WHITE PAPER ON

SUSTAINABLE LITHIUM INDUSTRY IN ACHIEVING NET ZERO

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Electric Forklifts
Electric Trucks
Lithium Salt Processing
Salt Lake
Aircraft
Space Photovoltaics
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Smart Grid
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Glass-ceramics
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Energy Storage Stations
Office Buildings
Robots
Lubricating Grease
Computers
Electric Bicycles
Offshore Wind Power
Construction Machinery
Electric Vehicle
Mobile Phones
Residential Areas
Shipping
Smart Benches

Changing the World with Lithium - Net Zero

To address climate change, one of the most urgent issues of our time, we need systematic transformation in every aspect of the society. One of the key processes is the shift of production and consumption system from being based on fossil energy to renewable energy, such as wind and solar energy. In this process, lithium plays a key role.

However, considering the complexity and massive scale of net zero challenge, it's impossible for any company to turn it into reality alone. The collaboration across industries and value chains, and at governmental and organizational levels is critical to unlocking the potential of net zero. It requires an ambitious climate goal to facilitate consensus and cohesion among governments and companies.

Therefore, Tianqi Lithium initiated the "Changing the World with Lithium - Net Zero".

Inviting value chain participants to achieve net zero in their business operations by no later than 2050 and working to reduce other emissions in the value chain.

The goal set by the initiative aligns the decarbonization progress of the lithium industry with the Paris Agreement. Regardless of the difficulties and dangers on the way to reach this goal, this initiative is of great importance for our society, this planet and the future generations.

Overview of Main Climate Actions in the Lithium Industry

Upstream procurement

- Build diversified lithium resources system
- Promote heavy vehicles powered by new energy
- Explore high-efficient salt lake lithium extraction

Midstream refinement

- Pilot and scale clean heat solutions
  - Electrification
  - Zero carbon/biomass/CO_2 derived fuels
  - Carbon capture and storage
- Reduce the impact of chemical materials on climate through green procurement

Downstream application

- Meet the electrification needs of more traffic scenarios
- Improve battery performance per unit of lithium raw material
- Match battery technologies with specific demand according to the application scenarios

Recycling of end-of-life battery materials

- Realize cascade utilization of more decommissioned power batteries
- Increase the supply of renewable lithium
- Build an efficient recycling system of power batteries

Value chain net zero vision

- Accelerate renewable power applications towards 100% renewable power supply
- Speed up the phase II electrification transformation and increase the share of electricity in energy consumption
- Advance the digital upgrade of the industries and improve the utilization efficiency of value chain resources and energy

Value chain net zero opportunities

- Formulate climate- and net-zero-related standards and guidelines
- Increase investment in technology R&D required for net zero, and create a platform to share technologies

Expert Reviews on the White Paper

Chen Liquan, Academician of Chinese Academy of Engineering and Honorary Chairman of the Advanced Battery Materials Industry Cluster

The White Paper provides a comprehensive and insightful decarbonization roadmap for the lithium industry with an ambitious goal of net zero. Such comprehensiveness and foresight will push all stakeholders to face the challenges of low-carbon transition in the lithium industry together and promote the fair and green development of the global lithium industry. Tianqi Lithium, a leading company in the industry, has the potential to lead the lithium industry to develop standards applicable to the whole industry chain, and gradually promote China's lithium industry to go global.

Cheng Huiming, Academician of Chinese Academy of Sciences and Director of Institute of Technology for Carbon Neutrality, Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences

Lithium, one of the key metals supporting energy transition, plays an important role in power, transportation, construction and other aspects. The low carbon and zero carbon emissions of the lithium industry constitutes a significant part of all industries' effort to achieve the goal of net zero carbon emissions. The lithium industry's path to net zero carbon emissions poses high requirements to decarbonization technologies, which involves challenges in technology R&D, commissioning costs and other aspects. This White Paper sets the goal of net zero for the lithium industry. The goal is inclusive and feasible, which can provide a systematic reference for relevant companies to set their own carbon reduction goals.

Zhao Tianshou, Academician of Chinese Academy of Sciences and Director of the Energy Institute for Carbon Neutrality, Southern University of Science and Technology

The path to zero carbon emissions will pose an impact on industrial development whether it's reducing carbon footprint or increasing carbon handprint. The White Paper sets a scientific net zero goal for the lithium industry, and comprehensively discusses the carbon footprint and carbon handprint throughout the whole life cycle (or the whole value chain) of lithium. With technical and economic analysis presented, it is of great reference value for the industry.

Lei Xianzhang, Academician of German National Academy of Science and Engineering and Chief Scientist of Carbon Neutrality at Southwest Petroleum University

From industrial monosodium glutamate, to white oil and the "philosopher's stone" supporting energy transition, the lithium industry has become a key industry supporting the energy sector to achieve net zero. The White Paper takes into account the feasibility and economy of decarbonization for the lithium industry. From the perspective of the feasibility, it analyzes in details the decarbonization technology roadmap for upstream, midstream, downstream companies and end-users according to the greenhouse gas emission status of the industry. In terms of the economy, it mainly considers the commercial potential of carbon capture recycling and power battery recycling.

As a global industry, the lithium battery industry needs to strengthen international cooperation and exchange, so as to address challenges and capture opportunities for the industry with concerted efforts. Tianqi Lithium, a leading company in the industry, is capable of leading the lithium industry to develop mechanism-based standards applicable to the whole industry chain, and gradually promote China's lithium industry go global.

Chai Qimin, Director of Strategy and Planning, National Center for Climate Change Strategy and International Cooperation

I'm glad to see the decarbonization roadmap for the lithium industry outlined in this White Paper - reducing carbon emissions to a lower level by 2030 and realizing net zero carbon emissions by 2050. It's an ambitious goal without doubt. For the lithium industry's commitment to decarbonization, some factors such as policy, international trading, technical standards, and carbon storage technology of production bases need to be taken into consideration in a comprehensive manner. With a call to action issued for industry players, the public sectors and financial institutions, the White Paper is expected to guide the transformation and development of the lithium industry towards the sustainability and net zero.

Chen Zhaoyang, Deputy General Manager of EHS at Amperex Technology Limited

The White Paper is of great significance for advancing the lithium industry's transition towards zero carbon emissions. As global uncertainties are growing, downstream customers concern more about the safety and stability of China's lithium supply chain. Thus, how to develop the capability of providing lithium resources in a more stable and reliable manner has become an important issue. Standing at the forefront of the lithium industry, the White Paper proposes a timeline for the transition towards zero carbon emissions - "resource availability, technology accessibility, and financial feasibility" - to help with the decarbonization of China's lithium supply chain.

Dai Yande, Special Allowance Expert of the State Council and Director of Professional Committee on Energy Economics, China Energy Research Society

To achieve the goal of carbon neutrality, China's energy consumption structure will undergo disruptive changes. Specifically, the consumption of non-fossil energy will account for more than 80%, and the power system will become the main force of decarbonization. In this case, the lithium battery industry will absolutely be an important player. Under a clear and logic framework, the White Paper, from an international perspective, describes the opportunities and challenges facing the lithium industry against the backdrop, and puts forward a goal-oriented action plan for the lithium industry, which is practical, profound and ambitious. This high-quality white paper points out the direction for the lithium industry's transition towards net zero carbon emissions, while the goal of net zero carbon emissions proposed by Tianqi Lithium is of great reference value for other participants in the value chain.

Kang Feiyu, Associate Dean of Tsinghua Shenzhen International Graduate School and Honorary Chairman of World Alliance for Low Carbon Cities

The White Paper shows the importance that Chinese companies attach to carbon emission reduction, especially the efforts put by Tianqi Lithium into this aspect. As lithium contributes a lot to the society in terms of electric vehicles, energy storage, electronic products, among others, the decarbonization of the lithium industry will play an important role in China's energy transition. Currently, China has an advantage in capacity in the global lithium industry, thus, we need to consider how to plan the path to zero carbon while maintaining our market share. The White Paper includes massive data and information, and puts forward the decarbonization path for the whole value chain of lithium industry. It will bring new impetus to the green development of the lithium industry.

Li Baohua, Deputy Dean of Institute of Materials Research, Tsinghua Shenzhen International Graduate School

Regardless of its advantages in global competition, China's new energy industry should avoid developing up front on its own. China's lithium industry has an advantage in capacity, but we also need to think more prudently about the overall situation. It is believed that the comprehensive perspective provided by this White Paper will facilitate the combination of the path to zero carbon with the lithium value chain safety, promote the sustainable development of the lithium industry and advance the safe development of China's lithium industry and new energy industry.

Li Xi, Chief Engineer of Green and Low Carbon Center, Sichuan Energy Conservation Association

Improving energy utilization efficiency, optimizing product manufacturing techniques, strengthening battery recycling and reuse, and promoting technological innovation and upgrading in the lithium industry are important directions for the sustainable development of the lithium industry. The White Paper puts forward some useful ideas and suggestions for the sustainable development of the lithium industry. It can help companies identify their own climate risks and opportunities, and establish an energy management system linked to operations, so as to empower upstream and downstream companies.

Li Yuan, Vice President of Guangzhou Emissions Exchange (CEEX)

In the context of climate change, achieving the net zero goal is a difficult but necessary task, which requires the transformation of the lithium industry through concerted efforts. With focus on the risks and opportunities of the lithium industry under the topic of climate change, the White Paper provides guidelines for each party who wants to take part in and cooperate for addressing the climate change. It also encourages the industry to formulate development and certification standards for the zero-carbon-emission supply chain, improve the mechanisms for international trading market entry and information disclosure, etc. I hope that the "Changing the World with Lithium - Net Zero" initiated by the White Paper can attract more companies and organizations to join the team for realizing decarbonization of the lithium industry.

Lin Xiao, CEO of Botree Cycling and Head of the Chinese delegation to ISO/TC333

As a key component that is indispensable to lithium batteries, lithium makes a greater contribution to the performance of lithium batteries and generates less carbon emissions than other battery metals throughout the whole life cycle. It also serves as a critical and indispensable resource and core material in major carbon reduction scenarios worldwide such as vehicle electrification and renewable energy storage. Thus, the sustainability of the lithium industry worldwide is not only the future of lithium industry, but also matters the development of industries on this planet moving towards the dual carbon goals. This White Paper is connected well with international methods and standards including ISO, IEA and SBTI, and proposes the decarbonization path for the whole value chain of the lithium industry.

Looking forward, it is suggested that Tianqi Lithium and other companies in the lithium value chain should contribute to improving the international standards for net zero, and jointly promote the fair and green development of the global lithium industry.

Wang Hongtao, Associate Professor at College of Carbon Neutrality Future Technology, Sichuan University

The carbon footprints of process technology, energy, and chemical agents account for a high proportion of carbon footprints generated in the manufacturing process of lithium electrodes. To this end, the White Paper carries out an in-depth analysis and explores the possibility of reducing emissions from midstream and upstream processes and raw materials. Meanwhile, it also puts forward proposals for using diversified and low-carbon sources of lithium minerals and the green and flexible processes for extracting lithium. The analysis and proposals are of great significance for the sustainability of production and operation, as well as interdisciplinary technological innovation and cooperation of the lithium industry.

Wu Mengqiang, Professor of School of Materials and Energy, University of Electronic Science and Technology of China

This White Paper innovatively proposes to analyze net zero and energy conservation of the lithium industry through the material flow and the energy flow, and also suggests a "four-pronged" net zero strategy for managing different links of the lithium industry's value chain. It provides some beneficial references for exploring the shift of lithium's role from the "white oil" to the "philosopher's stone" supporting energy transition.

Zhang Yalong, Executive Dean of Shenzhen Institute of Sustainable Development

From an international perspective and the view of an industry leader, this White Paper aligns with SDGs and analyzes challenges for the lithium industry in achieving the goal of sustainable development, with solutions provided correspondingly. It gives a good explanation about the synergy between zero carbon emissions and sustainable development. The decarbonization roadmap set for the lithium industry is perceptive and feasible with a specific vision and directions, which is helpful for the whole industry and companies in considering how to improve their ESG performance.

Zhao Jiasheng, Former President of China Nonferrous Metals Industry Association Lithium Branch

The lithium industry, an integral part of the nonferrous metals industry, is crucial to the development of strategic emerging industries and indispensable in promoting carbon neutrality. As a leading company in the lithium industry, Tianqi Lithium has compiled this White Paper based on the best practices in management innovation and carbon reduction. It gives full play to our leading role in improving the core competitiveness of China's lithium industry, and promoting the continuous improvement and major breakthroughs in industrial energy conservation and low-carbon technologies, so as to realize green upgrading of the industry, and achieve high-quality development and double-carbon goal of China's lithium industry.

Zhao Rui, Professor, Postgraduate and Doctoral Advisor at Southwest Jiaotong University

In order to enable the value chain of the lithium industry to develop in a fair manner, it's necessary to clarify the impact of policy guidance and market orientation on relevant parties in the lithium value chain. Combining with the latest and current trends of the industry, this White Paper clearly describes the stakeholders of the lithium industry in achieving net zero, and identifies the impact of energy substitution, market demand, and security mechanism in the low-carbon transition. The White Paper initiates a forward-looking net zero initiative and a call to action, so as to confront uncertainties in the low-carbon transition together with value chain participants. I hope that the release of this White Paper can attract more government departments, institutions, and companies to jointly promote the realization of the net zero for the global lithium industry.

Glossary

- IEA

The International Energy Agency (IEA) is an independent international organization founded in 1974 and headquartered in Paris, France. It is mainly engaged in the analysis and prediction of global energy markets, providing energy policy advice for governments and the private sector, supporting the R&D and application of energy technologies, and promoting energy market reform and international cooperation.

- Paris Agreement

Paris Agreement is an international treaty on climate change mitigation, adaptation, and finance. It was adopted by 197 United Nations (UN) member states at the United Nations Climate Change Conference in December 2015.

- Electrification

Electrification means using electricity to meet the power, heat and other energy needs and substituting the fossil fuels that would otherwise be consumed through replacing or transforming equipment.

- Photovoltaic, Energy Storage, Direct Current and Flexibility (PEDF)

PEDF refers to the form of building integrating PV power generation, energy storage, direct current and flexible electricity consumption.

- Renewable power

It refers to electricity produced from renewable energy sources by using different technologies.

- Renewable energy

It refers to energy from natural resources, such as sun, wind, tide, geothermal energy, hydro and biomass energy, which are constantly replenished and do not run out.

- Clean energy transition

It refers to the global energy sector's shift from fossil-based energy production and consumption system — including oil, natural gas and coal — to renewable energy sources like wind and solar.

- Scenario

It is a description of how the future unfolds based on the "if-then" statement. It typically includes initial socioeconomic conditions, key drivers of emission, temperature or other variables related to climate change, and future changes.

- "Dual carbon" goals

It is the short for carbon peaking and carbon neutrality goals. China aims to hit carbon emission peak by 2030 and achieve carbon neutrality by 2060, so it is also known as the "3060" Goals.

- Carbon capture and storage

It is the technology of capturing and storing greenhouse gases such as carbon dioxide generated from industrial activities, power generation and others.

- Greenhouse gases

It refers to the gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiant energy at thermal infrared wavelengths. The Kyoto Protocol mandates the regulation of six greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

- GHG abatement

Measures taken by a company to organize, reduce or eliminate its greenhouse gas emissions. In order to be clearly distinguished from "GHG avoidance, avoided emissions", the scope of emission reduction is usually restricted within the value chain.

- GHG avoidance, avoided emissions

Emission reductions that occur outside the life cycle or value chain of a product but result from the use of the product.

- CO_2 removal

A process in which CO_2 is removed from the atmosphere by deliberate human activities and durably stored, including afforestation, use of plant materials in buildings, direct capture and storage of CO_2 from the atmosphere, carbon mineralization by soil, ecological restoration, and biomass-based carbon capture and storage. These activities may be within or outside the value chain.

• Net Zero

As defined in ISO-IWA 42:2022 Net zero Guidelines, net zero refers to a condition in which human-caused residual GHG emissions are balanced by human-led removals over a specified period and within specified boundaries. In this report, net zero includes major greenhouse gases including CO_2.

• Carbon neutrality

As defined in IPCC-AR6, carbon neutrality refers to a condition where anthropogenic CO_2 emissions are balanced by anthropogenic CO_2 removals within the control scope of countries, regions, organizations or products, services and activities. On a global scale, net zero is completely equivalent to the concept of carbon neutrality. However, on a smaller scale, carbon neutrality allows companies to use carbon emission reductions or removals beyond their control scope to compensate for carbon emissions that cannot be eliminated despite efforts in emission reduction within their control scope, so as to achieve a balance between net emissions and net absorption at the level of company, product and activity. In this report, carbon neutrality includes CO_2 and other major greenhouse gases.

• Carbon footprint

Greenhouse gas emissions generated by business activities within the value chain. In terms of products, carbon footprint refers to the carbon footprint per unit product within the value chain. "Reducing carbon footprint" includes initiatives by companies to reduce emissions or increase CO_2 removals within the value chain.

• Carbon handprint

The amount of greenhouse gases equivalent to emissions avoided or CO_2 removals increased beyond the value chain from business activities, such as fixed asset investment, technology diffusion and product promotion, also known as Beyond Value Chain Mitigation (BVCM). "Increasing carbon handprint" refers to increasing above business activities that produce carbon fingerprints and their impact in order to mitigate climate change.

• Carbon "lock-in"

An economic system (including infrastructure, technology, investment mechanism and behavior mode) locked in the traditional high-carbon economic development model or institutional environment due to huge sunk cost risk or path dependence, and cannot achieve low-carbon transition. In this report, it refers to a passive situation in which specific industries concentrate on expanding production capacity and investing a large amount of industrial capital in technologies with high carbon emission levels or not yet mature for a period of time, resulting in failure to balance carbon reduction and asset risks during the future operation.

