1000 GWh. Across Europe, several local battery companies, including Sweden's Northvolt, France's Verkor, Britain's Britishvolt, Norway's Freyr, and Slovakia's InoBat Auto have been established, and large-scale battery production plans have been announced. In addition, Germany plans to invest 1 billion euros to support German lithium-ion power battery production by 2021. With the successive completion of 38 super factories, the production of electric vehicle batteries in Europe will also increase significantly. It is expected to produce 460 GWh in 2025 and 1140 GWh in 2030, which is 13 times of the expected supply this year (87 GWh). In addition, to ensure the supply of batteries, major car companies have begun to build their own lithium-ion power battery factories to achieve cost control and control the initiative of lithium-ion power battery supply. Among them, Tesla plans to build the future Gigafactory near Berlin into one of the largest factories in the world, with an expected production capacity of 250 GWh in 2030. Volkswagen Group plans to join hands with its partners to build six battery factories in Europe. Overall, Europe is expected to become the world's second largest supplier of power LIBs for electric vehicles in the near future, which will bring huge challenges to the Asian lithium-ion power battery market.

1.3.2 The Changing Trend of Lithium-Ion Battery Material Types

Statistics from SMM show that the total installed capacity of power LIBs in China continues to grow from 16 GWh in 2015 to 154 GWh in 2021 (Figure 1.9). In terms of battery types, NCM batteries and LFP batteries dominate the lithium-ion power

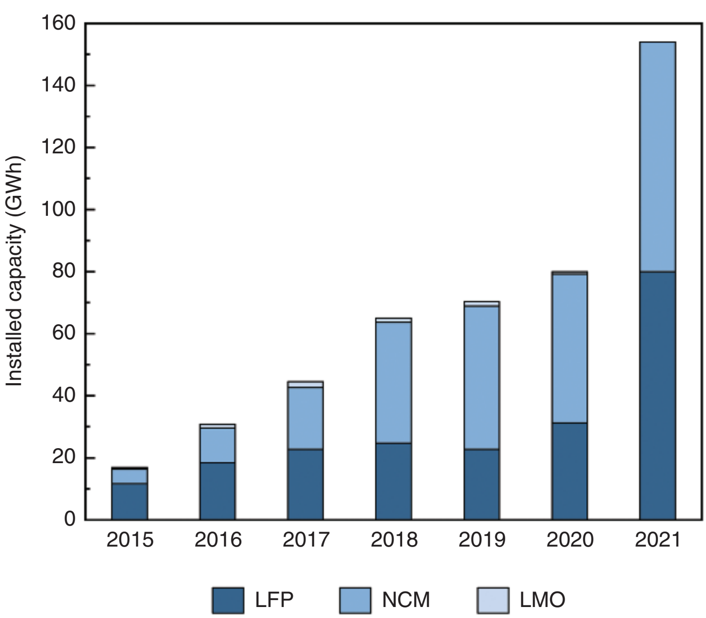

Figure 1.9 Main power batteries by material types and their installed capacities in China from 2015 to 2021. *Source:* SMM.

battery market. The high energy density of NCM batteries is gradually favored by the passenger vehicle market, reaching more than 60% in 2019. LFP batteries are mainly used in commercial vehicles and pure electric passenger vehicles. With the introduction of BYD's blade battery technology in 2020 and the advancement of battery assembly technology, low-cost LFP batteries will achieve breakthroughs in energy density. It will lead to an increase in the sales of LFP batteries in the short term; thus, the market share will rebound in 2020–2021.

1.3.3 Development Goals and Plans in Various Regions of the World

Since the commercial use of LIBs in 1991, the battery system with the LCO/LMO/LFP as the cathode electrode and the graphite as the anode electrode has basically been inherited. In recent years, due to requirements for the higher energy and safety of power LIBs, its technological development was thus boosted. Figure 1.10 shows the development history, status, and future trends of lithium batteries around the world [12]. It is worth noting that the energy density of the Panasonic 18650 battery has only approximately tripled between 1990 and 2015. At present, lithium batteries with an energy density of 240 Wh/kg have achieved mass production, and lithium batteries with an energy density of 300 Wh/kg or even 400 Wh/kg are still in development. As a result, countries worldwide are developing and planning to achieve electric vehicle range (>500 km, charging time <20 minutes) and cycle life (>3000 cycles).

