE) vehicle and an EV battery .

Figure 29: Typical Use of Minerals in an ICE Vehicle and an EV Battery



Source: IEA. ICE = Internal combustion engine.

Non-rechargeable (or primary) batteries use metallic lithium for the anode. These batteries are more expensive than most other types of disposable batteries like alkaline batteries but are superior concerning operational lifetime, size, stability, and durability. Primary lithium batteries are employed in various household applications such as calculators, cameras, and watches and medical devices such as heart pacemakers. The lithium anodes can be manufactured from pure, high quality lithium metal, which guarantees very good processing properties. The bulk material can undergo transformation into soft foils, with thicknesses as low as 30µm.

By far the most important use of lithium is in the manufacture of rechargeable batteries. Lithium-ion batteries are high-energy-density power sources, especially important to all mobile applications. At the same time these devices are also capable of high charge discharge rates, the second important requirement for utilization in mobility applications to achieve powerful acceleration in cars and e-bikes, as well as charge acceptance for energy recuperation during braking. The most important application of lithium salts in lithium-ion battery technology is their use in cathode material production. The main sources of lithium in this application are currently lithium carbonate and lithium hydroxide.

Lithium hydroxide and lithium carbonate are both used in lithium-ion batteries. Manufacturers favor lithium hydroxide for cathode technologies and high nickel chemistry batteries such as NCM811 (nickel-cobalt-manganese or NCM), which have a higher energy density. The numbers represent the relative proportion of each of the three metals in the battery. NCM622 cathodes can use either lithium hydroxide or carbonate, while lower nickel-bearing NCM cathodes require lithium carbonate.

Other lithium batteries such as LFP, which have a lower energy density but are lower cost, also use lithium carbonate. Lithium salts produced for batteries require a higher purity of product and usually designated as 'battery-grade'.

Table 1 shows the metal content for a selection of different cathode types and shows that a typical lithium-ion battery has between 80 and 120 g/kWh of lithium. A typical EV has an 80-kWh battery (Tesla Model 3), meaning it has some 6.4 kg (NMC111) to 9.6 kg (LFP) of lithium content (34.1 to 51.1 kg of LCE), depending on the type of battery technology. Tesla is currently using LFP batteries.

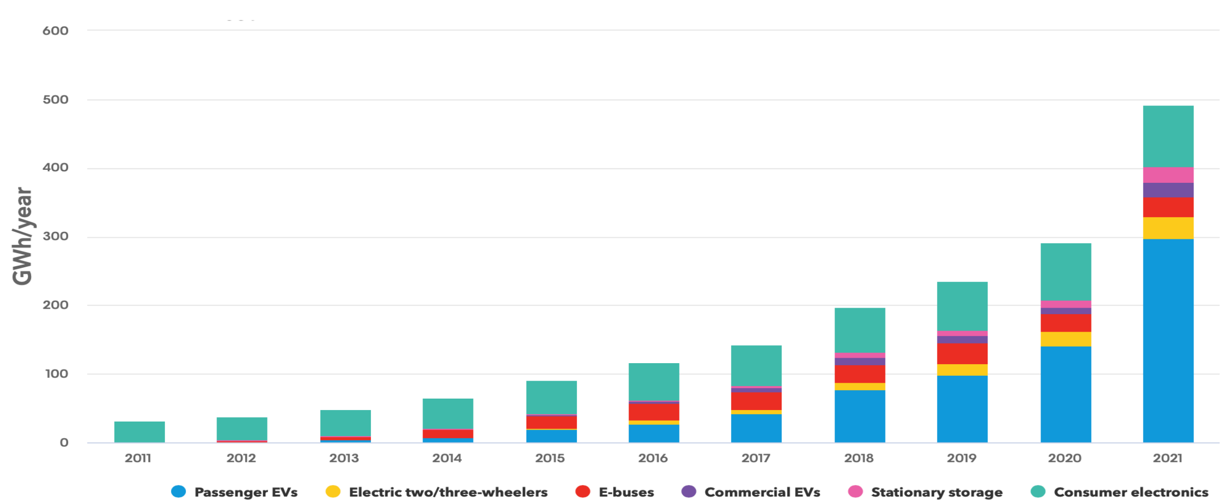
Table 1: Metal Content of Different Battery Cathodes kg/kWh

Metal	NMC111	NMC622	NMC811	NCA5	LFP
Nickel	0.333	0.525	0.653	0.725	0.000
Cobalt	0.333	0.176	0.082	0.065	0.000
Lithium	0.120	0.104	0.096	0.095	0.084
Manganese	0.312	0.164	0.076	0.000	0.000
Aluminium	0.000	0.000	0.000	0.011	0.000
Iron	0.000	0.000	0.000	0.000	0.674
Phosphate	0.000	0.000	0.000	0.000	0.374

Source: Fraunhofer ISI & Fraunhofer IZM 2021 for DERA 2021.

Figure 30 shows the annual lithium-ion battery demand by application from 2011 to 2021. The expectation by market consensus is that lithium hydroxide use will occur in higher quantities than use of lithium carbonate in EV markets because the market currently focuses on battery mileage (energy density) and will favor NCM cathode technologies. This is a key argument in current decision making in the construction of new lithium chemical processing facilities. However, some market commentators believe this will be less clear cut because as governments mandate petrol and diesel autos out of production, production of smaller electric cars will be required for consumers with less focus on battery mileage and will likely use the cheaper LFP technology.

Figure 30: Annual Lithium-ion Battery Demand by Application 2011 to 2021



Source: BloombergNEF - Electric Vehicle Outlook 2022. https://about.bnef.com/electric-vehicle-outlook/

Deloitte & Touche
1919 N. Lynn Street
Arlington, VA 22209
Phone: +1 571 882 5000
Fax: +1 571 882 5100