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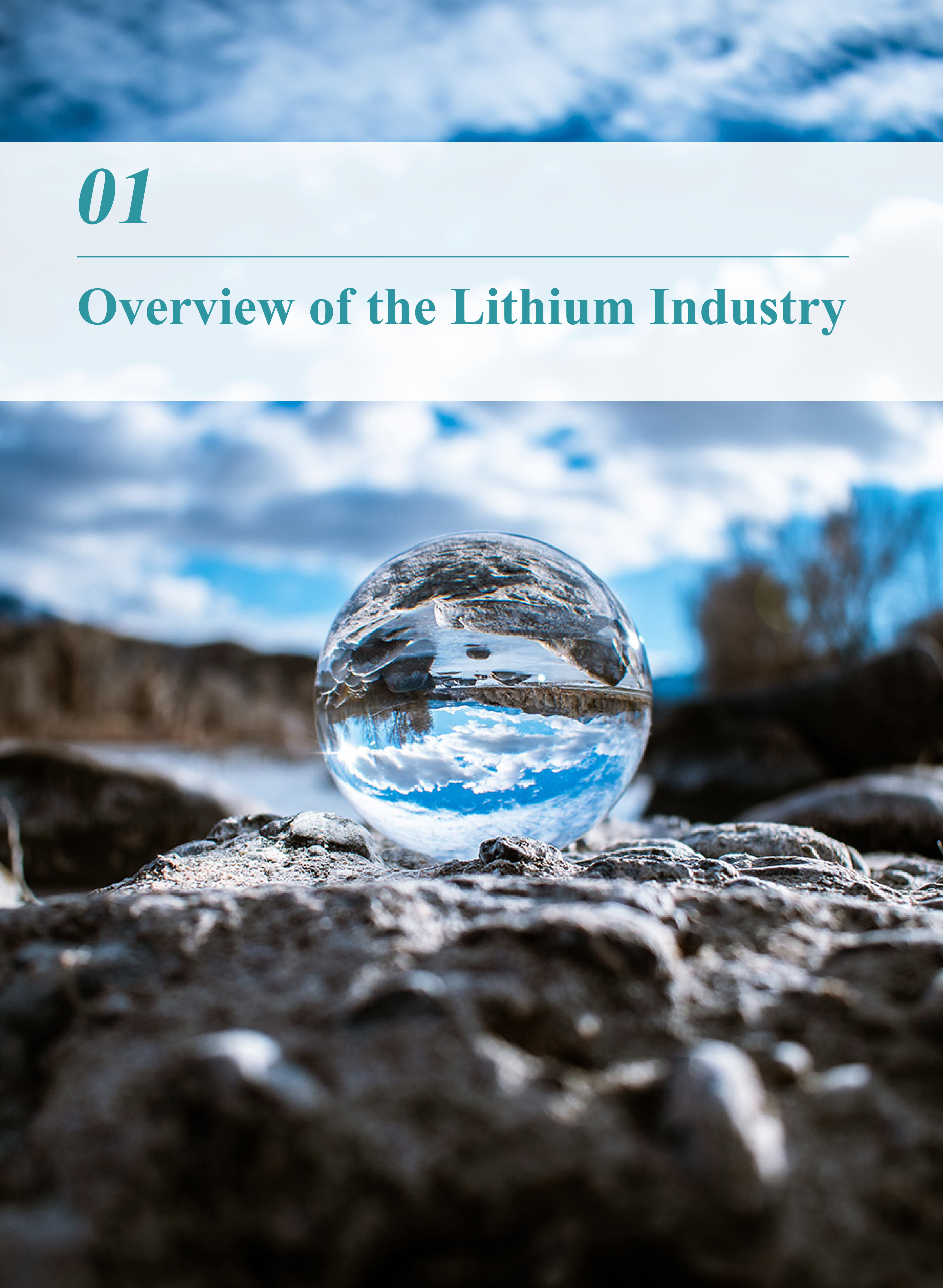


01

Overview of the Lithium Industry

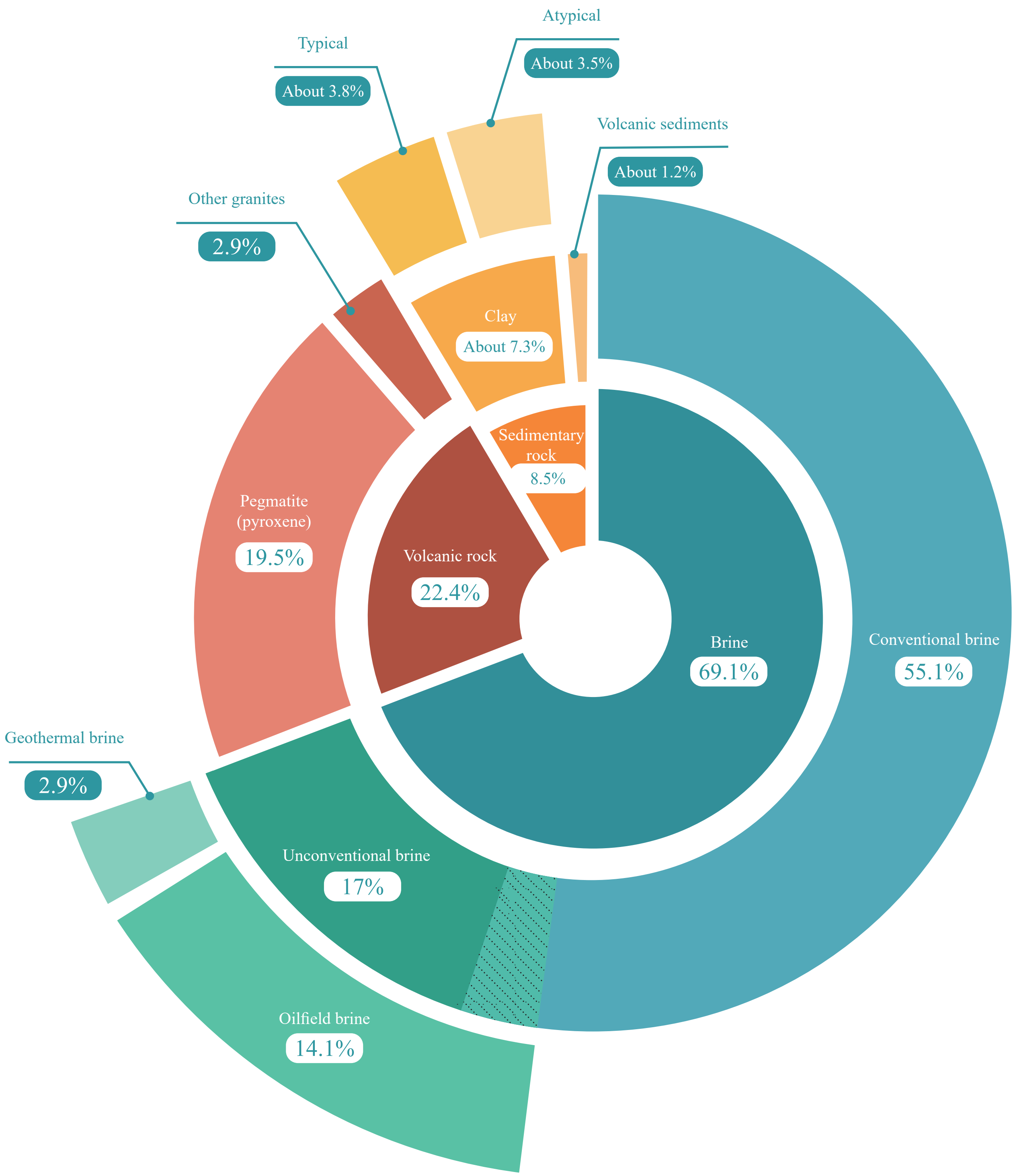
1.1 Origin and development of lithium »

- From "industrial monosodium glutamate" to "white oil"

'Lithium' comes from the Greek word 'lithos', which means 'stone'. The element lithium was first discovered in 1817 by Swedish chemist Johan August Arfwedson when analyzing the mineral petalite. He named this new element as "lithium", showing its presence in stone.

Lithium is the lightest and least dense metal on the periodic table. Lithium metal is highly reactive and flammable, so it does not exist in its pure state in nature. It is usually found in rocks or brines in the form of mineral compounds. Brine deposits account for about two-thirds of global lithium reserves, which are located in the "Lithium Triangle" where Chile, Argentina, and Bolivia meet (Sterba et al., 2019).

Lithium raw materials can be processed into such materials as lithium carbonate, lithium hydroxide, lithium chloride and lithium metal, which were mainly used in industrial fields like ceramics, glass, casting, metallurgy and lubricants in the early stage (Sykes et al., 2019) to enhance and adjust the performance of various materials and chemicals. So, it is also known as "industrial monosodium glutamate". However, with the increased use of lithium in batteries in recent years, lithium-ion batteries are more widely applied in electronics, electric vehicles, energy storage and others (Reddy et al., 2020). Thus, lithium is increasingly hyped as the "white oil" and "energy metal" due to its importance and value in the modern technology and the energy industries.



Note: "Unconventional" brine is a part of the brine deposit in strict sense. Due to the absence of feasible mining technology, it is listed separately in this figure. The reserves of conventional brine and unconventional brine are partly overlapped.

Figure 1. Storage Forms of Global Lithium Resources

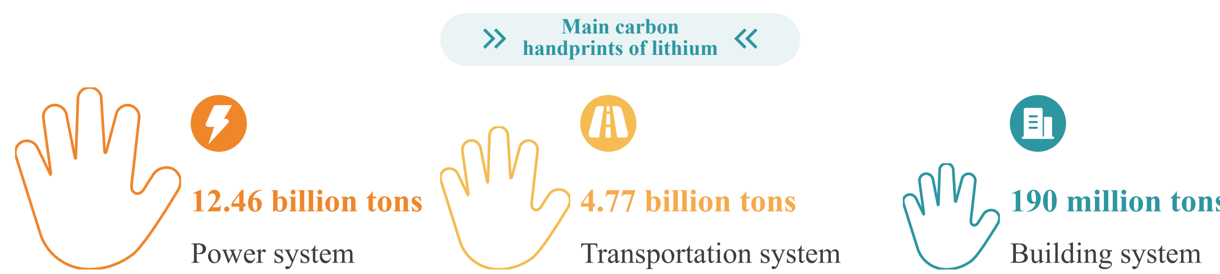
1.2 Role of lithium in achieving net zero

- From the "white oil" to the "philosopher's stone" supporting energy transition

In December 2015, the Paris Agreement was adopted by 197 UN member states at the UN Climate Change Conference (COP21) in Paris, aiming at significantly reducing global greenhouse gas emissions, holding the increase in the global average temperature of the present century to well below 2°C above pre-industrial levels, and pursuing efforts to limit the temperature increase even further to 1.5°C. To achieve this goal, actions are needed to reduce global greenhouse gas emissions dramatically from today's levels to net zero by mid-century.

Considering the fact that the energy accounts for about three-quarters of greenhouse gas emissions today (Ritchie et al., 2020), driving clean energy transition will be the key to achieving net zero proposed by the Paris Agreement. Power batteries and energy storage batteries will be crucial in this process. Given this, the lithium industry is entrusted an important mission for its development in this century - promoting the shift of lithium's role from the "white oil" to the "philosopher's stone" supporting clean energy transition as a key industry backing the goal of net zero.

"Philosopher's stone" is a mysterious element that can "turn stone into gold" in European alchemy legends. Referring lithium as the "philosopher's stone" in clean energy transition implies that lithium, as an energy storage material, serves as the "energy pack" and "regulating pool" in energy transformation. Lithium helps the transportation industry to break its dependence on petroleum fuel, increase the regulation capacity of the new power system with a gradually increasing proportion of renewable energy, reduce the randomness, intermittence and fluctuation of renewable energy. gradually eliminates its carbon footprint, and increases the carbon handprint by facilitating green electricity consumption and application.



1.2.1 Support the net zero transformation of power system

The building of new power system dominated by new energy is an important path to reach the double-carbon goal. However, the generation system powered by new energy such as solar and wind is intermittent, fluctuant and highly random. Thus, the energy storage system should be built at the same time in the process of renewable power replacing thermal power as the main source of power supply. It's quite important for the transformation of power system in a smooth manner. An energy storage system deployed reasonably is capable of smoothening the output of renewable energy, supporting the power grid, regulating the peak load and frequency, and improving the utilization of distributed renewable energy on the user side.

At present, pumped storage is the most widely used grid-scale energy storage technology worldwide, accounting for more than 90% of the total. However, the rapidly scaling up battery storage is the main source of new storage capacity (IEA, 2022d). In IEA's Net Zero Emissions by 2050 Scenario (NZE), the grid-scale battery storage capacity will embrace an increase by 44x to 680GW from 2021 to 2030, with an increase of about 140GW in 2030 alone (IEA, 2022d).

The lithium-ion battery presents the greatest potential for battery energy storage due to its excellent performance in terms of power, energy density, response speed and battery configuration. While lithium iron phosphate batteries, a type of lithium-ion battery, are preferred for grid-scale storage (IEA, 2022d). In 2021, the world saw an investment in grid-scale battery storage up to USD 7 billion, with lithium-ion batteries accounting for more than 90% of the total (IEA, 2022d).

The global energy system, by 2050, is expected to see a reduction of carbon emissions by 12.46* billion tons compared with those in 2020 with the help of the lithium industry, which secures the stable operation of new power system dominated by new energy and boosts the development of PV power and wind power and the electrification of energy utilization in the power industry.

*Calculated based on the IEA NZE Scenario (IEA, 2021b).

1.2.2 Support the construction of electrified transportation system

The wave of electrification represented by new energy vehicles (NEVs) is the most important pathway to decarbonizing transportation sector, especially road transport. In order to accelerate the decarbonization of transportation sector, several countries and regions have issued plans for banning petrol and diesel cars.

Driven by the goal of net zero, electric vehicles have ascended among the most dynamic markets in the clean energy sector in the past decade. Sales of light-duty electric vehicles in 2022 recorded 13.8 million. Back in 2012, only 120,000 electric vehicles were sold worldwide (IEA, 2023). According to the IEA NZE Scenario, there will be 56 million light-duty electric vehicles sold worldwide by 2030, capturing more than 64% of the market share. Nearly all light-duty vehicles sold will be electric by 2050 (IEA, 2021b).

As the most ideal electrode material for power batteries, lithium electrode has a higher energy density than other electrode materials in theory. It can provide greater discharge capacity and longer endurance at the same material volume or weight. In 2022, the market of power batteries for light-duty vehicles was almost completely shared by lithium nickel manganese cobalt oxide (NMC) batteries (60%), lithium iron phosphate (LFP) batteries (30%) and lithium nickel cobalt aluminum oxide (NCA) batteries (8%) (IEA, 2023).

By 2050, in the transportation sector, the lithium industry is expected to help reduce 4.77 billion tons of carbon emissions from passenger cars, light commercial vehicles, and heavy-duty trucks worldwide compared with those in 2020*.

*Calculated based on the IEA NZE Scenario (IEA, 2021b).

Note: Light-duty vehicles = passenger cars and vans; Heavy trucks = Medium and heavy-duty freight trucks.

1.2.3 Empower building energy system towards net zero

According to the analysis by IEA, all new buildings should be zero-carbon-ready by 2030 and more than 85% buildings should be net-zero-carbon-ready by 2050 in a bid to advance the goals of the Paris Agreement (IEA, 2022a). Zero-carbon-ready buildings are highly energy-efficient and environmentally sustainable buildings with less carbon emissions. Their operation relies on the integrated solution for new power system, while supported by the energy storage units of the building.

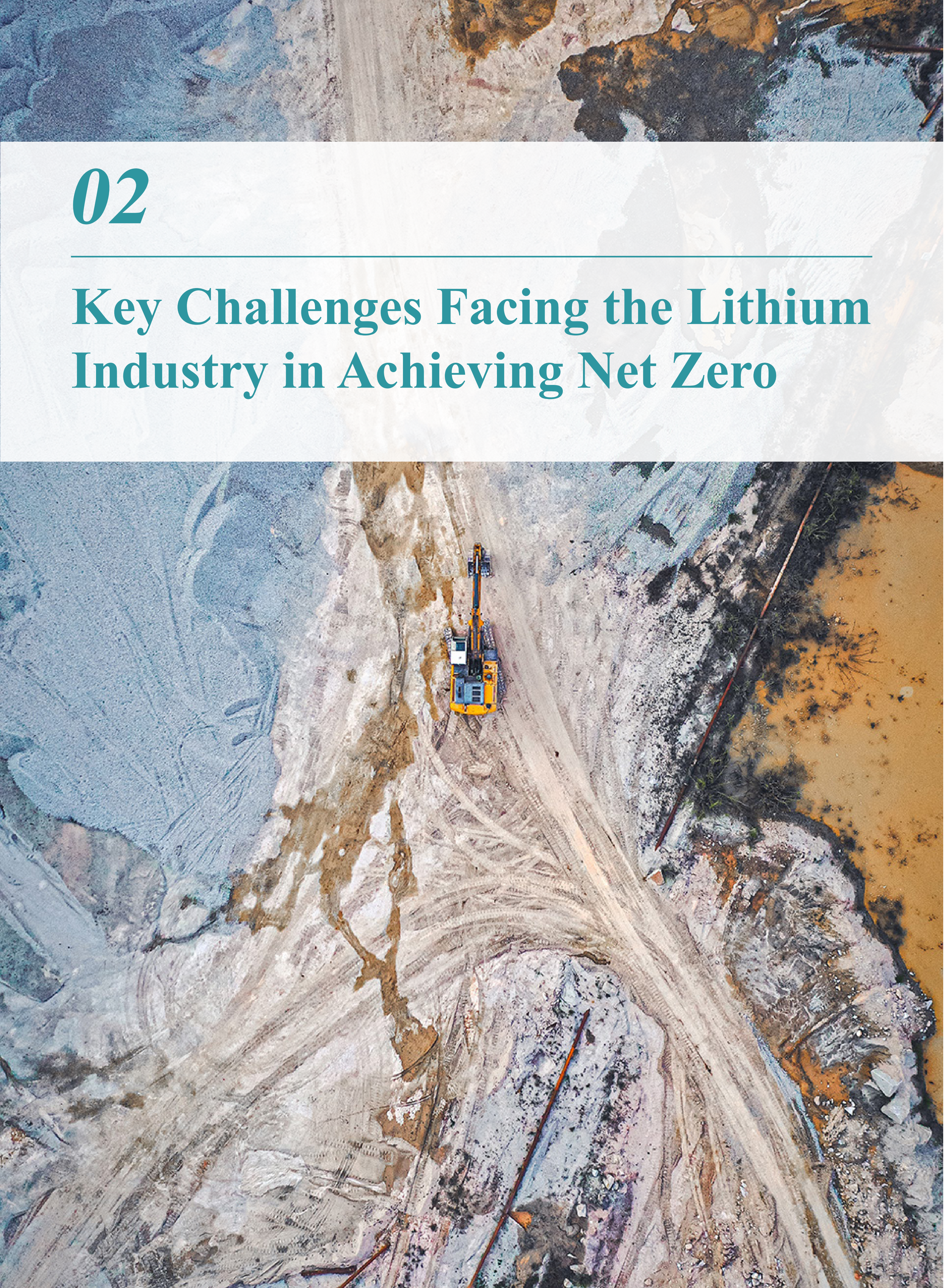
Specifically, the supporting energy storage system of the building can ensure that the building is "fully connected to the grid for power generation" and "makes full use of renewable power". In the PEDF technology system, the energy storage units of the building serve as a "charger" in the DC microgrid. They can buffer and store the solar power in the daytime to power the building in the nighttime. In this way, the high- proportion renewable power system can be regulated effectively, and the building's power generation and consumption quality can be improved.

4 billion kW of wind and solar power could be regulated, stored and consumed if this power distribution mode is adopted by 35 billion square meters of residential buildings and 10 billion square meters of office buildings in cities and towns in China, and 300 million electric vehicles are connected in the future, according to the analysis. This is equivalent to consuming 60% of the 7 billion kW wind and solar power as planned in China (Project Team of Research on Strategic Development Path of China's PEDF Building, 2022).

The energy storage demands of buildings are expected to become an important application scenario for lithium-ion batteries after 2030. The "PV power generation-storage-charging integration" facility based on lithium batteries is not only an important component of the PEDF technology system, but also a vital action to decarbonize the transportation sector.

By 2050, the construction sector is expected to see a reduction of power-related carbon emissions by 190* million tons compared with those in 2020 with the help of the lithium industry, which provides energy storage facilities for buildings powered by renewable energy.

*Calculated based on the IEA NZE Scenario (IEA, 2021b).



02

Key Challenges Facing the Lithium Industry in Achieving Net Zero

2.1 The progress of energy transition slows down due to supply-demand imbalance »

Lithium is one of the key metals influencing global clean energy transition and exhibits the highest growth in demand. According to the IEA NZE Scenario, global lithium demand is projected to rise from 74,000 tons of LCE in 2020 to approximately 3.65 million tons of LCE by 2030 (IEA, 2022b).