In China, the power battery development plan at various stages is very clear. The "Technical Roadmap for Energy-Saving and New Energy Vehicles" has detailed the corresponding requirements for each stage of China's power LIBs and new type batteries, which are mainly divided into three stages:

(1) In 2020, LIBs should meet the needs of pure electric vehicles over 300 km, that is, the energy density of a single unit will reach 300 Wh/kg and 600 Wh/L,

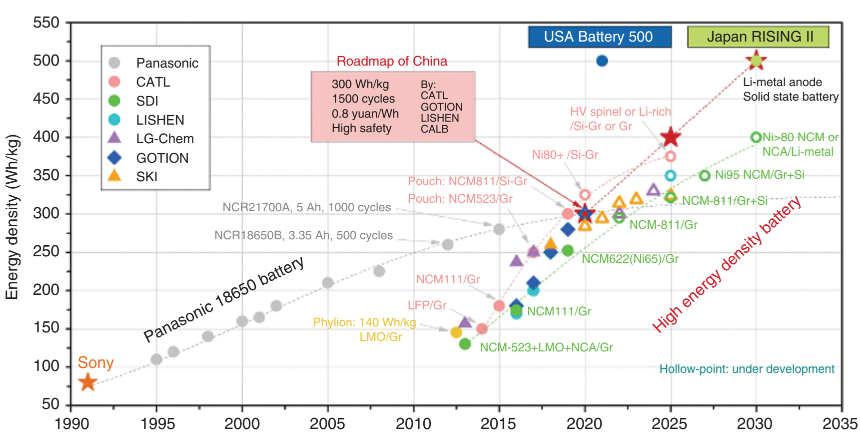

Figure 1.10 The history, current state, and development route of LIBs.
Source: Lu et al. [12] / with permission of Elsevier.

the unit cost will be reduced to 0.8 yuan/Wh, and the cycle life will be 1500 times;

(2) In 2025, LIBs should meet the needs of pure electric vehicles over 400 km, that is, the energy density of a single unit will reach 400 Wh/kg and 800 Wh/L, the unit cost will be reduced to 0.5 yuan/Wh, and the cycle life will be 2000 times;

(3) In 2030, LIBs should meet the needs of pure electric vehicles over 500 km, that is, the energy density of a single unit will reach 500 Wh/kg and 1000 Wh/L, the unit cost will be reduced to 0.4 yuan/Wh, and the cycle life will be 3000 times.

At present, against the goal of 300 Wh/kg, the research on power LIB technology mainly focuses on the development of Li-rich ternary cathode materials, silicon–carbon anodes, and electrolytes with wide voltage windows.

For example, Li-rich layered oxides (LLOs) deliver extraordinary capacity exceeding 250 mAh/g have greatly attracted research interests to further contribute the energy density. Despite the high capacity, LLOs suffer from poor rate performance and voltage fading as well as capacity decay during cycling. Guo et al. [13] from the Ningbo Institute of Materials Technology and Engineering (NIMTE)-CAS constructed abundant nanoscale defects via chemical delithiation and built dual Al2O3 layer via hierarchical surface configuration to suppress surface lattice oxygen release. Besides, they also designed 3D porous LLO and created oxygen vacancies through gas-solid interface reaction, facilitating the ionic diffusion to enable excellent rate capability [14]. Based on the scientific achievements, a 300-ton pilot production line of LLO cathode material has been established. By 2030, all-solid-state (ASS) batteries are expected to achieve large-scale commercialization, which will further promote the application of metallic lithium anodes to meet the energy density requirement of 500 Wh/kg.

In Japan, New Energy and Industrial Technology Development Organization (NEDO) released "Research and Development Initiative for Scientific Innovation of New Generation Battery" (RISING II) project in 2018. In terms of power batteries, they also focus on the research and development of ASS batteries. By 2025, the first generation of ASS batteries will be popularized, and its energy density will reach 300 Wh/kg. By 2030, the second generation will be popularized and is expected to realize 500 Wh/kg. In addition, Japan is also striving for developing new types of batteries such as sulfide-based ASS batteries and zinc-based batteries.

In South Korea, the Korea Battery Industry Association set the power electricity roadmap and four key materials roadmaps in 2018. The specific energy density of power battery will reach 330 Wh/kg and 800 Wh/l in 2025, and the cycle life of power battery will reach 15 years with 1000 cycles.

Europe: LIBs are part of the EU's efforts to develop a decarbonized and renewable energy society. The "Horizon 2020" plan, the latest framework of the EU's 10-year economic development plan, proposes to invest a total of 77.028 billion euros in industry, scientific research, business, and other fields from 2014 to 2020, of which a total of 114 million euros are earmarked for batteries, including lithium battery materials and transmission models and research and innovation of advanced lithium batteries. The energy density of power LIBs will reach 250 Wh/kg in 2025 and will continue to increase to 500 Wh/kg by 2030. In addition, the energy technology strategic development plan "Battery 2030+" proposes to invest more than 100 billion euros to promote the comprehensive development of the lithium-ion power battery industry chain, covering the entire process from raw materials to battery recycling.

The United States: The US Department of Energy (DOE) established the Battery 500 program in 2021. The total investment in the next five years is more than US$ 50 million, and the goal is to develop lithium metal batteries and replace the existing graphite anode with metal lithium, so that the energy density can reach 500 Wh/kg and the number of cycles will be 1000 times.

1.3.4 Critical Challenges for the Future Lithium-Ion Power Battery Industry

1.3.4.1 Reducing the Cost of Lithium-Ion Power Battery

The cost of raw materials accounts for more than 60%, which is the key way to reduce the overall cost of power battery [14]. Among them, the cost reduction of cathode materials lies in the metal resource price of upstream Li, Co, and Ni and the manufacturing process; the cost reduction of anode material lies in the raw material purchase of needle coke and graphite processing technology; the cost reduction of separator material lies in the improvement of the yield of the production process and the improvement of equipment; and the cost reduction of electrolyte is limited, and its large-scale production may help to reduce the price. However, under the existing technology, the cost reduction space for raw materials is very limited. The focus of cost reduction will be at the module and pack level, such as BYD's introduction of blade technology, which will reduce battery system costs by 20–30%.

1.3.4.2 Improving the Energy Density of Power Battery

The path of energy density improvement mainly includes two aspects: core density and system density. In terms of cells, new technological breakthroughs such as ASS and ternary Li-rich batteries need to be achieved, and technologies such as changing the ratio of cathode and anode electrodes electrode materials need to be optimized. In terms of battery packs, the modular cell-to-pack (CTP) scheme is designed to improve the efficiency of battery pack grouping, optimize the layout structure, and use low-density materials. For example, CATL's CTP technology, based on a NCM material battery technology architecture, can increase space volume utilization by 15–20%, reduce the number of internal components by 40% and indirectly increase system energy density by 10–15%. In addition, the blade battery designed by BYD based on LFP battery technology architecture can increase the volume energy density by 50%.

1.3.4.3 Improving Safety of Power Battery

Fire concerns of power battery generally includes charging spontaneous combustion (charging current is large), collision combustion (battery damage, internal short circuit), driving spontaneous combustion (battery damage, internal short circuit), and wading spontaneous combustion (battery sealing is insufficient, liquid causes external short circuit). These problems can cause the whole battery pack temperature to rise sharply, thermal runaway, and then spontaneous combustion explosion. Battery thermal runaway can be controlled by battery design or supporting facilities. For example, it can prevent the cathode electrode from releasing oxygen; suppressing the flammability of electrolyte; improving the sealing, heat insulation, and impact resistance of battery pack structure; and optimizing the battery thermal runaway management system.

1.3.4.4 Recycling Power Battery

The full life cycle of power battery involves many subjects and links. Only some enterprises master the life cycle data of their products, and the fragmentation of information restricts the recycling and reuse of power LIBs. In addition, retired batteries lack testing standards, and battery residual value assessment technology as well as the talent reserves are insufficient. In the process of battery design and manufacture, the manufacturers did not consider recycling and disposal factors.

1.4 Analysis of the Supply and Demand of Critical Metal Raw Material Resources for Power Lithium-Ion Batteries

LIBs play a crucial role in global electrification and help to tackle climate change. Global battery demand is expected to scale up 19 times compared to the current level by the end of 2030 [15]. This can be hardly achieved if relying on the current way of how the materials are sourced, produced, and used. The challenge can only be overcome with the collaborative efforts through the entire value chain. Among all the challenges, the supply of critical metal raw materials, i.e. lithium, nickel, and cobalt, are one of the most tough ones. Material production of lithium battery is very dependent on these critical metals. A recent report by the IEA suggests a typical electric car requires six times the mineral inputs of a conventional car [16], and currently, they are predominantly extracted from minerals on earth. These minerals are unevenly distributed geographically, with lithium raw material mainly produced in Australia, nickel in ASEAN countries (Indonesia and Philippines), and cobalt in the Democratic Republic of Congo (DRC). The scale-up in mineral sourcing might lead to negative social, environmental, and integrity impacts in these regions, especially for cobalt. The DRC is one of the world's least developed countries, whose economy hugely relies on cobalt. A total of 10–12 million people depend directly or indirectly on mining, and 80% of exports are mining products. However, severe social risks have been well documented in the DRC's artisanal mining industry, which include hazardous working conditions, deaths due to poorly secured tunnels, potentially various forms of forced labor, the worst forms of child labor, and exposure to fine dusts and particulates as well as the DNA-damaging toxicity [15]. All these issues have resulted in a rather fragile front-end LIB supply chain.

At the same time, driven by the strong demand in the field of lithium batteries, the price of these key metal materials has shown a rapid upward trend since the beginning of 2021, showing supply shortages of varying degrees.

To underscore the importance and potential risks associated with these critical metal resources, the White House's 100-day review under Executive Order 14017, issued in June 2021, dedicated an entire chapter to review the topic and concluded that reliable, secure, and resilient supplies of key strategic and critical materials are essential to the US economy and national defense.