The surge in demand for electric vehicles is the primary driver behind the growth in lithium demand. In the IEA NZE Scenario, global electric vehicle sales are expected to reach 56 million units by 2030, resulting in a demand of approximately 2.62 million tons of LCE solely from electric vehicles (IEA, 2021b).

The supply of lithium is causing concerns in the industry. In 2021, the growth rate of global electric vehicle sales exceeded expectations. Despite a 32% year-on-year increase in global lithium production, the growth rate of lithium demand has outpaced supply (McKinsey, 2022). Although lithium-producing countries are expanding their capacities to meet the growing demand, the balance between lithium supply and demand could be disrupted after 2025 (Figure 2). Unreasonable price volatility or unreliable supply could slow down the energy transition, and threaten the sales and application of electric vehicles, leading to a market detachment.

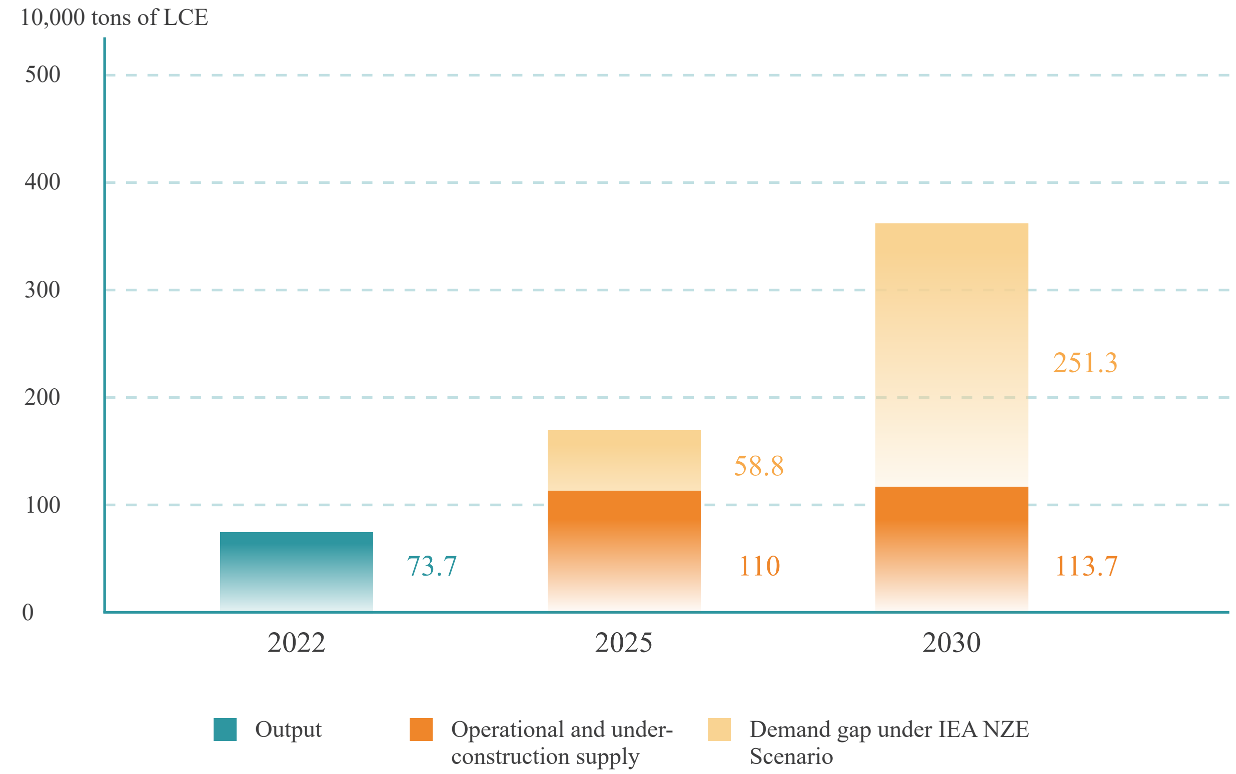


Figure 2. Gap between Promised Lithium Output and Demand (IEA, 2021b; IEA, 2021c)

2.2 Noticeable increase in carbon emission scale of the industry

Lithium resources in their natural form have low lithium content, and the extraction process consumes significant amounts of energy and chemical reagents. As a result, the carbon emissions per unit of lithium production are much higher compared with mature industrial products such as steel and cement. If current technologies meet the rapidly growing demand, the annual carbon emissions from the lithium industry could reach 30 million tons by 2030 (IRENA, 2022).

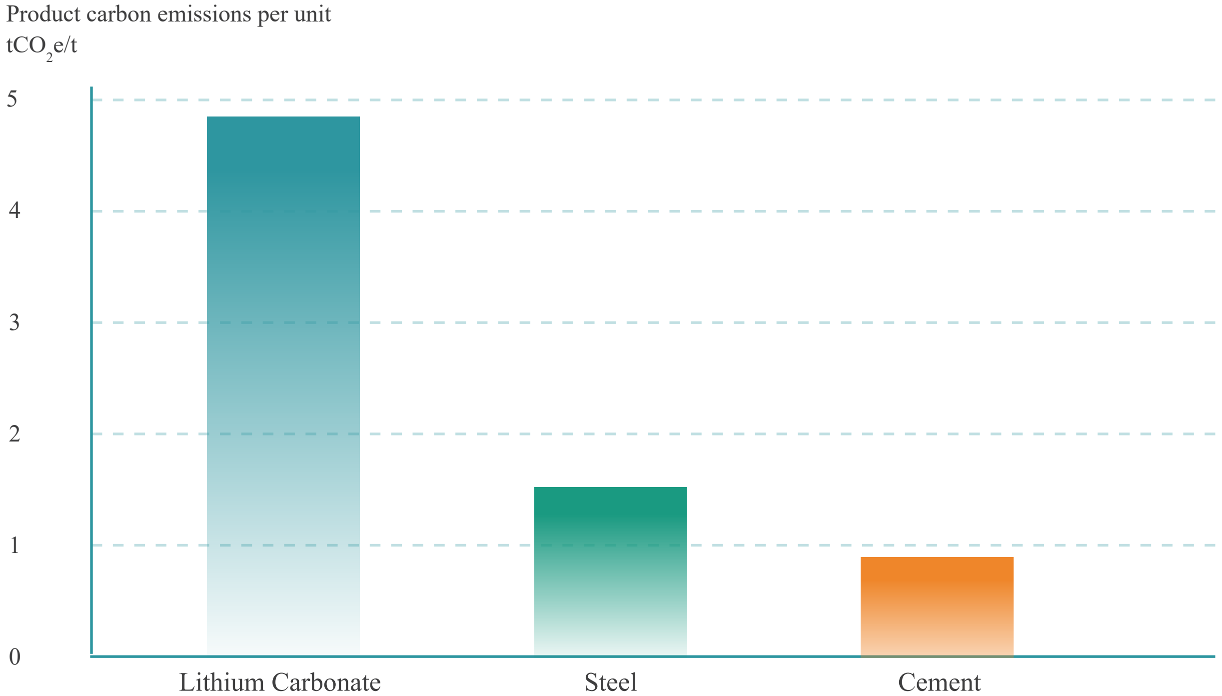


Figure 3. Average Greenhouse Gas Emission Intensities of Lithium Carbonate, Steel, and Cement Production (Fayomi et al., 2019; IEA, 2021c)

Energy-intensive lithium extraction technologies have an advantage but may pose a "carbon lock-in" risk. With the surging demand for lithium, the currently implemented and announced plans for new lithium mining mainly focus on hard rock projects. Hard rock mining and refining technologies are more mature compared with salt lake lithium extraction, with shorter production cycles and raw material qualities that better meet the processing requirements for battery-grade lithium carbonate and lithium hydroxide. However, the carbon intensity of hard rock lithium extraction is significantly higher than that of salt lake lithium extraction at present.

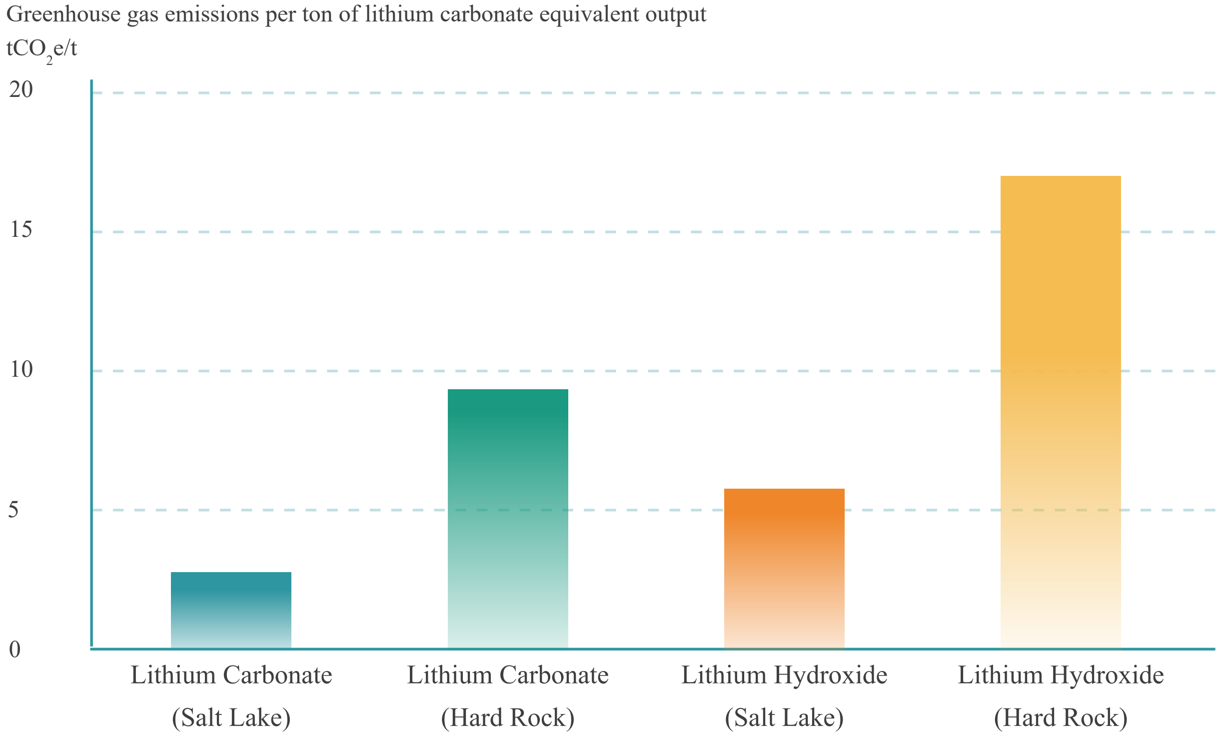


Figure 4. Lithium Greenhouse Gas Emission Intensities Classified by Resource Type and Processing Route (IEA, 2021c)

Carbon "lock-in": An economic system (including infrastructure, technology, investment mechanism and behavior mode) locked in the traditional high-carbon economic development model or institutional environment due to huge sunk cost risk or path dependence, and cannot achieve low-carbon transition. In this report, it refers to a passive situation in which specific industries concentrate on expanding production capacity and investing a large amount of industrial capital in technologies with high carbon emission levels or not yet mature for a period of time, resulting in failure to balance carbon reduction and asset risks during the future operation.

Market and regulatory constraints on the "carbon footprint" of lithium batteries are gradually emerging. As NEV manufacturers set emission targets, governments incorporate net zero goals into legal requirements, and regulatory agencies issue battery-related regulations, implicit carbon emissions from power battery production and lithium and other raw materials are receiving increasing attention.

New energy vehicle manufacturers

Many automakers have set net zero targets for the value chain, such as BMW Group (2021) and Volkswagen (2021). The emissions from lithium electrode materials are an important part of the carbon footprint in the process of manufacturing electric vehicles. The achievement of net zero in the automotive industry value chain inevitably requires actions from the lithium industry.

Laws and regulations of major markets

Taking the European Union (EU) as an example, its climate law sets clear targets for achieving carbon neutrality in the European economy by 2050. At the same time, the battery regulation adopted by the European Parliament in June 2023 imposes stricter requirements on the sustainability of power batteries, including product carbon footprints and recyclable components (see Table 1). This will also provide reference for regulatory measures in other countries.

Table 1. Updated EU Battery Regulations on Product Carbon Footprints and Recyclable Components (European Parliament, 2023)

Carbon footprint	• Starting from January 1, 2025, power batteries must be accompanied by a carbon footprint statement. • Starting from July 1, 2026, power batteries must be accompanied by a carbon footprint rating label. • Starting from January 1, 2028, power batteries must meet the requirements for maximum carbon footprint threshold (yet to be announced).
Recyclable components	• Starting from July 1, 2028, power batteries must be accompanied by documentation indicating the content of recyclable components. • Starting from July 1, 2031, power batteries must include a minimum of 6% recycled lithium. • Starting from July 1, 2036, power batteries must include a minimum of 12% recycled lithium.

2.3 Possible asset stranding under rapid expansion

Climate change is one of the main risks leading to asset stranding in resource-based industries. Currently, the lithium industry is not fully prepared for net zero, which, therefore, necessitates a balance between increasing supply capacity and reducing carbon emissions. To meet the demand for clean energy transition while ensuring sustainability, it is important to consider diverse mineral resources and adopt flexible layout of lithium extraction processes, so as to avoid the carbon technology lock-in caused by rapid expansion of production through intensive utilization of existing processes within a short period of time.

The development of salt lake lithium extraction technologies from salt lake brines will impact the industry's development decisions. Currently, salt lake lithium extraction faces challenges such as long production cycles and unstable quality, placing it at a disadvantage in the competition with hard rock projects at scale. However, salt lake brine resources have large reserves and low carbon emissions in the mining process. Therefore, once the emerging salt lake lithium extraction technologies become mature, they may have advantages in terms of scale, cost, and carbon emissions, or pose a challenge to hard rock projects and associated refining facilities that have not yet recouped their investments.

The development of low-carbon refining technologies will affect the value of midstream assets. The energy structure, energy efficiency, and carbon emissions of the hard rock lithium extraction process based on sulfuric acid roasting still have significant room for improvement. The rapid development of clean and efficient thermal technologies may significantly impact the valuation of refining capacity that requires large-scale investments.

03

Key Strategies of the Lithium Industry for Achieving Net Zero

As for clean energy transition, lithium is one of the most critical minerals on Earth. To transform lithium from "white oil" to the "philosopher's stone" supporting energy transition, the lithium industry needs to take effective actions to address the challenges it faces. In this section, an analysis is conducted on the key strategies for addressing challenges in different links of the lithium industry's value chain. Four measures are proposed to support the lithium industry's transition towards net zero.

Upstream lithium sources	Midstream lithium extraction processes	Downstream resources	End-of-life battery materials
Diversification	**Greening**	**Efficient utilization**	**Regeneration**

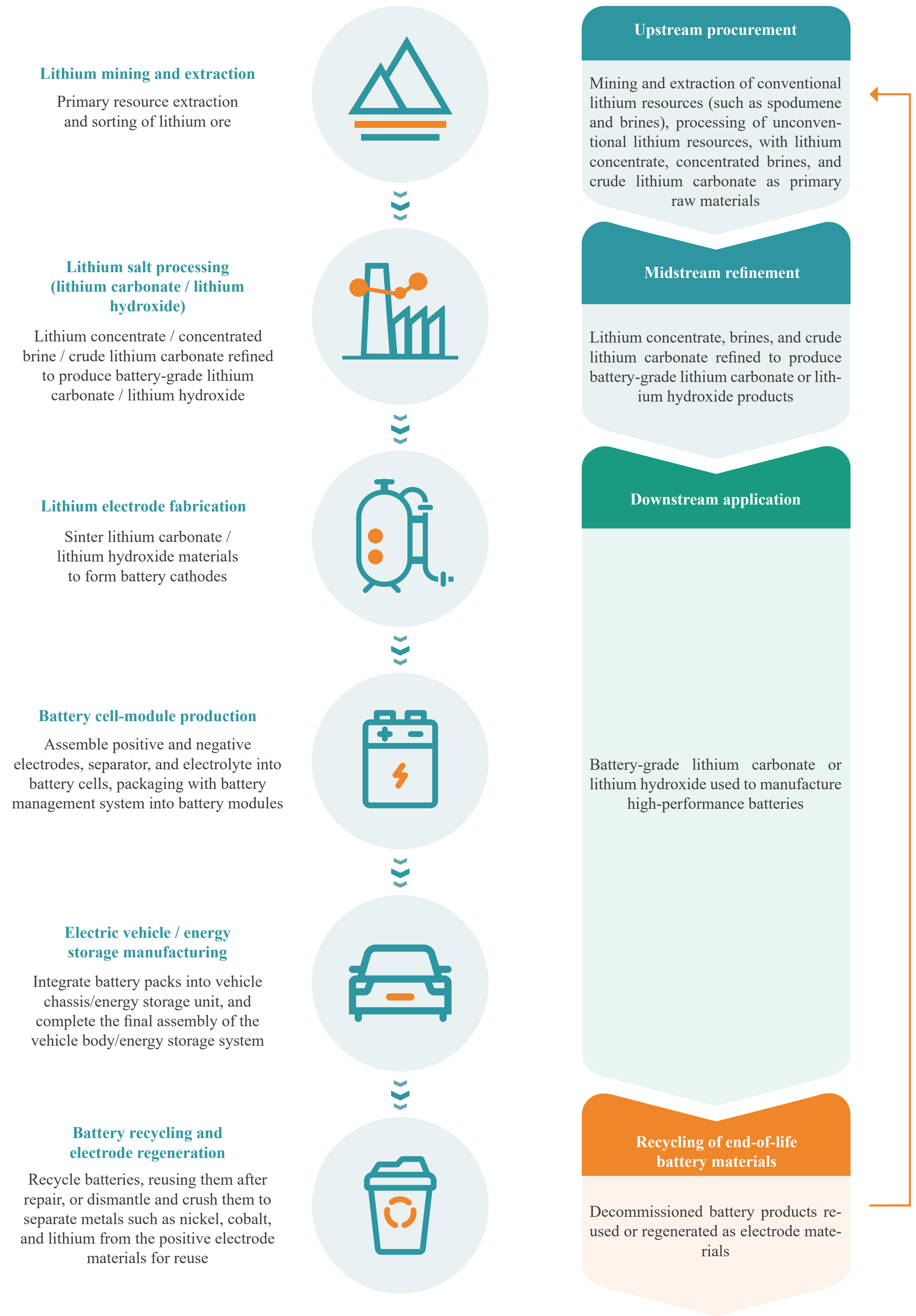


Figure 5. Lithium Industry Value Chain Diagram

3.1 Diversification of upstream lithium sources

3.1.1 Build diversified lithium resources system

Currently, the lithium resource extraction that has been implemented and planned to be implemented is mainly from hard rock projects, mainly due to the shorter production cycle and faster capacity ramp-up compared with salt lake lithium extraction (IRENA, 2022). However, brine resources account for about two-thirds of the global lithium reserves (Sterba et al., 2019). In order to meet the surging demand for lithium, the lithium industry must strive to increase the market share of salt lake lithium extraction to establish a diversified lithium resource system.

The development of salt lake lithium extraction is hindered by its significant process variations and low maturity. Different regions have different compositions of brine, resulting in significant variations in resource endowment. In South America, brines are dominated by carbonates with low magnesium content, providing high-quality lithium resources that can be obtained through evaporation and precipitation as lithium brine or extracted as crude lithium carbonate for primary raw materials (Xu et al., 2021). In China, except for the Tibetan region, brines are dominated by sulfates with high magnesium content, making lithium extraction more challenging. Many lithium extraction processes are still in the exploratory stage, with limited scale or high cost of projects already in operation, or quality difficult to meet the requirements of battery-grade products (Xu et al., 2021).