In the successive part of this chapter, the geographical distribution of lithium, nickel, and cobalt and their production status have been introduced, followed by a discussion on the supply and demand outlook.

1.4.1 Geographical Distribution of Critical Metal Raw Materials and Their Production Status

1.4.1.1 Lithium

Lithium is a relatively rare element on earth, whose abundance in the earth's crust is 0.0065%, ranking 27th. Although seawater contains rich lithium resources, around 260 billion tons, currently it is not commercially available as the content is low, only 0.17 mg/l.

According to the latest USGS report [17], in 2020, the global lithium mine reserves were approximately 21.06 million tons. Among them, Chile has the most reserves, about 9.2 million tons, accounting for about 43.7% of global reservation. Australia ranks second in reserves, with reserves of about 4.7 million tons in 2020, accounting for 22.3% of global reserves. Argentina ranks the third in resource reserves. The detailed data of global lithium reserves in 2020 are listed in Table 1.3.

The global lithium resources are mainly divided into two types, namely rock minerals and brine minerals, of which closed basin brine accounts for 58%; pegmatite (including lithium-rich granite) accounts for 26%; hectorite clay accounts for 7%; and oilfield brine, geothermal brine, and lithium borosilicate ore each account for 3% [18].

The world's brine lithium resources are mainly distributed in the "Lithium Triangle" plateau areas of Chile, Argentina, and Bolivia in South America; western United States; and western China. The world's rock lithium resources are mainly distributed in Australia, China, Zimbabwe, Portugal, Brazil, Canada, Russia, and other countries.

Approximately 82 200 metric tons of lithium ore were mined in 2020 globally. Australia is the main contributor, with 40 000 metric tons lithium yield, accounting for almost half of the world's production, followed by Chile and China, with 21.9% and 17.0% contributions, respectively. The detailed data of global lithium mine yield in 2020 are listed in Table 1.4.

1.4.1.2 Nickel

According to the latest USGS report [17], in 2020, the global nickel mine reserves were approximately 94 million tons. Among them, Indonesia has the most reserves, about 21 million tons, accounting for about 22.4% of world total. Australia ranks

Table 1.3 Global lithium mine reserves in 2020.

Country	Lithium mine reserves (metric tons)	Percentage (%)
United States	750 000	3.6
Argentina	1 900 000	9.0
Australia	4 700 000	22.3
Brazil	95 000	0.5
Canada	530 000	2.5
Chile	9 200 000	43.7
China	1 500 000	7.1
Portugal	60 000	0.3
Zimbabwe	220 000	1.0
Rest of world	2 100 000	10.0
World total	21 055 000	100

Source: Data from USGS [17].

Table 1.4 Global lithium mine yield in 2020.

Country	Lithium mine yield (metric tons)	Percentage (%)
United States	—	—
Argentina	6 200	7.5
Australia	40 000	48.7
Brazil	1 900	2.3
Canada	—	—
Chile	18 000	21.9
China	14 000	17.0
Portugal	900	1.1
Zimbabwe	1 200	1.5
Rest of world	—	—
World total	82 200	100

Source: Data from USGS [17].

second in reserves, with the amount of about 20 million tons in 2020, accounting for 21.3% of global reserves. Brazil ranks third in resource reserves. The detailed data of global nickel reserves in 2020 are listed in Table 1.5.

The global nickel resources are mainly divided into two types: laterite nickel and nickel sulfide ore, which account for 60% and 40% of total reserves, respectively. Laterite nickel mines are mainly distributed in countries within the Tropic of Cancer, including Australia, New Caledonia, Indonesia, Brazil, and Cuba, while

Table 1.5 Global nickel mine reserves in 2020.

Country	Nickel mine reserves (metric tons)	Percentage (%)
United States	100 000	0.1
Australia	20 000 000	21.3
Brazil	16 000 000	17.0
Canada	2 800 000	3.0
China	2 800 000	3.0
Cuba	5 500 000	5.9
Dominican Republic	—	—
Indonesia	21 000 000	22.4
New Caledonia	—	—
Philippines	4 800 000	5.1
Russia	6 900 000	7.3
Rest of World	14 000 000	14.9
World total	93 900 000	100

Source: Data from USGS [17].

nickel sulfide mines are mainly distributed in Russia, Canada, Australia, South Africa, and China.

Laterite nickel mines are mostly open-pit mines, which are convenient for mining, but the processing technology is more complicated due to their low grade. With the recovery of nickel prices and progress in the refining technology, the proportion of primary nickel produced from laterite ore has steadily increased. The proportion of nickel supply from laterite ore increased from 51% in 2017 to 62% in 2019, which has completely changed the previous dominated industry pattern of sulfide ore.

Approximately 2.5 million metric tons of nickel ore were mined globally in 2020. The main contribution comes from the ASEAN region, where Indonesia produced 0.76 million tons (accounting for 30.7% of world's production), and Philippines produced 0.32 million tons with 12.9% worldwide share. Russia ranks third, with a yield of 0.28 million tons similar to that of Philippines, accounting for 11.3% of the global total. The detailed data of global nickel mine yield in 2020 are listed in Table 1.6.

1.4.1.3 Cobalt

According to the latest USGS report [17], in 2020, the global cobalt mine reserves were approximately 7.1 million tons. Among them, Congo has the most reserves, about 3.6 million tons, accounting for about 50.5% of the world's total. Australia ranks second in reserves, with reserves of about 1.4 million tons in 2020, accounting for 19.6% of global reserves. Cuba ranks the third in resource reserves. The detailed data of global cobalt reserves in 2020 are listed in Table 1.7.

Table 1.6 Global nickel mine yield in 2020.

Country	Nickel mine yield (metric tons)	Percentage (%)
United States	16 000	0.6
Australia	170 000	6.9
Brazil	73 000	2.9
Canada	150 000	6.1
China	120 000	4.8
Cuba	49 000	2.0
Dominican Republic	47 000	1.9
Indonesia	760 000	30.7
New Caledonia	200 000	8.1
Philippines	320 000	12.9
Russia	280 000	11.3
Rest of World	290 000	11.7
World total	2 475 000	100

Source: Data from USGS [17].

Table 1.7 Global cobalt mine reserves in 2020.

Country	Cobalt mine reserves (metric tons)	Percentage (%)
United States	53 000	0.7
Australia	1 400 000	19.6
Canada	220 000	3.1
China	80 000	1.1
Congo	3 600 000	50.5
Cuba	500 000	7.0
Madagascar	100 000	1.4
Morocco	14 000	0.2
Papua New Guinea	51 000	0.7
Philippines	260 000	3.6
Russia	250 000	3.5
South Africa	40 000	0.6
Rest of World	560 000	7.9
World total	7 128 000	100

Source: Data from USGS [17].

Table 1.8 Global cobalt mine yield in 2020.

Country	Cobalt mine yield (metric tons)	Percentage (%)
United States	600	0.4
Australia	5 700	4.2
Canada	3 200	2.4
China	2 300	1.7
Congo	95 000	70.4
Cuba	3 600	2.7
Madagascar	700	0.5
Morocco	1 900	1.4
Papua New Guinea	2 800	2.1
Philippines	4 700	3.5
Russia	6 300	4.7
South Africa	1 800	1.3
Rest of World	6 400	4.7
World total	135 000	100

Source: Data from USGS [17].

Cobalt rarely forms separate ores and is mostly associated with copper, nickel, manganese, iron, arsenic, lead, and other deposits. Cobalt resources usually exist in the following areas [17]: sediment-hosted stratiform copper deposits in Congo and Zambia; nickel-bearing laterite deposits in Australia and its nearby island countries, i.e. Indonesia, Philippines, New Caledonia, and Cuba; magmatic nickel-copper sulfide deposits hosted in mafic and ultramafic rocks in Australia, Canada, Russia, and the United States; manganese nodules and crusts on the floor of Atlantic, Indian, and Pacific Oceans

The total yield of cobalt mine was 135 000 metric tons in 2020, predominantly from Congo. Congo alone has produced 95 000 tons, contributing to over 70% of the global total. Russia and Australia ranked second and third, accounting for 4.7% and 4.2%, respectively. The detailed data of global nickel mine yield in 2020 are listed in Table 1.8. Compared to lithium (Table 1.4) and nickel (Table 1.6), cobalt presents the most unbalanced global supply, which is extremely dependent on a single country, i.e. Congo.

1.4.2 Supply and Demand Outlook of Critical Metal Raw Materials

1.4.2.1 Lithium

The Lithium Carbonate Equivalent (LCE) in 2020 is around 369 000 tons, among which, LIBs account for 59%, while the rest 41% comes from the industrial fields. The demand domain in LIB can be further divided into consumer electronics, electric vehicles, electric mobilities, e.g. scooters, electric bikes, and energy storage.

While electric vehicles have only begun to grow in the last few years, their share is increasing very fast, already consuming 35% of global lithium demand. Energy storage is another fast-growing area, benefiting from energy transition to solar and wind, although it contributed only 3% in 2020.

In the industrial field, lithium is normally used as a raw material for glass and ceramics, grease, flux, and polymers, and it can also be used in solid fuels, aluminum smelting, and other fields. Lithium demand in the industrial field is rather stable, and its share in total lithium demand will be significantly reduced with the massive adoption of electric vehicles and energy storage (Figure 1.11).