Other lithium resources, including unconventional minerals (such as mica, and clay), unconventional brines, and secondary lithium resources (from lithium-containing slag of mining and processing process (referred to as "lithium-containing slag"), lithium battery recycling, etc.), have also gained increasing attention in the industry. Many new lithium extraction technologies have demonstrated their feasibility through pilot projects. However, due to factors such as low process maturity, low product quality, low production capacity, and high costs, these technologies have not been put into large-scale applications yet.

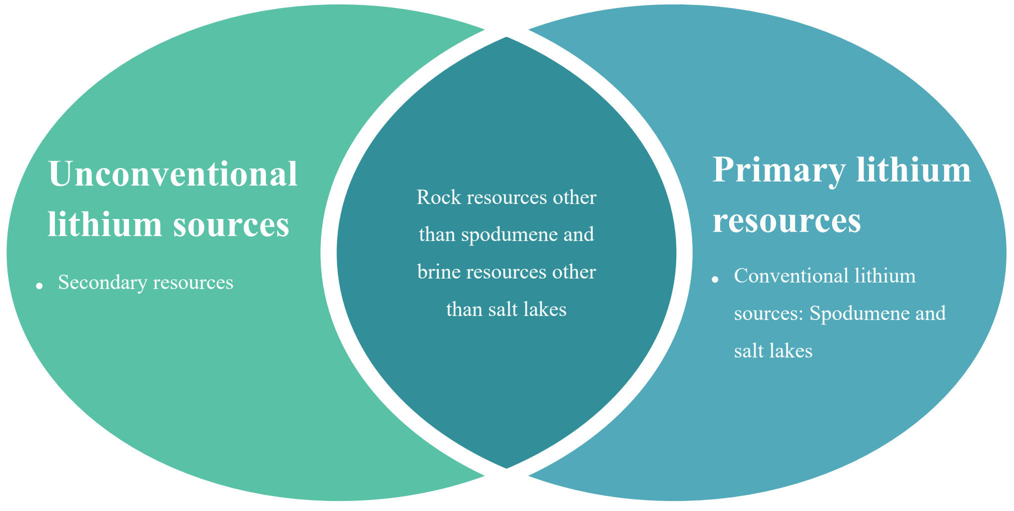


Figure 6. Classification of Lithium Sources

Continuous innovation in lithium extraction technologies is key to building a diversified lithium resource system. Companies with expertise in ore or salt lake lithium extraction processes should focus on optimizing process combinations to reduce mining and processing costs and minimize carbon emissions. Additionally, other unconventional lithium resources can serve as important supplements to meet the lithium demand in achieving net zero. Technological breakthroughs will unleash the production potential of salt lake lithium extraction and unconventional lithium minerals, driving the evolution of the industry landscape. Factors such as efficiency, cost, and energy consumption will significantly impact the outcomes. Table 2 summarizes the development technologies, advantages, and disadvantages of common conventional primary resources, unconventional primary resources, and secondary lithium resources.

Table 2. Technologies for the Development of Diverse Lithium Resources
(Gao et al., 2023; He Fei et al., 2022; Xu Lu et al., 2021; Zhang Xiufeng et al., 2020)

Lithium Resource Type		Process	Product	Process Route	Advantages	Disadvantages
Conventional primary resources	Spodumene beneficiation	Flotation method	Lithium concentrate	Mainly including two methods: direct flotation and reverse flotation. In direct flotation, finely ground ore is added to a strong alkaline medium, stirred, and subjected to multiple scrubbing and desliming steps. Anionic collectors are added to directly select lithium concentrate. In reverse flotation, lithium depressants are added to an alkaline medium, and cationic collectors are used to selectively float other minerals, leaving behind lithium concentrate.	Direct flotation and reverse flotation methods have been extensively researched, demonstrating mature technologies and wide applicability. They are well-suited for the removal of sulfides, quartz, mica, and feldspar, etc.	The gravity separation method has high investment costs.
		Thermal decomposition method	Lithium concentrate	By employing measures such as heating and cooling, we can selectively destroy certain gangue minerals and spodumene minerals, which have different properties, to separate spodumene.	It offers a high recovery rate.	The roasting process requires high temperatures, resulting in significant energy consumption. It also does not allow for comprehensive recovery of other valuable metal components.
	Brine crude extraction	Precipitation	Lithium carbonate	After evaporative concentration of brine, lime is added to remove magnesium ions, and then sodium carbonate is added to precipitate lithium carbonate.	This method has been widely applied, and the process is mature with high reliability.	It is only suitable for salt lakes production cycle.
		Roasting-leaching method	Lithium carbonate	Lithium carbonate is obtained through the roasting and leaching of sulfate-type brine, followed by secondary magnesium removal using soda ash and lime milk, and then drying.	This method has a high lithium recovery rate and simple process, and is also suitable for lithium recovery from tailings.	This method requires a large amount of water and the equipment is prone to corrosion.

Lithium Resource Type		Process	Product	Process Route	Advantages	Disadvantages
Uncon-ven-tional primary resources	Lithium extraction from brine	Precipitation method	Concentrated brine / lithium carbonate	Extraction of subsurface brine followed by concentration and precipitation through solar evaporation, similar to salt lake lithium extraction.	It can be coupled with oil well extraction and geothermal extraction, with high lithium concentration.	High environmental risks and low production efficiency.
	Lithium extraction from lithium mica	Roasting method with complex salts (sulfate roasting method)	Lithium carbonate	Mix roasted lithium ore with an excess of potassium sulfate (or calcium sulfate, or a mixture of both) to convert the lithium in the ore into lithium sulfate. Then, leach the lithium sulfate with dilute sulfuric acid to obtain a purified lithium solution, which is subsequently precipitated to obtain lithium carbonate.	This method has a relatively high leaching rate, simple process, and minimal equipment corrosion.	It requires a large material flow rate, high reaction temperature, and relatively high energy consumption.
	Lithium extraction from clay	Roasting/acid leaching	Lithium carbonate	Thacker Pass Project of Lithium Americas: After sulfuric acid leaching of lithium from clay, lithium carbonate is obtained through evaporation and crystallization, followed by precipitation using sodium carbonate. Clayton Valley Project of Cypress: Lithium carbonate is obtained by leaching lithium solution with sulfuric acid, followed by purification and concentration of the solution.	These projects combine the advantages of speed of ore lithium extraction and low costs of salt lake lithium extraction, resulting in high lithium recovery rates and the potential for co-production of other salt products.	This method produces lower grade lithium with lower lithium recovery rates, and is currently in the research stage.
		Cation exchange leaching	Lithium carbonate	Tesla's 2021 Patent: Lithium extraction process using clay aqueous solution impregnation. The process involves grinding clay with saturated sodium chloride to control the leaching of lithium ions from the clay while minimizing the leaching of other impurities. Sonara Project: The project involves mixing clay with calcium carbonate, sodium sulfate, and potassium sulfate, followed by grinding and roasting, and then leaching lithium carbonate with water after milling.	It avoids high-tempera-ture roasting and the use of sulfuric acid leaching, which has low energy consump-tion and is environmen-tally friendly.	It may be challenging to control the process and there may be a higher presence of impurities.

Lithium Resource Type		Process	Product	Process Route
Secondary resources	Byproduct industrial brine	Precipitation method	Lithium carbonate	Similar to the process of lithium extraction from underground brine deposits, for example, oilfield brine or brine produced as a byproduct of seawater desalination.
	Byproduct industrial lithium slag	Roasting/acid leaching	Lithium carbonate	Similar to the process of lithium extraction from clay. It is common to produce lithium carbonate as a byproduct during the extraction of rare earth elements or fluorides.
	Recyclables of positive electrode materials	Roasting/acid leaching	Lithium carbonate	Some domestic companies have already achieved the preparation of battery-grade lithium carbonate using waste materials from lithium iron phosphate batteries as raw materials, through processes such as pyrometallurgical roasting, leaching with hydrochloric acid, transformation and impurity removal, alkali treatment and impurity removal, and lithium precipitation with soda ash.

3.1.2 Create green mining and beneficiation system of lithium minerals

3.1.2.1 Efficiency of energy resources in mining areas

Improving the energy efficiency of ore lithium extraction processes

Processes such as spodumene beneficiation and rough brine concentration require high-power equipment such as air compressors, fans, water pumps, and rotary facilities. The energy consumption of ore crushing and grinding operations typically accounts for 40% to 80% of the mineral processing process (Zhang Chengqiang, 2003). Measures such as upgrading grinding equipment, adding grinding aids, promoting the use of ore beneficiation automation, optimizing and streamlining beneficiation processes can reduce the energy consumption of crushing and grinding operations (Zhang Chengqiang, 2003).

Improving the evaporation efficiency of salt lake lithium extraction

Traditional brine concentration processes rely on solar energy in evaporation ponds, which, however, have low production efficiency and long cycles. By installing innovative solar thermal flat-plate devices above the evaporation ponds, sunlight can be converted into mid-infrared radiation that is strongly absorbed by water, resulting in an increase of over 100% in evaporation efficiency, so as to reduce evaporation time and production cycles (Menon et al., 2020).

Exploring comprehensive utilization of lithium-containing slag

Taking spodumene as an example, the slag generated after sorting can be used as a substitute for clay as raw materials for shaft kiln calcination, cement blending, ceramic glazed tile production, and as a partial substitute for cement in concrete mixtures, etc. (He et al., 2018; Lemougna et al., 2019; Tan et al., 2018). Upstream companies can further explore the regeneration and utilization of lithium-containing slag to achieve efficient utilization of lithium resources. By utilizing the active components of lithium-containing slag to partially replace cement clinker and producing concrete prefabricated building materials with CO_2, it not only achieves comprehensive utilization of lithium-containing slag but also provides a new solution for chemical sequestration of CO_2.

3.1.2.2 Green power in mining areas

Maximizing the use of renewable energy in mining areas to achieve 100% green power for lithium extraction is crucial for achieving net zero extraction. Most lithium-rich mining regions in the world, whether in mining areas or salt lakes, have good lighting conditions and open spaces. Mining in such areas often require the simultaneous construction of microgrids during mining area development to meet the power demands of operations.

Taking China's Tibet and Qinghai for example, the local solar resources belong to Class I or Class II areas, providing favorable conditions for the construction of photovoltaic power stations. By deploying photovoltaic and energy storage units, it is possible to use solar power in mining areas to meet the electricity needs of mining facilities. For spodumene mining areas, construction of photovoltaic power stations and ecological restoration projects can be considered. If the mining area microgrid is connected to the main power grid, surplus solar power generated in the mining area can be fed back to the grid, earning power generation revenue for the mining area. For mining areas that are not suitable for power station construction, 100% green power can also be achieved through the purchase of renewable energy.

3.1.2.3 Low-carbon transportation modes in mining areas

The process of spodumene mining requires continuous operation of mining trucks, which typically consume large amounts of diesel and generate greenhouse gas emissions. The substitution of hydrogen fuel cell mining trucks for conventional mining vehicles and the utilization of on-site green hydrogen production through microgrids and/or photovoltaic facilities in the mining areas can achieve on-site net zero while also being economically viable. Currently, there are application cases of hydrogen fuel cell mining trucks with a capacity of up to 100 tons. For example, Anglo American Plc has launched a prototype hydrogen-electric hybrid mining truck in South Africa, which integrates renewable power generation and hydrogen production and refueling. Multiple fuel cell modules can collectively provide up to 800 kW of power (Anglo American, 2022).

Focusing on Tianqi Lithium

Diversified layout of lithium resources

Currently, spodumene from Australia is the main source of raw materials for Tianqi Lithium (hereinafter referred to as "the Company", "our Company", "we"). The mature sulfate process allows us to consistently provide reliable products to the market. The Company also recognizes that salt lakes, as the largest global lithium reserve, will play a more important role with the rapid growth in lithium demand. Salt lake lithium extraction also represents a potential source of lithium mining for net zero.

In order to ensure the availability of salt lake resources, we actively expand our presence in salt lake resources through acquisitions and investments both domestically and internationally. In August 2014, the Company acquired a 20% stake in Zhabuye Lithium High-Tech Co., Ltd. in Shigatse City, Tibet, China. Zhabuye Lithium holds the exploration rights for Zhabuye Salt Lake, which is located in the Tibet Autonomous Region of China and is estimated to have 1.79 million tons of LCE lithium resources. In December 2018, the Company completed the acquisition of a 23.77% stake in Sociedad Química y Minera de Chile S.A. (SQM), a leading global supplier of lithium products with over 20 years of experience in salt lake lithium extraction. SQM's lithium salt lakes in the Atacama Desert have high lithium concentrations and large reserves.

Driving upstream lithium mining to set zero-carbon targets

Talison Lithium, Tianqi Lithium's lithium concentrate supplier, has set a goal to expand production without increasing carbon intensity to 2030, and achieve net zero Scope 1 & 2 emissions by 2050 or earlier. To achieve this goal, Talison Lithium has identified opportunities and is developing a decarbonisation plan in line with evolving technologies. To date Talison Lithium has adopted the use of high-quality diesel to improve fuel efficiency, and integrated a selection of electric and low emissions auxiliary equipment and light vehicles.

3.2 Greening of midstream lithium extraction processes

3.2.1 Promote emission reduction in existing processes

Sulfuric acid roasting is the current mainstream method for lithium extraction from ore, which is widely used in the industry due to its high lithium extraction efficiency and simplicity. Other methods, such as alkaline pressure leaching, sulfate roasting with salts, and chlorination roasting, all lack economic viability or operability (Zhang Xiufeng, 2020). Therefore, this section primarily focuses on decarbonization strategies within the sulfuric acid roasting process, which are also relevant for other lithium salt preparation methods similar to sulfuric acid roasting.

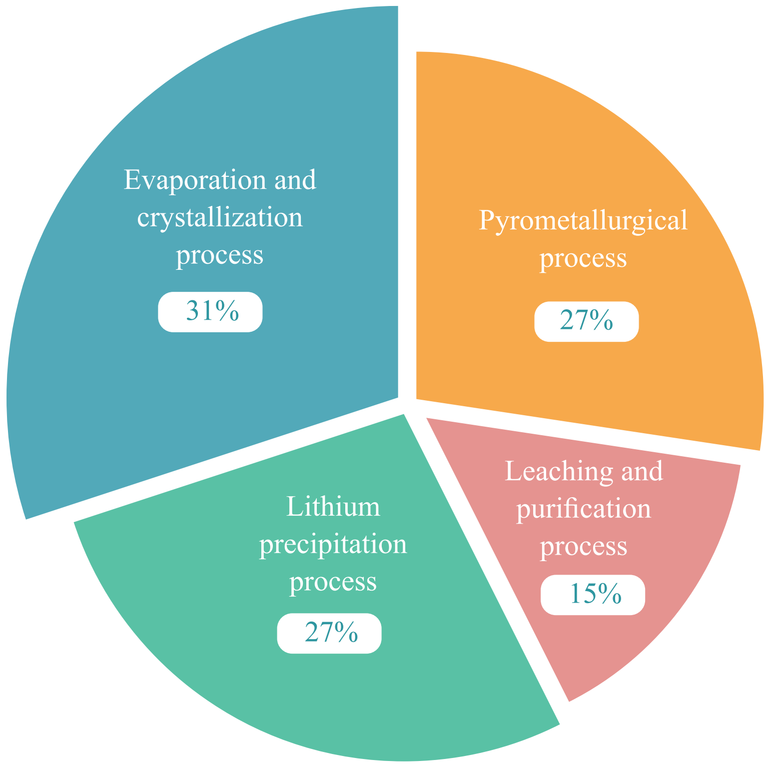


Figure 7. Distribution of Electricity Consumption in the Process of Lithium Carbonate Production Using Sulfuric Acid Roasting Method (Du Guoshan, 2020)

3.2.1.1 Energy efficiency

Improving the efficiency of electric-driven equipment

In the sulfuric acid roasting process, electricity is used relatively dispersedly, in which the main electrical equipment in the pyrometallurgical process includes exhaust fans, clinker mills, rotary kilns, etc. The equipment used in the leaching and purification processes includes storage tanks, agitated tanks, and transfer pumps. The equipment used in the lithium precipitation process includes lithium precipitation tanks, centrifuges, and agitated tanks. The evaporation and crystallization process primarily involves steam compressors, circulation pumps, etc. (Du Guoshan, 2020). By using frequency-controlled motors or soft start devices in this equipment, electricity consumption can be reduced by 20%-30% (Du Guoshan, 2020). Additionally, the use of automated new process equipment can further improve the energy utilization efficiency in the production process.

Improving the energy efficiency of thermal systems

The lithium extraction process using the sulfuric acid roasting method shares similarities with the new dry cement process. Therefore, design concepts from the new dry cement process can be applied to improve the utilization of waste heat at the kiln head and kiln tail, as well as optimize the overall efficiency of fuel and hot air systems.

Multi-stage cyclone preheating system

The multi-stage cyclone preheating system utilizes the heat energy in the flue gas to preheat the raw materials entering the burner, thereby reducing the amount of external energy required for heating. The principles of the multiple-stage cyclone preheater and multi-channel burner in the new dry cement process are also applicable to the rotary kiln in the sulfuric acid roasting method. Innovative applications of these technologies have been achieved domestically, demonstrating significant energy-saving effects.

Oxygen-enriched combustion technology in kilns

Under oxygen-enriched combustion conditions, the reaction between fuel and oxygen is more thorough, leading to a more complete combustion process. Compared with conventional air combustion, oxygen-enriched combustion can eliminate or reduce the incomplete combustion products in the combustion process, thereby improving fuel utilization. Currently, oxygen-enriched combustion has been applied in cement kilns, achieving a 6% reduction in comprehensive energy consumption (Zhang Zhongming, 2021).

3.2.1.2 Renewable power

According to the IEA's prediction, China's carbon emissions per unit of electricity in the power system will decrease by over 3% annually after 2020, with an average annual reduction of 260 million tons (IEA, 2021a). At the same time, the share of electricity in the refining process in the midstream industry is expected to increase from the current 20% to 40% or even higher through partial electrification. Midstream companies can increase the proportion of renewable power and achieve power decarbonization in the refining process through the following two modes:

Direct procurement or agency procurement of renewable power. Midstream companies can quickly increase the proportion of renewable power in their electricity consumption by investing in wind or solar power plants in remote areas, directly purchasing or procuring renewable power.

On-site deployment of distributed solar photovoltaic systems on rooftops or open space. When constructing new production bases, the feasibility of building solar power plants on site or in nearby areas should be comprehensively considered. Additionally, the scale of substations and access systems should be planned based on the demand for green hydrogen, reserving substation capacity for green power hydrogen production units.

3.2.1.3 Clean heat

Promoting the "electrification" of medium and low-temperature heat demand

Industrial heating technology needs to adapt to heating technologies with lower lifecycle emissions while meeting the requirements of **temperature** (the temperature provided by the heat source should meet the temperature demands of industrial manufacturing processes), **heat flux** (the heat must have high heat flux to maintain a reasonable production rate), **reliability** (the operation of production facilities is continuous, and the heat source must meet all-day and year-round availability), and **cost-effectiveness** (ICEF, 2019).