1.4.2.2 Nickel

The total nickel demand in 2020 is around 2.39 million tons [18]. As the main characteristics of nickel are high hardness and oxidation resistance, most of the world's finished nickel (near 70%) has been used in the production of stainless steel. The major applications for nickel and their corresponding demand share are illustrated in Figure 1.12.

The contribution from the battery sector only account for 6% of the overall nickel consumption in 2020, which is dramatically different from that of lithium (Figure 1.11) and cobalt (Figure 1.13), where the contribution from the battery sector is greater than 50%. However, with the continuous advancement of electric vehicles, the demand for nickel in the battery industry is expected to grow rapidly in the next few years. Nickel sulfate is a key raw material for LIBs, mainly used in the production of NCM and NCA battery precursors/cathode materials. The market

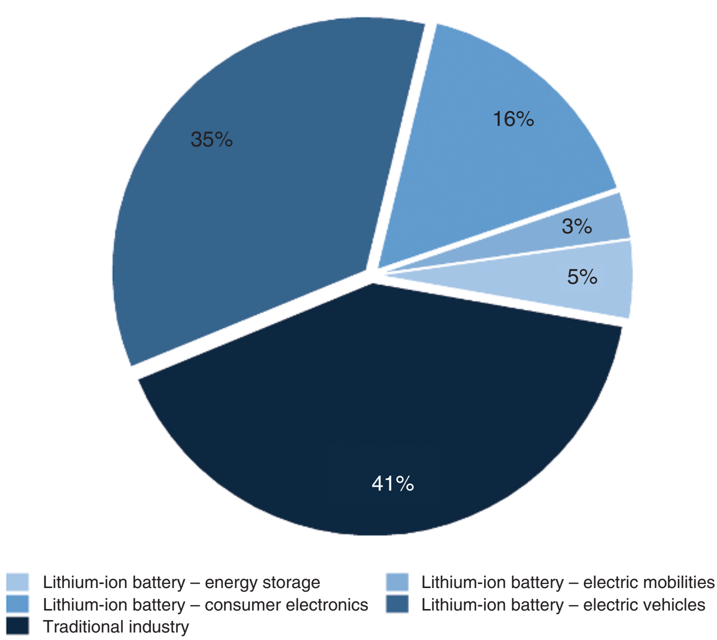

Figure 1.11 Lithium demand by application in 2020. *Source:* Data from Antaike [18].

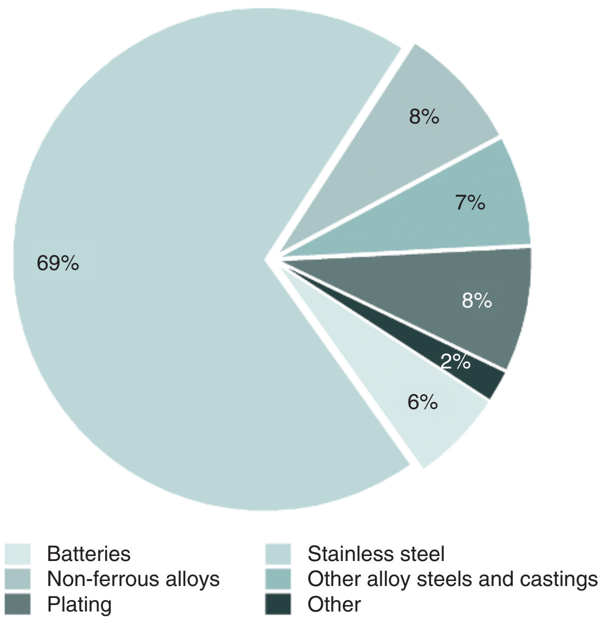

Figure 1.12 Nickel demand by application in 2020.
Source: Adapted from Fraser et al. [19].

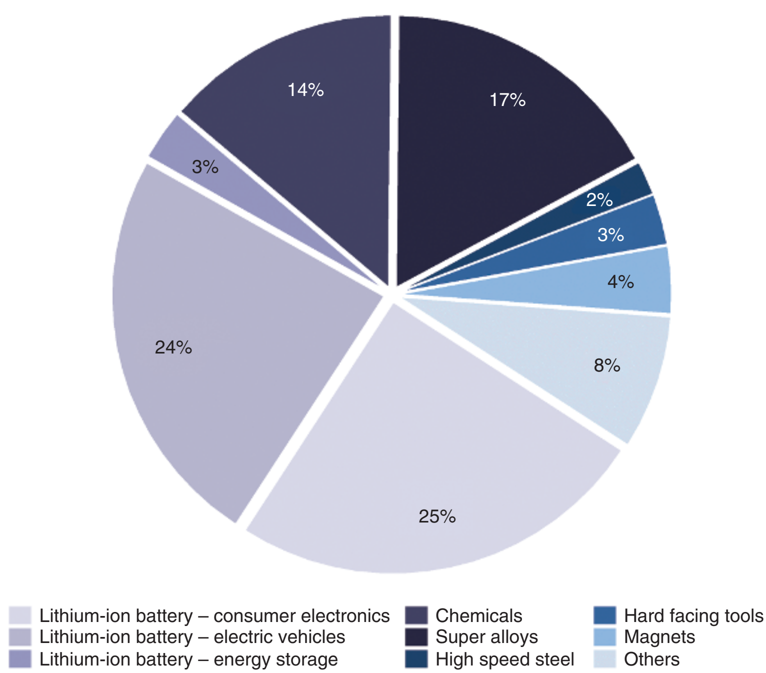

Figure 1.13 Cobalt demand by application in 2020. *Source*: Cobalt Institute [20].

presently is moving toward NCM ternary batteries of high nickel content because of the pursue for higher battery energy density and continued cost reduction (to replace cobalt with nickel to reduce total raw material cost), and the considerations of supply chain security, thereby further stimulating the demand for nickel in batteries.

1.4.2.3 Cobalt

The total cobalt demand in 2020 is around 140 000 tons [18], where metallurgical application accounts for 48% and LIBs for the rest 52%. The details can be found in Figure 1.13. For metallurgical application, cobalt's strength and resistance nature at high temperature make it an ideal choice to produce high-temperature alloys in power plants, high-speed steel drill bits, and blades as well as for use in hard face, carbide, and diamond tools for cutting applications and magnets. In addition, cobalt can also be used to make catalysts and desiccants. As for the LIB, cobalt is an important raw material for its manufacturing. Cobalt tetraoxide is used for LCO battery cathode, whereas cobalt sulfate is used for cathode material of ternary NCM and NCA battery. In the past 10 years, the growth in demand for cobalt has mainly come from the development of 3C batteries, such as use in smartphones, tablets, laptops, notebooks, computers, etc. Due to the rapid adoption of electric vehicles, the increase in cobalt demand is mainly driven by the battery sector in these two years, therefore, adding up the proportion of cobalt used in LIBs.

1.4.3 Scenario Without Recycling

Various research organizations [15, 21, 22] have predicted that due to energy transition toward renewable energy, especially in the electric vehicle and energy storage sectors, the demand for lithium, nickel, and cobalt will experience a huge increase in this decade and onward. Global battery alliance (GBA) [15, 21] predicts 6.4 times increase of lithium, 2.1 times increase of cobalt, and 24 times increase of class I nickel in 2030 as compared to that in 2018 [15]. The prediction from IEA is even more aggressive; according to their sustainable development scenario (SDS), the demand of lithium will grow by 43 times, nickel by 41 times, and cobalt by 21 times in 2040 when compared with that in 2020 [21].

At present, the supply of either lithium, nickel, or cobalt mainly comes from primary mineral resources. From the initial mine exploration to a new mine that can be officially put into operation is a long process, which usually takes up more than 10 years. Because of this, it is rather difficult to fulfill such tremendous growth; lithium, nickel, and cobalt minerals all have their key challenges [22], which are summarized below in Table 1.9, and all of them will experience shortage in this decade.

IEA predicts that the deficit in lithium supply will start from 2023 onward accompanied by a rapid gap increase, though the supply and demand unbalance may even begin in 2021. As for cobalt, the supply shortage will occur from 2024 and experience a similar trend as lithium. Nickel's supply is the most secure among the three, where the unbalance only starts from 2028 (Figure 1.14).

Table 1.9 Lithium, nickel, and cobalt minerals key challenges.

Mineral	Key challenges
Lithium	• Possible bottleneck in lithium chemical production as many smaller producers are financially constrained after years of depressed prices • Lithium chemical production is highly concentrated in a small number of regions, with China accounting for 60% of global production (over 80% for lithium hydroxide) • Mines in South America and Australia are exposed to high levels of climate and water stress
Nickel	• Possible tightening of battery-grade Class 1 supply, with high reliance on the success of HAPL projects in Indonesia; HAPL projects have track records of delays and cost overruns • Alternative Class 1 supply options (e.g. conversion of NPI to nickel matte) are either cost-prohibitive or emissions-intensive • Growing environmental concerns around higher CO_2 emissions and tailings disposal
Cobalt	• High reliance on the DRC for production and China for refining (both around 70%) set to persist, as only a few projects are under development outside these countries • Significance on artisanal small-scale mining makes the supply vulnerable to social pressures • New supply is subject to developments in nickel and copper markets as some 90% of cobalt is produced as a by-product of these minerals

Source: Data from IEA [22].