Compared with heat systems relying on fossil fuels, electric heating has advantages such as precise temperature control, rapid switching, and less maintenance (ICEF, 2019). According to the IEA's forecast, the carbon emissions reduction achieved through "re-electrification" in China's industrial sector between 2020 and 2060 will account for 45% of the total emissions reduction during the same period. Most of the medium and low-temperature heat demand will be met through electric boilers, heat pumps, and industrial waste heat (IEA, 2021a). The Implementation Plan for Carbon Peaking in the Industrial Sector issued by the Ministry of Industry and Information Technology, the National Development and Reform Commission, and the Ministry of Ecology and Environment also proposes promoting the electrification of industrial energy use, with a focus on electrification transformation of medium- and low-temperature heat sources below 1,000°C in industrial production processes.

Currently, natural gas and steam are the main sources of heat in the sulfuric acid roasting process. Natural gas is primarily used as the heating energy source for the rotary kiln, while steam is mainly used for the temperature increase in the purification process and lithium precipitation process (Du Guoshan, 2020). Based on industrial heating requirements, the feasibility of electrifying different heating processes in the sulfuric acid roasting method is analyzed in Table 3.

Table 3. Feasibility of Electrification in Different Processes of Sulfuric Acid Roasting Method

Process Stage	Process Description	Feasibility of Electrification
Roasting-induced transformation	Roasting lithium spodumene at 1,000-1,100°C to transform its crystal structure from α-phase to the extractable lithium β-phase through leaching process.	High-temperature thermal demand, which is difficult to be replaced by electric heating technology, suitable for increasing the proportion of zero-carbon fuels such as hydrogen, ammonia, biomass-derived synthetic fuels, etc.
Acid roasting	Roasting a mixture of β-spodumene and sulfuric acid at around 250°C to extract lithium in the form of lithium sulfate from the mixture.	Medium to low-temperature thermal demand, which is suitable for electric heating technology, and can be adopted in regions where electricity has cost advantages.
Chemical treatment	Processes including concentration by evaporation of lithium sulfate solution, evaporation crystallization of lithium-rich mother liquor, and lithium precipitation.	Saturated steam demand, can be supplied by utilizing waste heat from high-temperature kilns or by using electric heating technology in regions where electricity has cost advantages.

Acid roasting and chemical treatment require medium-to low-temperature heat sources, with a possibility of achieving electric heating within a relatively short time:

Acid roasting

Indirect resistance heating (a common technology for externally heated rotary kilns) is applicable, where the heater is placed outside the rotating high-temperature alloy shell to transfer heat to the internal process materials. The heating element used is a resistor made of graphite, silicon carbide, or nickel-chromium alloy.

Chemical treatment

The enrichment evaporation of lithium sulfate solution, evaporation crystallization of lithium brine, and lithium precipitation processes often use steam as a heat source. The energy efficiency can be improved by using Mechanical Vapor Recompression (MVR) evaporators as an alternative to multiple-effect evaporators. In addition, high-temperature heat pump technology can also be employed to recover heat energy from flue gas below 200°C and produce saturated steam. If the heat pump is driven by renewable power, it can achieve net zero steam supply.

Exploring the biomass natural gas technology and increasing its share

Biomass natural gas is a high-quality biogas with a methane content of over 95%, possessing similar properties to pipeline natural gas. According to the IEA's forecast, the supply of biogas and biomethane in China is expected to double by 2030 compared with the levels in 2020, and increase by more than two-fold by 2060 (IEA, 2021a). The proportion of biogas injected into the gas pipeline system is projected to grow from almost zero in 2020 to 3% and 15% in 2030 and 2060, respectively (IEA, 2021a).

To explore the use of biomass natural gas as a fuel, the following two modes can be considered:

- **Purchased biomass natural gas** — If a gas operator has the capability to supply biomass natural gas, it can be prioritized for procurement.

- **On-site production of biomass natural gas** — If a park equipped with water electrolysis units for hydrogen production is located in an area with biomass resources such as straw and kitchen waste in the vicinity, small-scale modular biogas generators and hydrogenation-methanation units can be deployed in the park for on-site production of biomass natural gas.

Adopting hydrogen compressed natural gas and increasing the share of blue hydrogen and green hydrogen

The use of hydrogen compressed natural gas is an effective measure to reduce carbon emissions in the roasting-induced transformation. Hydrogen has the characteristics of fast flame speed and strong dilution ability compared with natural gas. By blending an appropriate proportion of hydrogen into natural gas, thermal efficiency can be improved and carbon emissions can be reduced. Most combustion devices can adapt to these changes through process parameter adjustments (Ren Ruoxuan et al., 2021). According to the IEA's forecast, by 2060, the share of green hydrogen mixed into kiln fuels will reach approximately 5% of the total heat demand (IEA, 2021a).

In the roasting-induced transformation process, two modes of hydrogen compressed natural gas can be considered:

- Purchased hydrogen compressed natural gas — If suitable suppliers are available in the industrial park where the factory is located, procurement of hydrogen-doped natural gas can be prioritized.

- On-site hydrogen blending for purchased natural gas — Conventional natural gas can be purchased and hydrogen can be blended on site within safety limits, with preference given to blue hydrogen or green hydrogen as the hydrogen source.

- Grey hydrogen: Hydrogen production through fossil fuel reforming, with significant CO_2 emissions during the hydrogen production process.

- Blue hydrogen: Industrial by-product hydrogen or grey hydrogen equipped with CCUS (Carbon Capture, Utilization, and Storage) equipment, with lower CO_2 emissions during the hydrogen production process.

- Green hydrogen: Hydrogen production from water electrolysis using renewable power.

Therefore, when constructing a new lithium extraction plant using the sulfuric acid roasting method, the availability of short-term blue hydrogen and long-term green hydrogen needs to be comprehensively considered:

Short-term attention should be paid to industrial by-product hydrogen resources in neighboring regions

Blending industrial by-product hydrogen with natural gas is economically feasible. The cost of industrial by-product hydrogen mainly depends on the price of hydrogen-rich mixed gas, and the cost of industrial by-product hydrogen per unit of heat value is usually lower than the price of a natural gas station. If hydrogen blending is done according to the natural gas scenario, industrial by-product hydrogen can be priced based on equivalent heat value to natural gas, which is approximately 7 yuan/kg, making it the lowest-cost source of hydrogen, only one-third the price of green hydrogen (IEA, 2022e).

Long-term attention should be paid to the production capacity of green hydrogen in the industrial park or factory area

With the development of electrolytic water hydrogen production technology and the continuous expansion of renewable energy scale, the production cost of green hydrogen may decrease to a competitive level in the future. According to the IEA's forecast, the average cost of hydrogen production from renewable energy will decrease to around 9 to 12 yuan/kg as early as 2050, equivalent to the cost of blue hydrogen (IEA, 2021a).

The circular economy model of coupling the pyrometallurgical refining of lithium with the chlor-alkali chemical industry

In 2020, industrial by-product hydrogen accounted for approximately one-fifth of China's hydrogen supply, reaching 7.1 million tons, with the main sources including petroleum refining, steel manufacturing, and chemical production. Among them, the annual production of caustic soda in China remains relatively stable at 30 to 35 million tons per year, which can generate 750,000 to 875,000 tons of by-product hydrogen annually (IEA, 2022e).

Caustic soda is an important chemical reagent in the lithium extraction process using the sulfuric acid roasting method, and chlor-alkali chemical parks typically have strong purchasing power and bargaining capabilities in green electricity procurement. When building new lithium extraction capacity, it is possible to establish an industrial chain coupling with adjacent chlor-alkali chemical parks to enhance the feasibility of green electricity procurement. This approach can also help reduce the procurement cost of industrial by-product hydrogen and the implicit emissions from purchased chemical reagents, and explore the comprehensive utilization of lithium slag and calcium carbide slag resources. By-product hydrogen generated during the PVC electrolysis process in chlor-alkali parks can be utilized for carbon-neutral natural gas preparation. In addition, by-product oxygen generated from hydrogen production unit by water electrolysis in nearby parks can also be utilized for oxygen-enriched combustion in the rotary kiln during the sulfuric acid roasting process for lithium extraction.

3.2.1.4 Carbon capture and utilization

Oxygen-enriched combustion can also increase the CO_2 concentration in the flue gas and reduce CO_2 capture costs while achieving energy savings in the kilns. According to the verification results from domestic cement kilns, the CO_2 concentration in the exhaust gas can be increased from 20% to 80% under the conditions of oxygen-enriched combustion (Zhang Zhongming, 2021).

The Low Emissions Intensity Lime And Cement (LEILAC) technology in Europe provides a good solution for the CO_2 generated from carbonate decomposition, which involves adding a sealed precalciner before the cyclone preheater, where the high-temperature flue gas from the rotary kiln is introduced to heat the limestone in the decomposed raw materials, and to recover the produced high-purity CO_2. The second-phase demonstration of this project has already been carried out at the Heidelberg Cement plant in Germany, which is expected to commence operations within 2023 (Heidelberg Materials, 2022).

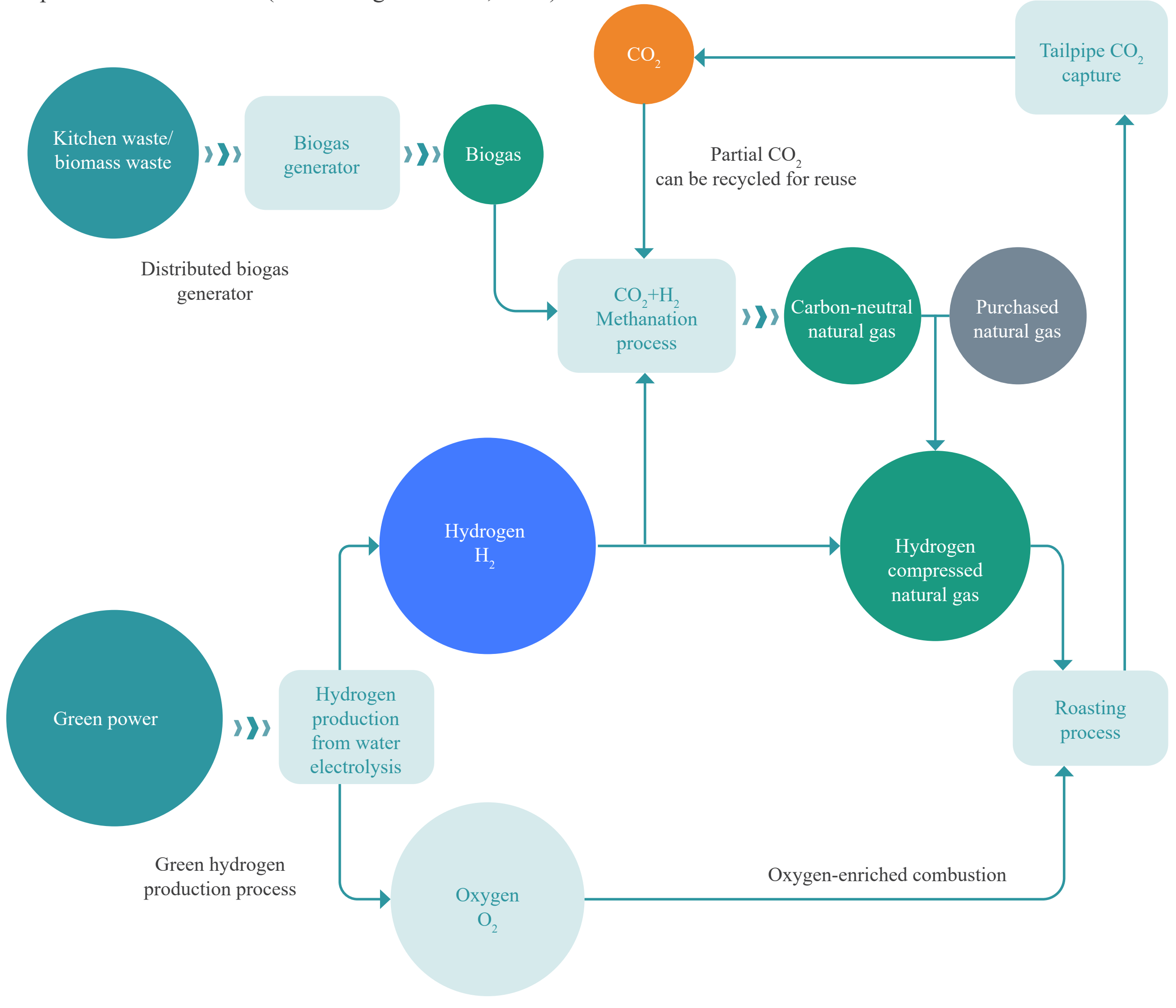


Figure 8. Schematic Diagram of Achieving Net Zero in the Roasting-induced Transformation Process Based on Natural Gas as Fuel

Synthesis of carbon-neutral natural gas with green hydrogen after CO_2 capture

The CO_2 captured from the roasting kiln can be combined with hydrogen gas through the Sabatier Reaction at high temperatures to synthesize natural gas, which can then be reintroduced into the kiln as a supplementary fuel for the gas system. When combined with a biomass natural gas unit, a net zero CO_2 cycle system can be established. The roasting process is essentially powered by renewable energy sources and does not generate carbon emissions.

Utilized as raw materials for building materials after CO_2 capture

China has the potential to produce building materials from CO_2 and has initiated some demonstration projects in this regard (Hu Xiang, 2021). It is estimated that the utilization of CO_2 for building materials in China will reach 85 million to 115 million tons per year by 2050 (IEA, 2022e).

The utilization of CO_2 and slag cement for carbonation to produce building materials is becoming an economically attractive measure for carbon sequestration. Currently, institutions such as Zhejiang University in China (Cai Bofeng et al., 2021), SolidiaTech in the United States (Sahu & Meininger, 2020), and CarbonCure Technologies in Canada (Sandeep, 2021) are developing CO_2 mineralized concrete technology. This technology involves a reaction of CO_2 with calcium hydroxide in concrete, permanently storing CO_2 in the concrete and enhancing its compressive strength and durability (Monkman et al., 2016).

Exploring the use of by-products from lithium refining processes, such as lithium-containing slag (residue after lithium extraction from slag), as an active material in conjunction with CO_2 mineralization technology can produce carbon-negative slag-based concrete materials, which contributes to the net zero and circularization of lithium refining processes.

3.2.1.5 Green chemical agents

The implicit carbon emissions from purchased chemical agents are significant upstream emissions in the lithium chemical industry. Various lithium extraction processes require a large amount of chemical agents, such as soda ash, caustic soda, and sulfuric acid. To achieve net zero, midstream and upstream companies can incorporate climate factors into their procurement processes and prioritize chemical agents from low-carbon processes to drive down their implicit emissions.

Soda ash

Currently, there are primarily three preparation methods for soda ash available in the market. The difficulty level of decarbonizing different soda ash production processes is summarized in Table 4.

Table 4. Analysis of Low-Carbon Processes for Producing Soda Ash
(Bian Zhifu, 2013; Dong Wenlin, 2007; Zhang Kewei, 2019; Zhou Guangyao, 2006)

Process for Soda Production	Low-carbon Process Route	Difficulty Level of Decarbonization	Market Share
Ammonia soda process	• The brine refining and heavy alkali calcination stages of the process require medium-to-low-temperature heating. The use of electric heating systems can meet the heating needs, and the use of renewable energy can achieve decarbonization in the production process. • For the calcination stage of heavy alkali, CO_2-containing flue gas can be recycled into the limestone calcination stage as an auxiliary material or incorporated into a high-temperature thermal solution for carbon capture and natural gas calcination, achieving near-net-zero emissions in the production process.	Relatively high	Relatively high
Combined soda process	• Compared with the ammonia soda process, the combined soda process has higher utilization rates for sodium and chlorine, as well as lower comprehensive energy consumption per unit. It utilizes CO_2 byproduct from synthetic ammonia as raw material, without the need for limestone and coke consumption. • For the combined soda process that adopts the process of "one-time salting, two-time ammonia absorption, one-time carbonization", it can also be equipped with CO_2 capture and natural gas calcination processes, achieving the recycling of CO_2 and enabling near-net-zero emissions in the alkali production process.	General	Relatively high
Natural soda process	• The production of dense soda ash mostly using natural soda both at home and abroad as a raw material adopts the monohydrate soda ash process, which involves steps such as evaporation concentration, centrifugal separation, and calcination dehydration. By procuring renewable power, it is possible to achieve near-net-zero emissions in the production process. • The natural soda process and other methods for producing soda ash account for only a small proportion in China's soda ash industry.	Relatively low	Relatively low

Caustic soda

The diaphragm caustic soda evaporation process is the most common method for caustic soda production in China. Approximately 50% of the total production volume of caustic soda is produced using this method. Electrolysis, evaporation, and solidification are the major energy-consuming processes, accounting for over 90% of the energy consumption (Cheng Qiang, 2018). If steam is provided using electric boilers, electricity will be the primary form of energy utilized in caustic soda production. By utilizing renewable power, the indirect emissions of the production process can be significantly reduced. Additionally, the electrolysis process also generates hydrogen gas and oxygen as by-products. If hydrogen gas is used as fuel for heating or to power fuel cells, the share of renewable energy can be further increased, achieving net zero in the production process.

Sulfuric acid

The production of sulfuric acid from iron pyrite typically generates a significant amount of excess heat (net energy output rather than energy consumption). By utilizing the heat from the reaction process for steam generation or electricity production, the external electricity demand for sulfuric acid production can be greatly reduced. At the same time, procuring renewable power can enable the sulfuric acid production process to achieve net zero.

3.2.2 Deploy flexible lithium extraction processes

The midstream lithium industry has a high concentration of production capacity. Only a few companies worldwide are capable of producing high-quality and high-purity lithium chemicals, particularly lithium hydroxide, with five companies accounting for three-quarters of global capacity (IEA, 2021c). Due to high concentration, the lithium extraction flexibility of midstream companies plays an important role in diversifying upstream lithium resources.

3.2.2.1 Direct lithium extraction from salt lake brines

China's lithium reserves are mainly located in salt lakes in the western regions, which have a higher magnesium-to-lithium ratio compared with salt lakes in South America. Due to the similar properties of magnesium and lithium, the high magnesium-to-lithium ratio in Chinese salt lakes results in difficulties in separation, high lithium loss, and high development costs when using the South American evaporation and precipitation method for lithium extraction (Song et al., 2017). To this end, some Chinese companies are striving to compensate for the disadvantages of resource endowment through technological innovation in order to reduce dependence on overseas lithium resources (Grant, 2020).

The direct lithium extraction (DLE) technologies offer new possibilities for lithium production. DLE, currently in the pilot phase, refers to the extraction of lithium directly from brine using filters, membranes, ceramic beads, or other equipment, significantly reducing the duration of lithium extraction and chemical reagent consumption (Vera et al., 2023). Furthermore, DLE can be applied to extract lithium from post-extraction underground brines and in brine mining areas where establishing evaporation ponds is not suitable, such as direct lithium extraction technology developed by Volt Lithium, a Canadian lithium development and technology company. The technology can remove impurities and pollutants in the brine, and the purified brine can be used for direct lithium extraction and be concentrated into lithium hydroxide solution through its IES technology. The technical validation for oilfield brine has been realized in 2023.

3.2.2.2 Off-site refining of crude lithium carbonate from salt lakes

Currently, salt lake lithium extraction results in higher impurity levels and unstable or unreliable product quality compared with lithium extraction from ores. In order to meet the growing demand for high-quality lithium salts driven by the electric vehicle industry, major salt lake lithium-producing regions need to further develop and optimize the purification process for crude lithium carbonate.

The industry can also explore the transportation of concentrated brines or crude lithium carbonate extracted from brines to regions with more mature production processes for subsequent treatment. This approach is similar to the lithium concentrate exported by Australia to Chinese lithium salt processing companies in the hard rock lithium extraction process, leveraging their respective industrial advantages to improve the quality of lithium extracted from salt lakes.

Focusing on Tianqi Lithium

Enhancing production energy efficiency

Tianqi Lithium has made improving energy efficiency in its production as an important component of its greenhouse gas emission reduction strategy. The Company has implemented numerous energy efficiency projects, ranging from LED lighting systems to waste heat utilization, and innovative applications of multi-stage cyclone preheating systems during the roasting-induced transformation stage. We have been continuously exploring ways to further reduce unit product energy consumption.

Energy Efficiency Projects in 2022

Shehong Production Base	Chongqing Production Base		
Replace high-energy-consuming electrical equipment (such as transformers and motors) with low-energy-consuming devices	Adopt a new crystallization method to produce anhydrous lithium chloride	Install variable frequency drives on tail gas fans and implement large-scale transformations in electrolytic cells	Replace existing silicon rectifiers in electrolysis with more efficient ones
An annual reduction of electricity consumption by over **7,000 MWh**	An energy consumption reduction of metallic lithium electrolysis by **over 5%**	A power consumption reduction by approximately **15%**	A power utilization efficiency increase by **5%** to **8%**

Promoting the use of renewable power

The transition to renewable power will serve as a short-term measure for Tianqi Lithium to reduce greenhouse gas emissions. The Shehong production base has achieved full utilization of renewable power (hydropower) by signing a green power supply agreement with an electricity provider since 2021. At the same time, Jiangsu Zhangjiagang Production Base has completed the installation of 6,000 square meters of photovoltaic panels. It is expected that this installation will generate an annual electricity output of 1,200-1,500 MWh. Tianqi Lithium will continue to promote the increase in the proportion of renewable power usage by means such as on-site renewable energy generation, green power procurement, and green power certificates.

Building new types of cooperation with suppliers

More than half of Tianqi Lithium's carbon footprint is embedded in raw materials. A significant portion of these emissions arises from inorganic chemicals such as sodium carbonate, sodium hydroxide, and concentrated sulfuric acid. Collaborating with our suppliers through strategic procurement to reduce their carbon footprint is one of the key strategies for achieving net zero targets by 2050.

We will develop emission reduction roadmaps for upstream raw materials that have a significant impact on Scope 3 emissions and gradually integrate them into our supplier management processes. We will prioritize partnerships with suppliers who are active in climate actions, and collaborate with suppliers to reduce emissions, including setting emission reduction targets and strategies.

3.3 Efficient utilization of downstream resources

3.3.1 Efficient materials utilization

The main materials in power batteries include positive electrodes, negative electrodes, separators, and electrolytes. Their technology is the core driving force behind improving the performance of power batteries. As the industry strives to reduce reliance on high-value metals such as cobalt and nickel, it is equally important to improve the battery performance per unit of lithium raw materials and incorporate it as a key parameter in the evaluation of lithium-ion batteries (typically including energy, power, cost, lifespan, and safety), which will effectively promote the efficient utilization of global lithium resources.

3.3.1.1 Positive electrode materials: reducing the lithium content per unit capacity

The positive electrode material in a lithium-ion battery is lithium-containing metal oxide or phosphide, which serves as a source of active lithium ions required for the electrochemical reactions in the battery and have a significant impact on the performance of power batteries.

Taking ternary lithium batteries and lithium iron phosphate batteries as examples, the theoretical lithium content per unit capacity can be reduced to 50g/kWh. However, the actual lithium content in current products is 80-140g/kWh, which is double or even higher than the theoretical minimum value, indicating that there is still room for improvement (Slowik et al., 2020).

According to the forecast of the International Council on Clean Transportation, there will be a significant decrease in lithium content per kilowatt-hour in ternary lithium batteries and lithium iron phosphate batteries over the next 20 years. Compared with current levels, the lithium demand per unit capacity can be reduced by more than 40%. The increase in energy density will be the main driving force behind this change (Slowik et al., 2020).

Table 5. Lithium Content in Electric Vehicle Battery Cathodes (g/kWh) in 2020 and 2040 (Slowik et al., 2020)

	NCM-111	NCM-532	NCM-622	NCM-811	NCA	Lithium Iron Phosphate
2020	140	130	120	110	110	80
2040	80	70	70	70	60	50

3.3.1.2 Negative electrode materials: enhancing performance while minimizing lithium loss

Lithium-ion batteries form a solid electrolyte interface (SEI) film during the initial charge and discharge process. This film is generated by the reaction between the electrolyte and the surface of the negative electrode, with a significant impact on the conductivity, stability, and lifespan of lithium-ion batteries. However, the formation of the SEI film results in the loss of some lithium ions from participating in the charge and discharge processes. The industry refers to the ratio of the lithium released during the initial lithiation process to the lithium initially consumed as the initial coulombic efficiency (ICE).

The commonly used pre-lithiation technology involves incorporating high-lithium content substances into the battery materials to replenish lithium in the electrode materials, which helps to mitigate capacity losses to some extent. There are various methods for lithium supplementation available in the market, which, based on the location of lithium supplementation, can be classified into two categories: negative electrode lithium supplementation and positive electrode lithium supplementation.

Negative electrode lithium supplementation

It includes physical mixing with metallic lithium, such as adding lithium metal powder to the negative electrode or applying metallic lithium foil on the electrode surface; chemical lithiation, which involves chemical pre-lithiation of the negative electrode using lithiumating agents like butyl lithium; self-discharge lithiation, where the negative electrode contacts with metallic lithium in the electrolyte to complete self-discharge lithiation; and electrochemical pre-lithiation, where metallic lithium is introduced as a third electrode in the battery, and pre-lithiation is achieved by charging and discharging between the negative electrode and the metallic lithium third electrode.

Positive electrode lithium supplementation

According to the type of compounds, positive electrode lithium supplementation can be classified into binary lithium-containing compounds represented by Li_2O, Li_2O_2 and Li_2S; ternary lithium-containing compounds represented by Li_6CoO_4 and Li_5FeO_4; and organic lithium-containing compounds represented by Li_2DHBN and $Li_2C_2O_4$.

On the other hand, graphite electrodes, as the most widely used negative electrode material currently, have achieved a specific capacity (>350 mAh/g) that is close to their theoretical specific capacity (372 mAh/g) after years of development (Zhang et al., 2021). The industry is seeking to replace graphite negative electrodes with silicon-based negative electrodes, which offer higher specific capacity (3,579 mAh/g) (Ma et al., 2022). However, the initial coulombic efficiency (ICE) of silicon-based negative electrodes is typically between 50% and 85%, much lower than the 80%-95% of graphite negative electrodes, which remains a major obstacle for the application of silicon-based negative electrodes (Li et al., 2020).

To this end, more researchers have taken the improvement of the ICE in silicon-based negative electrodes in an experimental direction. They are exploring optimization strategies in areas such as structural adjustment, pre-lithiation, interface design, binder design, and electrolyte additives, etc. In some cases, studies have achieved ICE values exceeding 90% for silicon-based negative electrodes, but currently, these advancements are primarily limited to the laboratory level (Sun et al., 2022).

3.3.1.3 Electrolyte: novel high-performance lithium salts

Electrolyte lithium salts provide ions and facilitate ion transport in lithium-ion batteries. Currently, lithium hexafluorophosphate (LiPF6) is the most widely used commercial solute lithium salt. However, LiPF6 faces issues such as poor thermal stability, easy hydrolysis, and rapid battery capacity degradation, which also pose risks for safety. It is expected that LiPF6 will be replaced by electrolytes with higher conductivity, thermal stability, and chemical stability in the future. One of the most promising electrolytes is lithium bis(fluorosulfonyl)imide (LiFSI), which has a very low probability of side reactions and can also suppress expansion effects.

3.3.2 Carbon emission reduction in electrode production

In terms of comprehensive energy consumption, the advanced values of lithium iron phosphate and ternary lithium positive electrode materials can reach 565 kgce/t and 685 kgce/t, respectively, showing a significant improvement compared with previous process energy efficiency (800-1,600 kgce/t) (Administration for Market Regulation of Hunan Province, 2019). Substantial emission reduction in production emissions can be achieved by continuously increasing the share of electric energy and the proportion of renewable power.

Electrode producers should also focus on eliminating process emissions generated during the electrode production process. Taking lithium iron phosphate electrodes as an example, preparation methods can be divided into solid-phase synthesis and liquid-phase synthesis. The solid-state synthesis method, specifically the carbon thermal reduction method, is currently adopted by over 90% of companies for its advantages such as simple process and mature technology. In addition, there are also some companies that use the method of self-heating evaporation liquid-phase synthesis (Leadleo.com, 2019). Both methods require sintering treatment of lithium carbonate, which results in the decomposition of lithium carbonate and the emissions of carbon dioxide. To mitigate these emissions, the application of carbon capture technologies will be necessary.

3.3.3 Expansion of application scenarios

Battery capacity is the most crucial factor determining the driving range of electric vehicles. Battery configuration optimization and innovation are the most effective measures to increase battery capacity in the short term. The growth of electric vehicle driving range can meet the demands of various transportation electrification scenarios, thereby amplifying the carbon handprint potential of lithium-ion batteries.

- CTP (Cell-to-Pack) technology, also known as module-less technology, is gradually becoming the mainstream application in current battery configurations. This technology can be divided into two technical routes: one is the complete elimination of modules, represented by BYD blade batteries, and the other is the integration of small modules into large modules, represented by Contemporary Amperex Technology Co., Ltd. (CATL). CTP technology improves battery capacity and energy density by increasing the internal space utilization and reducing packaging weight of battery packs (Wu Hao & Zhang Peng, 2022).

- CTC (Cell to Chassis) technology is gaining increasing attention as an emerging technology. CTC can be seen as an extension of CTP, which refers to the integrated design of the battery, chassis, and lower body of a vehicle, which involves directly placing battery cells on the vehicle chassis, thereby achieving a higher degree of integration and improving battery capacity and energy density (Wu Hao & Zhang Peng, 2022).

3.3.4 Market positioning and segmentation

In the field of power batteries, different battery technologies have their own advantages and disadvantages. In addition to the mainstream lithium iron phosphate batteries and ternary lithium batteries, emerging battery technologies represented by solid-state lithium batteries and sodium-ion batteries also demonstrate certain application potentials. The characteristics of the four aforementioned battery technologies are compared in Figure 9.

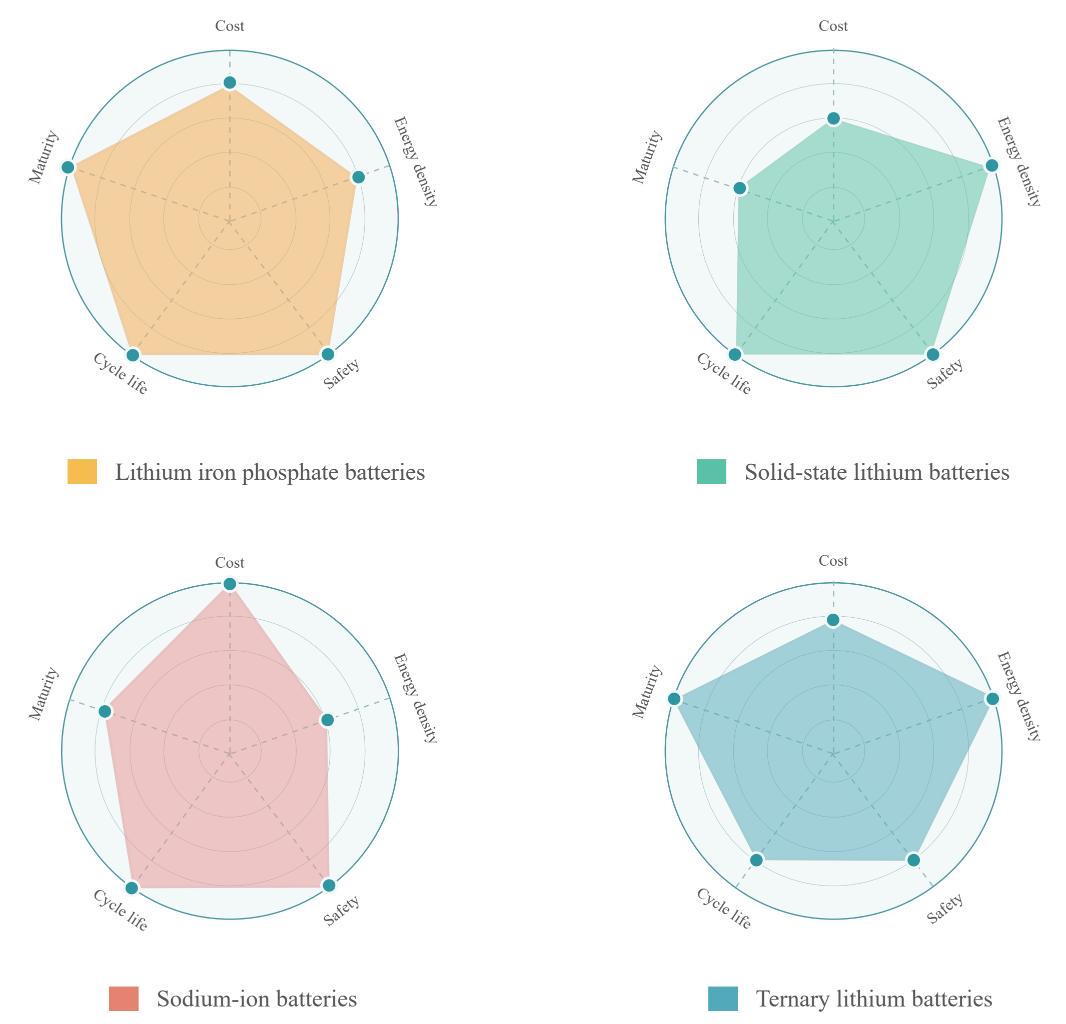


Figure 9. Comparison of Characteristics of Different Types of Power Batteries

Appropriate battery technologies need to be matched to the specific scenario requirements of electric vehicles and energy storage industries. Through market positioning segmentation, the advantages of different types of batteries can be fully utilized, mitigating the risk of stranded assets and alleviating concerns about supply-demand imbalances. For example, Volkswagen recently announced plans to use high-energy density batteries, such as high-nickel batteries (NCA95, NMCA, and NMC9.5.5) in premium vehicles, and lithium iron phosphate batteries in entry-level vehicles (S&P Global, 2021). The potential battery technologies applicable to power batteries and energy storage batteries are summarized in Table 6.

Table 6. Applicability of Different Battery Technologies (Including Alternative Technologies) in The Field of Power Batteries and Energy Storage Batteries

	Scenario Segmentation	Battery Technologies Suitable for Short-term Applications	Battery Technologies Suitable for Long-term Applications
Power batteries	Entry-level passenger vehicles	Lithium iron phosphate batteries	Lithium iron phosphate batteries
	Mid-to-high-end passenger vehicles	Lithium iron phosphate batteries, ternary lithium batteries	Lithium iron phosphate batteries, ternary lithium batteries
	Performance-oriented passenger vehicles	-	-
	Light-duty commercial vehicles	Lithium iron phosphate batteries	Lithium iron phosphate batteries
	Medium- and heavy-duty commercial vehicles	-	Fuel cells
Energy storage batteries	Short-term energy storage	Lithium iron phosphate batteries	Lithium iron phosphate batteries
	Long-term energy storage	-	Liquid flow batteries, sodium-ion batteries

Focusing on Tianqi Lithium

Tianqi Lithium has developed a new synthesis process and low-temperature drying technology for lithium sulfide. Compared with traditional processes, this technology does not use organic solvents, nor does it produce organic waste liquid, posing lower risks for safety and environment. The lithium sulfide products lay a foundation for the Company's response to the development of next-generation solid-state battery technologies based on sulfur-based materials, and the enhancement of product diversification and added value.

3.4 Regeneration of end-of-life battery materials

According to the lifespan of electric vehicles, a wave of decommissioned power batteries is expected to occur in the near future. It is estimated that by 2030, the global supply of decommissioned lithium-ion batteries may exceed 200 GWh per year, surpassing the total demand for lithium-ion battery energy storage by utilities (McKinsey, 2019).

After reaching the end of their useful life, power batteries can be processed through cascaded utilization or dismantling for recycling, offering promising market prospects. According to predictions, the market size for power battery recycling is expected to increase from 5.5 billion yuan in 2021 to 58.8 billion yuan in 2025 and 299.7 billion yuan in 2030, of which the value of lithium accounts for over 60% of the total market size (Deloitte, 2022). Regenerated lithium resources will serve as an important supplement to primary lithium resources.

Considering the composition and cycle life of power batteries, currently, lithium iron phosphate batteries are more suitable for cascade utilization, while ternary lithium batteries are more suitable for direct recycling:

- Ternary lithium batteries contain valuable metals such as nickel and cobalt, in addition to lithium, making direct recycling more economical.

- Lithium iron phosphate batteries have a higher cycle life and still retain a significant battery capacity after decommissioning, making them more suitable for cascade utilization. At the same time, cascade utilization can help spread the cost of lithium iron phosphate battery recycling and improve its economic viability.

3.4.1 Cascade utilization of power batteries

Cascade utilization is an effective means to increase the utilization of lithium resources and reduce battery recycling costs. Power batteries typically retain 70%-80% of their original capacity when they end their first service (McKinsey, 2019). However, achieving large-scale cascade utilization still faces several challenges, including:

- Policies: There are safety concerns related to the cascade utilization of power batteries, and the relevant management systems are still in the exploration stage.

- Standards: Battery consistency and traceability management systems have not been established, which increases the difficulty of battery repair and refurbishment.

- Costs: Complex regulatory requirements increase the cost of cascade utilization,which weakens the cost advantage of decommissioned batteries.

- Performance: Decommissioned batteries lack performance and quality assurance, leading to low acceptance of cascade utilization by downstream companies.

Therefore, the industry urgently needs to enhance the feasibility of cascade utilization after power battery decommissioning. Relevant actions include:

- Considering cascade utilization of power batteries during the automotive design stage.

- Collaborating with policy makers to establish certification standards for cascade utilization of power batteries.

- Establishing a digitally transparent management system for the entire supply chain of power batteries.

- Establishing collaborative plans for power battery disassembly, recycling, and cascade utilization.

3.4.2 Disassembly and recycling of power batteries

Disassembly and recycling are the ultimate means to address the disposal of decommissioned batteries, and also an important path to alleviate the supply-demand imbalance of lithium resources. The disassembly and recycling of power batteries can be divided into three stages: pre-treatment, physical disassembly and recycling, and extraction and refining of raw materials, which can provide various types of raw materials for the production of power batteries.