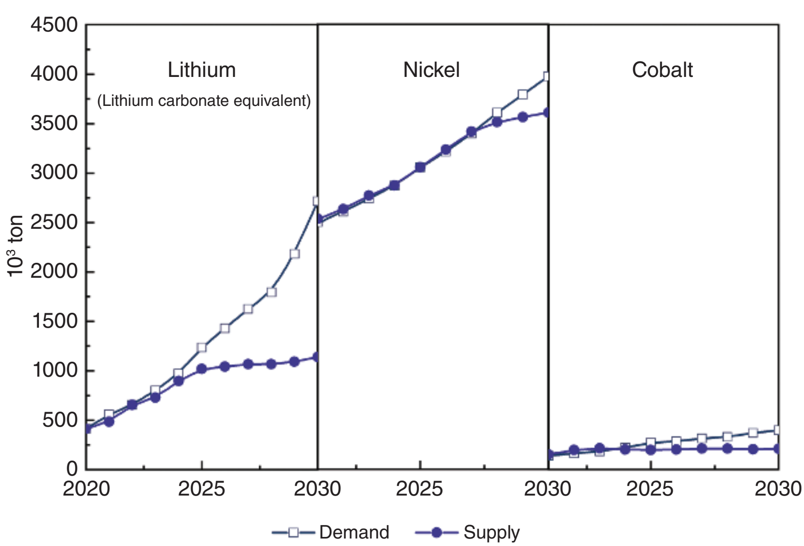

Figure 1.14 Supply and demand forecast for lithium, nickel, and cobalt.
Source: Data from IEA [22].

1.4.4 Scenario with Recycling

Metal recycling has the potential to be a significant resource of secondary supply, although it comes with its own set of challenges. Recycling comprises physical collection and metallurgical processing. Potential sources for recycling include tailings from process scrap used during manufacturing and scrap from end-of-life products.

All the LIBs installed today will eventually reach the end of life depending on the applications. The normal service life for a battery is ~5 years for consumer electronics, ~6 years for small electric mobilities, ~8–10 years for electric vehicles, and ~10 years for energy storage. When these batteries are retired, they can become valuable resources containing considerable amount of lithium, nickel, and cobalt. Especially those LIBs installed in electric vehicles, whose capacities are usually higher than 50 kWh, will cause serious safety and environmental problems if they are not properly disposed. According to the study from Circular Energy Storage (CES) [23], the expected EV battery that will reach the end of life is expected to be 174 GWh worldwide in 2030. This number is even larger than the total installed electric vehicle battery capacity in 2020, which is 136.3 GWh based on GGII data [24]. The expected retired battery amount is listed in Figure 1.15.

While not many electric vehicle batteries have reached the end of their normal life, even fewer of them will eventually be recycled. As more such batteries are retired after mid-century, along with more regulated recycling channels and strict recycling policies and regulations, recycling will be an important addition to the main sources of lithium, nickel, and cobalt. Recycling batteries will help to curb volatility in the supply chain and prices of raw materials or battery manufacturing

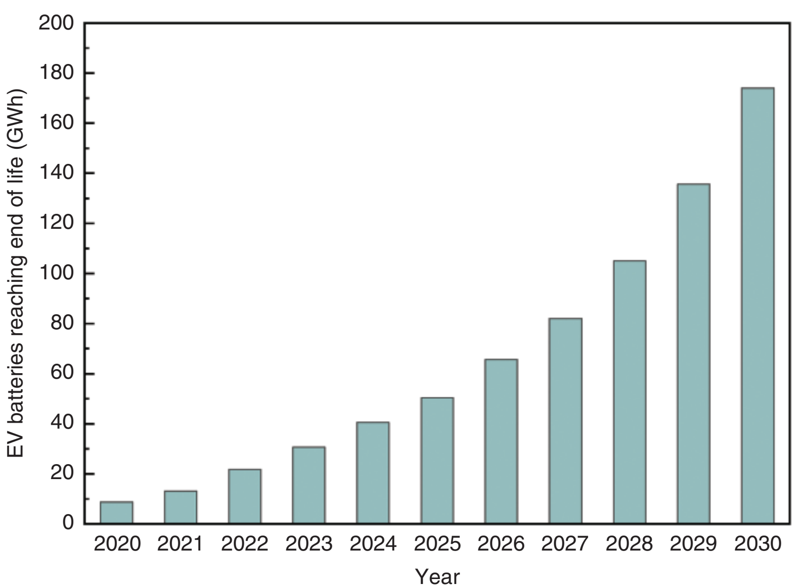

Figure 1.15 EV battery reaching end of life.

and can therefore play a key role in alleviating energy security concerns in countries that rely heavily on imports of these minerals. Based on the recent IEA report, in their SDS scenario, recycling and reuse of EV and storage batteries can reduce the primary supply requirement for minerals by 5% for lithium, 8% for nickel, and 12% for cobalt in 2040 [22].

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