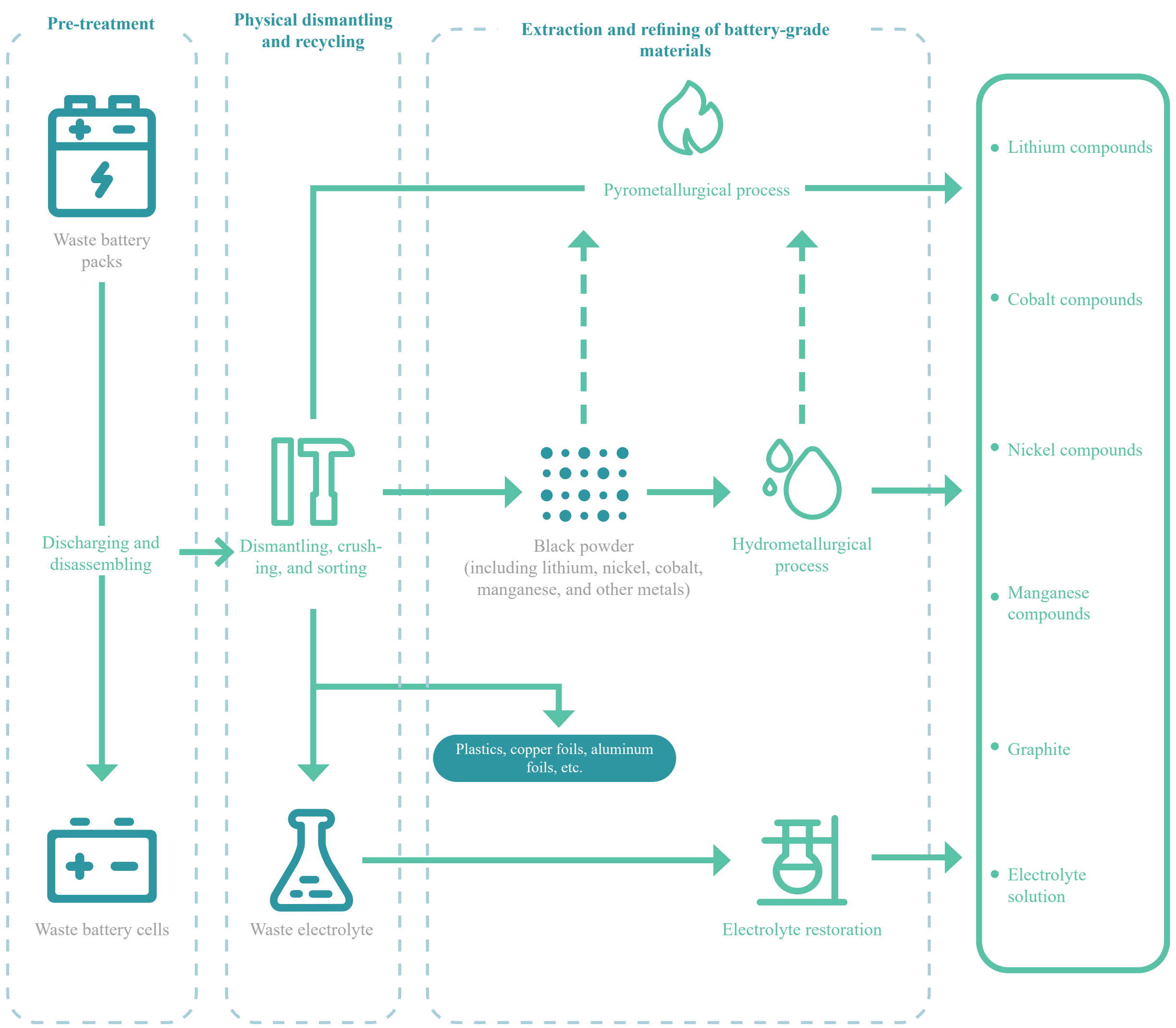


Figure 10. Typical Process for The Recycling of Power Battery Materials (Deloitte, 2022)

Currently, there are three main power battery recycling processes in the market: pyrometallurgical recycling, hydrometallurgical recycling, and direct recycling. The advantages and disadvantages of these different processes are compared in Table 7.

Table 7. Comparison of Power Battery Recycling Processes

(IEA, 2021c, Deloitte, 2022; Huatai Securities, 2022; CITIC Securities, 2022)

Method		Process	Advantages	Disadvantages
Hydro-metallurgy	Inorganic acid leaching	The metals of lithium and cobalt can be leached out using hydrochloric acid, nitric acid with hydrogen peroxide, sulfuric acid with ethanol, or phosphoric acid with hydrogen peroxide. Among them, the use of phosphoric acid with hydrogen peroxide allows for the direct separation of lithium iron phosphate and ternary lithium materials, which are positive electrode materials for lithium batteries.	The method offers advantages such as low cost and high leaching efficiency. Some processes, such as phosphoric acid with hydrogen peroxide, are suitable for the separate recovery of LFP and NCM positive electrode materials from mixed lithium batteries.	It generates toxic gases and acidic wastewater, requiring high equipment requirements.
	Organic acid leaching	In addition to the commonly used formic acid, there have been attempts to use oxalic acid and citric acid for leaching, which can achieve higher lithium recovery rates.	This method requires fewer steps, is easy to operate, and allows for high recovery of positive electrode materials.	It requires a large amount of reagents, resulting in incomplete leaching, a slow leaching rate, and high costs of organic acids.
	Supercritical fluid leaching	Supercritical CO_2 or supercritical water can be used for impregnation, followed by leaching with sulfuric acid and hydrogen peroxide to obtain lithium and cobalt through electrodeposition.	This method achieves high leaching rates.	It has high equipment pressure and temperature requirements, leading to high energy consumption.
Pyrometallurgy	Vacuum thermal decomposition	Under anaerobic conditions, graphite can react directly with the positive electrode to form lithium carbonate.	This process is relatively short and allows for the direct production of lithium carbonate materials. It also enables the recovery of multiple metals, and the process is relatively simple.	The method requires large equipment investment and has high energy costs.
	Sulfuric acid roasting (pyrometa-llurgy)	By synergistically processing solid waste, cobalt, graphite, and lithium carbonate can be obtained through the roasting of a mixture of negative electrode materials and positive electrode materials.		
	Sulfuric acid roasting (microwave method)	After mixing the positive electrode material with sulfuric acid, acid roasting is performed. The reaction between the sulfate and the positive electrode material yields lithium oxide and cobalt oxide that are then selectively separated based on their solubilities. The lithium is subsequently precipitated using carbonate to form lithium carbonate through selective dissolution, followed by precipitation. Sulfuric acid can be recycled for further use in the process.		
Direct recycling	——	From the perspective of the composition and structure of failed materials, direct recycling aims to address the failure issues of the materials without the need to disrupt their inherent structure, which allows for the regeneration of the material's structure, thereby restoring its electrochemical activity.	The cathode material is not decomposed into elemental components. Instead, its crystal structure is retained for regeneration. This method is particularly suitable for electrodes that contain fewer high-value metals.	It has limitations in terms of flexibility, and requires customized approaches tailored to the specific chemical composition of each cathode material. The recovered cathode material can only be used for the production of batteries of the same type.

The recycled raw materials have a lower carbon footprint, and increasing the proportion of regenerated lithium and other materials can accelerate the decarbonization process in the industry. A study by Chen et al. on NCM811 batteries indicates that batteries produced using regenerated materials from different processes have lower carbon emissions compared with batteries produced using primary materials, of which the hydrometallurgical process (33.4%) and direct recycling process (51.8%) contribute to the most significant savings.

To further reduce the carbon emissions of regenerated power batteries, two main optimization directions are:

Improving the energy efficiency of regeneration processes to reduce carbon emissions in the regeneration process

For pyrometallurgical process, reference can be made to the emission reduction measures applicable to the midstream refining of lithium salt. For hydrometallurgical process and direct recycling, as electricity is the main energy consumption type, shifting towards renewable power can rapidly reduce greenhouse gas emissions during the process.

Expanding the scope of resource recovery to dilute the carbon footprint of regenerated materials

In the stage of battery dismantling and raw material sorting, the separation and subsequent recovery of materials should be enhanced through processes such as multi-stage sorting, advanced oxidation, electrochemical delamination, and coating removal. At the same time, increasing the recycling of other components in addition to the positive electrode materials in batteries, such as electrolytes and separators, can enhance the quantity and value of regenerated materials, thereby diluting the carbon footprint of regenerated materials.

3.4.3 Business forms of circular economy

The establishment of a standardized and streamlined system for recycling used power batteries to ensure a stable battery supply is crucial for promoting the development of the circular economy in the power battery industry. At the same time, a robust battery recycling system can help minimize the risks of safety and environmental hazards caused by unregulated recycling practices and prevent the phenomenon of market competition leading to the dominance of inferior products.

The industry alliance model, promoted by extended producer responsibility systems, is the most traditional power battery recycling model. In this model, an alliance composed of industrial members from the upstream and downstream sectors acts as the main body for collecting and recycling decommissioned batteries, forming a closed-loop cycle for lithium battery recycling and regeneration. The industry alliance model has wide-ranging recycling channels and requires strong technical expertise. Collaboration between upstream and downstream partners in the industry chain can reduce fierce market competition, effectively reduce overall process costs, and enhance overall operational efficiency. However, this model involves significant risk-sharing among members, as companies are bound together within the industry alliance and need to bear the potential risks brought by other members in the battery recycling chain.

In recent years, some members along the industry value chain have expanded their involvement in the decommissioned power battery recycling process, based on their traditional business advantages, leading to the emergence of different forms of power battery recycling models in the market:

Automotive OEM battery recycling model

Building a closed-loop industrial chain of "battery production - vehicle production - battery regeneration - screening and evaluation - reuse" can create economies of scale.

Battery manufacturer battery recycling model

Battery manufacturers, as the main entities for battery recycling, establish an ecological closed-loop of "battery production - use - cascaded utilization - recycling and resource regeneration", which leverage their channel advantages to create a commercial model for closed-loop recycling of battery materials and cascaded utilization of used batteries.

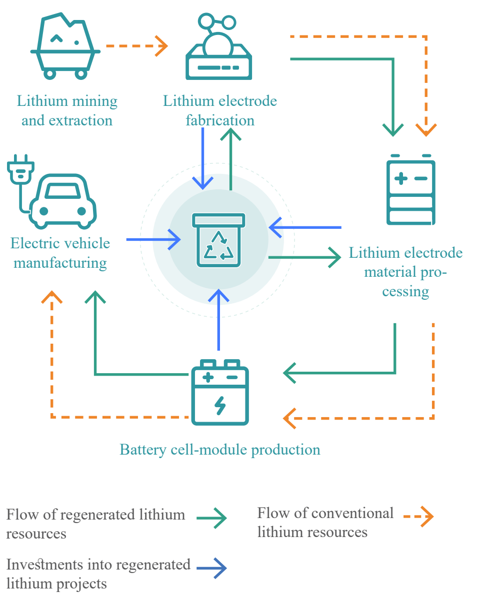
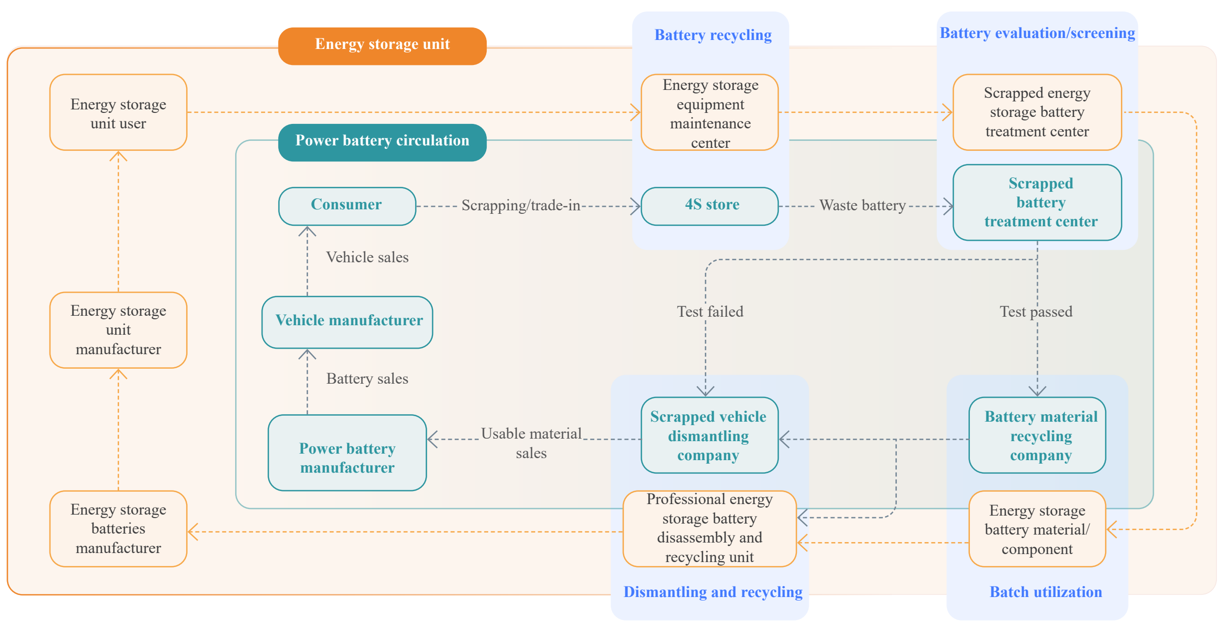


Figure 11. Business Models for the Recycling and Reuse of Electric Vehicle Batteries.

Independent manufacturer battery recycling model

The independent battery recycling model revolves around the regional value chain of NEVs and establishes a recycling network to complete the closed loop from battery recycling to the sale of electrode materials. After establishing the supply and procurement agreements with customers, independent battery recycling manufacturers determine the layout of recycling facilities to form stable channels for recycling and sales.



Research on decommissioned power battery recycling

Tianqi Lithium focuses on the research of the recycling of decommissioned power batteries, and cooperates with third parties to establish a company specializing in R&D of resource regeneration technology, as well as recycling and cascade utilization of decommissioned power batteries. Through extensive collaboration with value chain participants, Tianqi Lithium aims to ensure the green disposal of decommissioned power batteries, which will contribute to reducing global reliance on primary lithium resources and mitigating the climate impact of lithium extraction. We will continue to explore potential opportunities to incorporate regenerated lithium salt into our product portfolio.

Research and development of comprehensive utilization technologies for mineral resources

Tianqi Lithium is actively involved in the research and development of comprehensive utilization technologies for mineral resources, and by 2021, the Company had established the basic capability to carry out comprehensive recycling and utilization of lithium slag resources through the construction of a related laboratory. In 2022, the Company conducted research on the comprehensive recycling and utilization of lithium slag from two lithium salt plants and successfully developed a process package for production line construction. The developed process package offers advantages such as fewer required chemicals, higher production capacity, reasonable process layout, and energy savings compared with traditional process packages.

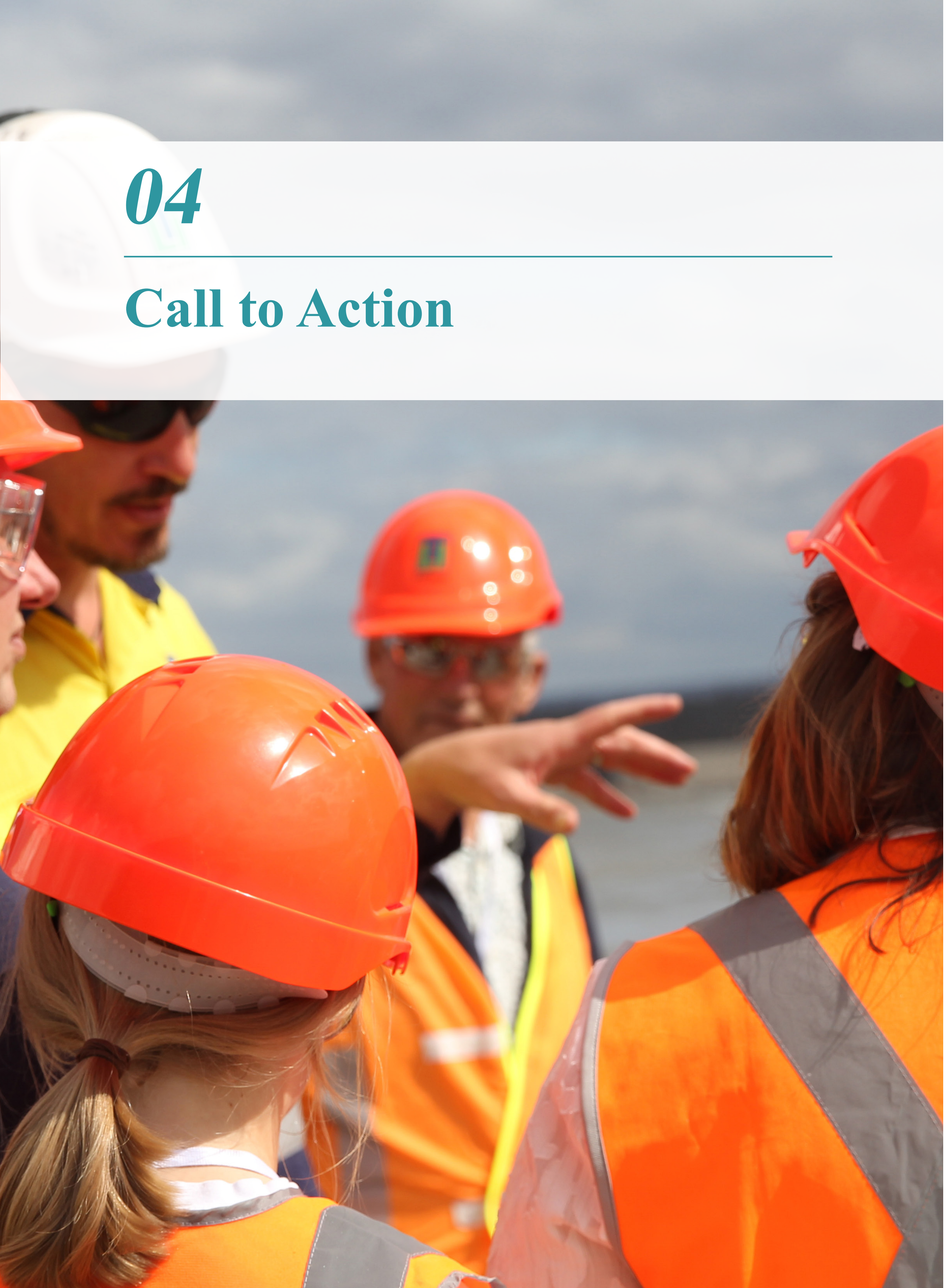
By building a high-value utilization production line for lithium slag, Tianqi Lithium is able to achieve the resource utilization, reduction, and harmless treatment of lithium slag, while providing low-carbon and clean raw materials for downstream industries. Currently, the Company's recycled products from lithium slag include:

- **Silicon-aluminum micro powder:** It reduces the mining amount of ore raw materials in the glass ceramics industry and lowers energy consumption in glass ceramics production. Up to now, Tianqi Lithium has completed the pilot-scale (60t/dry basis) process package output and patent layout for silicon-aluminum micro powder.

- **Tantalum-niobium concentrate:** It finds wide applications in the fields of electronics, biomedical engineering, special alloy, hard alloy, chemicals, superconducting industry, and precision ceramic glass production. Currently, 80% of the tantalum-niobium concentrate is imported. Niobium is used in the production of high-quality steel, while tantalum is utilized in military production. Currently, there is a potential to recover 5 tons of tantalum-niobium from 200,000 tons of lithium slag. The Company completed the pilot-scale test at the end of 2022 and is expected to complete the demonstration-scale test in 2023.

- **High-purity gypsum:** It has extensive applications in various fields such as construction, crafts, sculptures, industrial molds, and healthcare. After the preceding processing and recovery of lithium slag, Tianqi Lithium processes the remaining lithium slag into gypsum.

- **Zeolite processing:** The lithium slag contains silicate components, which can be processed to form porous materials.



04

Call to Action

According to the United Nations Environment Programme (UNEP) Emissions Gap Report, despite the unprecedented decline of greenhouse gas emissions due to COVID-19 in 2020, the emissions (52.8 $GtCO_2e$, excluding LULUCF) in 2021 continued to rise, higher than that in 2019 and hitting a record high.

The world is seeing intensified impact of environmental disasters, from the heat waves and fires in Greece, Siberia, Türkiye and the United States, to the floods in China, Germany, among others, making climate action more urgent than ever. "Unless there are immediate, rapid and large-scale reductions in greenhouse gas emissions, we will be unable to limit global heating to 1.5°C," said UN Secretary General António Guterres. "The consequences will be catastrophic."

To keep up and reach the 1.5°C target, the lithium industry must achieve sustainable growth for clean energy transition and net zero. This section introduces potential actions for different departments to take to facilitate the process.

4.1 Value chain participants »

- Find the way to sustainable growth

Clean energy transition presents both huge opportunities and decarbonization pressure to the lithium industry. The sustainable growth of the lithium industry requires extensive investment and cooperation of participants in the value chain. Many actions will benefit industry players financially and strategically.

Energy efficiency and renewable power

Improving energy efficiency and renewable power is inevitable for the lithium industry to cut greenhouse gas emissions rapidly in the short term and achieve phased emission reduction goals.

Energy efficiency, as one of the most effective ways of reducing emissions, can save enormous costs for companies. Meanwhile, as solar and wind energy become more cost competitive, and there are reforms in the electricity market and more investment in the renewable energy projects, companies face less barriers on the way towards renewable power. Downstream customers promise to purchase raw materials from more efficient manufacturers, which further promotes manufacturers' business decisions.

R&D innovation

The sustainable growth of the lithium industry relies on innovation and breakthroughs in key technologies.

For example, DLE technologies can support scale extraction of lithium from high magnesium lithium salt lake brines, and hydrogen fuel and bio-based synthetic fuel can support natural-gas-based heat decarbonization. Some of these technologies depends on intra-industry breakthroughs while others on inter-industry collaboration. Companies can set a budget specifically for the investment in key technologies and make breakthroughs through independent research and development, external development, cooperative development, investment, etc. By doing so, companies will be able to reduce emissions while improving resource efficiency and creating new revenue streams in sustainable products and services, leading to lower costs and better profitability.

Cooperation between the industry and the government

Influential companies in the industry can call on participants in the value chain and other stakeholders to form alliances, build strategic partnerships and set common goals. The aim is to jointly develop decarbonization methods and standards for the industry, and share experience and achievements in decarbonization.

The government can encourage such activities through meetings, endorsement and financial support. Meanwhile, the engagement with policy makers may influence the industry in decision making and make it prepared for upcoming policy changes or proposals, so as to maximize the overall effectiveness of climate policies.

Product labeling

The industry can develop a certification and labeling system to put labels on qualified power batteries based on the limits set on battery lifecycle emissions and recyclable components.

With certified labels, manufacturers can demonstrate that their products are more sustainable and increase customers' trust and loyalty as a result. They can also better comply with regulations and standards in countries and regions and open up new markets.

Industry data quality improvement

Due to the shortage of data, the data on energy consumption and greenhouse gas emissions in the lithium industry used by many publications are provided by companies a long time ago.

As a result, outsiders may hold misconceptions about the industry's emission status and thus misunderstand the climate impact of production processes and the emission reduction potential of different decarbonization pathways. Lithium salt production companies can regularly calculate and disclose the lifecycle environmental impact of their products, and update the existing data accordingly.

Public education

Public awareness of climate change may affect their daily behaviors.

On the one hand, it's possible to encourage the public to support the sustainable growth of the lithium industry by educating them on the key role of lithium in clean energy transition and providing potential decarbonization solutions. On the other hand, it's possible to dismiss some consumers' potential concerns about electric vehicles and make electric vehicles more acceptable in the market by promoting their advantages in lifecycle environmental impact.

Strengthening climate disclosure

Through climate disclosure, companies help investors understand their assessment of potential climate risks and preparation for stronger business resilience.

This could boost confidence of investors, long-term investors in particular, which is greatly significant for the lithium industry that is expanding with a huge demand for capital. Currently, the TCFD recommendations are the most widely used standards for climate disclosure, providing clear guidance for producing consistent and comparable disclosures of climate-related information (see Tianqi Lithium TCFD report).

4.2 Public sector »

- Strengthening policy framework and mechanisms

Although the industry has been led by regulatory actions towards sustainable development, more oversight is needed to guide business decision-making and offer incentives for systematic change. The portfolio of diversified policy tools combines environmental and economic motivations and brings best environmental benefits and cost-effectiveness.

Tax incentives

Tax incentives are important to stimulate deployment of clean technologies.

For example, in the past decade, China's fiscal subsidy policies for new energy vehicles have greatly promoted the research and development, production, and application of NEV technology. Likewise, the government can provide tax credits or reduction for companies using low-carbon heat to produce lithium products, or tax credits for companies investing in low-carbon heat technology.

Command and control

Command-and-control policy tools define the mandatory requirements for companies.

From the technical perspective, it's possible to require the lithium salt processing industry to stop using specific fossil fuels to generate heat after a specific date, or adopt specific low-carbon technology to generate heat. From the perspective of performance, it's possible to set mandatory energy consumption quota or emission quota for the lithium salt processing industry. From the perspective of framework, the government can set qualification requirements for the disposal of decommissioned power batteries and raise the entry threshold for the industry.

Environmental information disclosure

Power battery and automobile manufacturers are required to report emissions or other climate-related information.

Command and control can help make regulators better informed so that these companies can be more reasonably incorporated into other regulatory systems in the future, such as industry standards or emissions trading. At the same time, the report can help the public better understand how different products impact the environment and thus make their purchasing decisions.

Government procurement

Government procurement policy tools can provide a specific market for manufacturers of new products, and compensate for the positive externality of low-carbon innovative technologies.

Urban transportation system, as one of the main buyers of NEVs, has greatly promoted the scale application of NEVs in the past decade. As the industry moves rapidly, the procurement requirements related to climate performance, such as power consumption per 100 km, power battery carbon footprint, lithium content per unit capacity, and so on, could bring major changes and technological innovation and development to the industry.

Government's R&D support

The investment in clean technology R&D by the Chinese government has been surging in recent years, which is critical to the development of many clean technologies.

Heat production is one of the main sources of emissions in many industrial sectors. Developing clean thermal technology is an effective way to eliminate industrial emissions. Hydrogen fuel, ammonia fuel, biomass and bio-based synthetic fuel, geothermal energy, nuclear energy, electrification and other clean thermal technologies have great potential for heat decarbonization. However, these technologies are constrained by technological and/or economic gaps to various degree, which can be bridged by the government's R&D support.

Infrastructure development

Infrastructures, such as electric power transmission lines or hydrogen pipelines, are needed to transit to clean industrial heat.

The government can play a key role in promoting or directly developing such infrastructures through licensing, financing, etc.

4.3 Financial institutions

- Prioritizing innovative investment and financing opportunities

Financial institutions can fund low-carbon transformation and sustainable development of the lithium industry. To make full use of capital and achieve net zero, it is necessary to develop diversified financial products for the transformation, ensuring more financial support in key areas of sustainability of the lithium industry.

Financial product construction:

Loan products

The green / sustainable loan provides funds and preferential interest rates for eligible projects in the lithium industry, which can promote energy-saving and emission reduction actions and optimize energy mix of the industry. Prior to the issuance of green loans, banks can evaluate the overall environmental benefits of projects through an industrial green assessment system, in order to avoid funding potentially non-compliant companies. Meanwhile, the government can subsidize to motivate banks to carry out green credit business.

Bond products

The green / sustainable bond is another way to finance environmental projects. Financial institutions can evaluate and identify qualified green assets in the same way applied in green loans. In recent years, there are bonds linked to sustainability without requirements for companies to use funds for environmental projects. Instead, such bonds require companies to fulfill certain sustainable development commitment, so as to ensure that the return of bonds is linked to environmental benefits. It can also potentially finance areas key to decarbonization of the value chain, such as salt lake lithium extraction and power battery recycling.

Investment products

By considering environmental factors during the portfolio allocation, investors can fund companies that meet environmental standards. To ensure excellent environmental performance of funded companies, investors can develop targeted climate indicators, such as energy consumption per unit product and greenhouse gas emissions of lithium salt producers, and refer to external ESG rating systems, such as MSCI, S&P CSA, and CDP. Inclusion of these indicators into strategies of investment screening or integration can help investors identify potential climate leaders.

Insurance products

One of the ways to reduce uncertainties in the implementation of climate actions by the lithium industry is to provide innovative green insurance, so as to help these projects get easier access to approval or investment and create business opportunities for insurance companies. For example, insurance companies can insure renewable energy projects to make sure that project owners save certain costs at least annually. Insurance companies can also insure alternative projects of energy efficiency and clean heating technology to make sure that project owners save certain costs and reduce potential risks of project delay every year.

Disclosure of influence:

Transparency and credibility are crucial for the sustainable development of green finance. To this end, financial institutions should efficiently communicate with companies supported by green finance to regularly understand progress and performance of their projects, and disclose the environmental impact of their green finance products annually. This helps financial institutions evaluate how effective and defective the products are, and also increases public awareness and recognition of green financial products.

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Tianqi Action

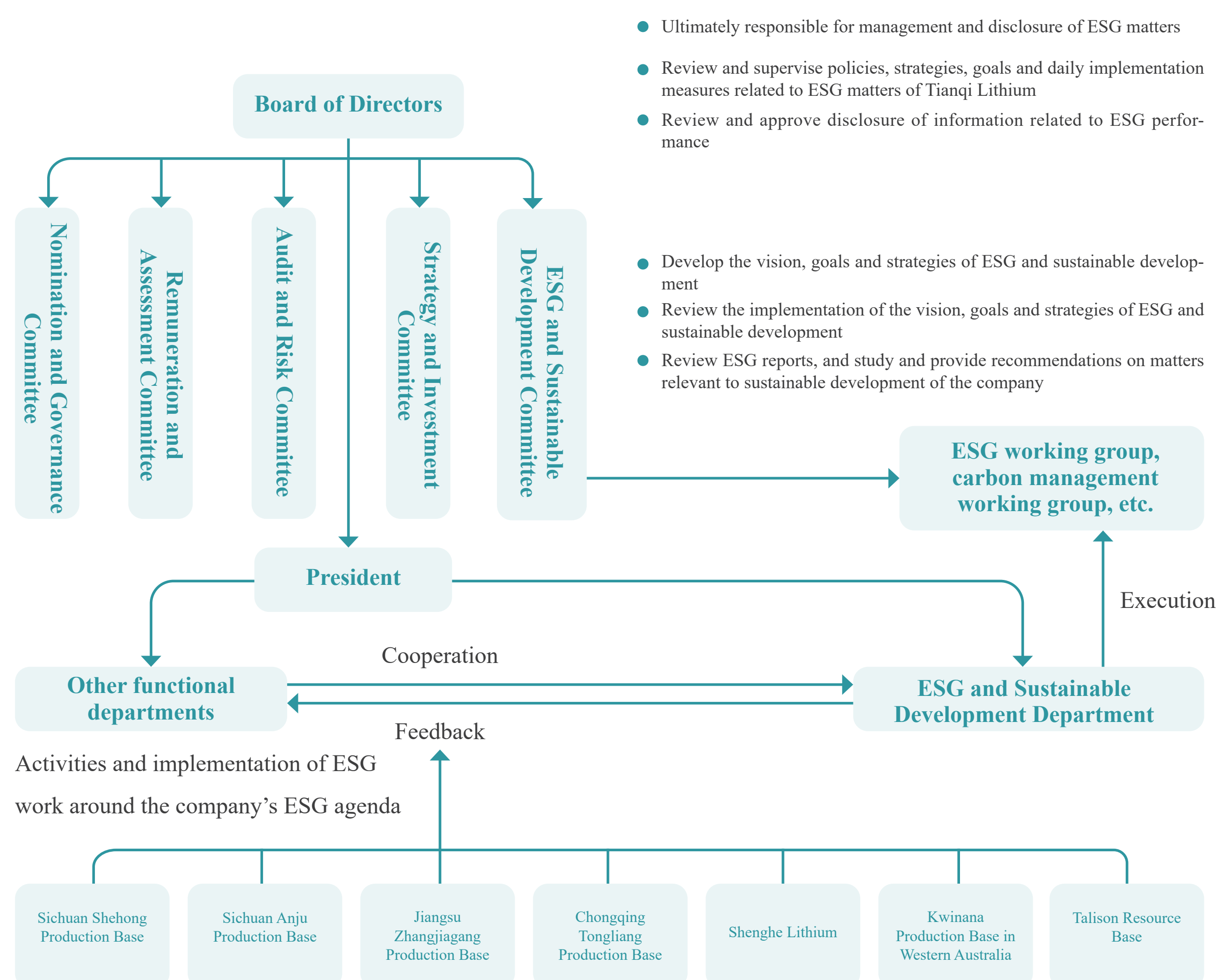
2022 Tianqi Lithium Task Force on Climate-related Financial Disclosure (TCFD) Briefing

Governance

Tianqi Lithium has built a sound climate governance framework to promote the design and implementation of its low-carbon strategy. The company delegates climate-related matters to the ESG and Sustainable Development Committee, which has a group specifically managing climate-related matters. The Board of Directors supervises climate-related issues through the ESG and Sustainable Development Committee.

The ESG and Sustainable Development Committee mainly develops and reviews the company's vision, goals, and strategies related to the climate change, and provides recommendations to the Board of Directors on necessary climate actions for better performance. The ESG and Sustainable Development Committee also examines external trends, risks and opportunities related to the climate change to minimize the negative impact of climate risks, and supports the company in seizing climate-related business opportunities.

ESG and Sustainable Development Governance Structure



Strategies and risk management»

Tianqi Lithium's climate risk management is under the scope of its ESG and Sustainable Development Committee, and included in its overall risk management system. We continue to incorporate the findings of climate risk management into our strategic planning to boost our climate resilience in different potential world scenarios. Generally, our climate risk identification process includes:

- Top-down risk assessment: refer to TCFD recommendations, climate publications, and industry disclosures, and consider the impact of various climate risks on strategies and businesses
- Bottom-up scenario analysis: assess the strategic resilience of the Company in various climate scenarios commonly used around the world
- Importance assessment: engage with stakeholders to assess their level of concern, and rate potential business impacts

Tianqi Lithium Risk Management System

1 First Line of Defense

Business units

2 Second Line of Defense

Functional supervision departments

Risk Management Department

3 Third Line of Defense

Audit and Risk Committee

ESG and Sustainable Development Committee

Internal auditing

The results of our assessment of climate risks and opportunities in 2022 are as follows:

Risks

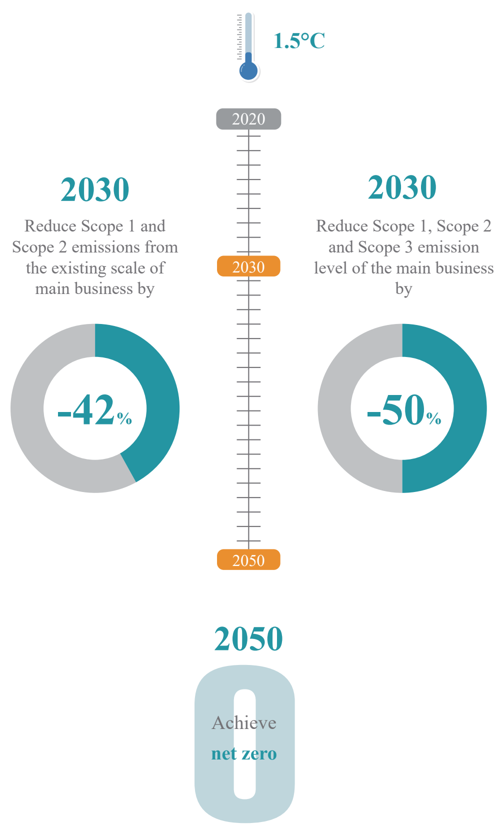
Type	Category	Risk Description	Possibility	Potential Financial Impact	Countermeasures
Transformation risks	Market uncertainty	The price of raw materials and sensitivity of automobile manufacturers lead to the uncertainty in the future market size of various power batteries. The main raw material of high-nickel ternary lithium batteries is lithium hydroxide, while that of lithium iron phosphate batteries and low-nickel ternary lithium batteries is lithium carbonate. Changes in the power battery market will affect the demand for different types of lithium salts. If Tianqi Lithium's capacity expansion plan is inconsistent with the demand growth in downstream markets, its revenue may decrease resulting from the declining product demand.	Medium	High	• Keep monitoring and predicting market demands • Build production bases for different products • Adopt flexible production lines
	Changes in consumer behaviors	More and more automobile manufacturers have paid attention to greenhouse gas emissions throughout the entire value chain and set net zero targets. Given that lithium-ion batteries are one of the major sources of greenhouse gas emissions in the production of electric vehicles, the emission reduction needs of automobile manufacturers may cause manufacturers of power batteries and lithium positive electrode materials to incorporate greenhouse gas emissions into their procurement requirements in the future. Failure to meet these requirements may lose customers to other suppliers with better environmental performance.	High	High	• Calculate the carbon footprint of major products and share the results with customers • Set product carbon intensity targets and implementation plans
	Increase in raw material costs	Spodumene is an important raw material of lithium salt. Since the end of 2020, the undersupply of lithium salt resulting from strong global demand has driven the continuous rise in the prices of spodumene and lithium salt. Lithium concentrate is the main source of lithium for Tianqi Lithium, and the price rise of spodumene and its auxiliary materials due to undersupply will put up the procurement costs.	High	High	• Invest in upstream mineral resources

Type	Category	Risk Description	Possibility	Potential Financial Impact	Countermeasures
Transformation risks	Carbon pricing mechanism	Since 2013, China has launched seven regional carbon markets. The national carbon market was officially launched in 2021 and is only applied for the power generation industry now. Tianqi Lithium's production base in Tongliang, Chongqing is most likely to be included in the carbon market. According to the latest regulations of the Chongqing Ecology and Environment Bureau, industrial companies that recorded greenhouse gas emissions of 13,000 tons of carbon dioxide equivalent or above in any year from 2018 to 2020 should be included in the list of the key greenhouse gas emission companies in 2021 for quota management.	Medium	Medium	• Set up budget for energy efficiency, carry out energy efficiency projects in various production bases, and link project progress to performance
	Transition to low-emission technologies	Heat-related emissions are the main source of greenhouse gas emissions in lithium salt production, and the focus of lithium salt producers in long-term emission reduction. Currently, natural gas is the major energy for lithium salt production. The transition to net zero inevitably requires a shift towards greener heat sources, such as electricity and hydrogen energy. However, many chemical companies, including Tianqi Lithium, have rotary kilns and other core equipment with decades of years of service life For most of the time, the transformation of rotary kiln is either unfeasible or expensive. This means that building new factories blindly to meet future emission reduction needs may lead to shocking carbon lock-in, which further prevents companies from achieving emission reduction targets or forces assets to be decommissioned in advance.	Medium	High	• Adopt shadow pricing methods to make the costs of greenhouse gas emissions part of the ROI measurements
	Increased concerns or negative feedback from stakeholders	As investors are increasingly interested in issues related to the climate change, a lack of action or inadequate information disclosure may cause them to withdraw investment.	Medium	Low	• Regularly disseminate sustainable development performance through sustainable development reports and other media channels
Physical risks	Increase in severity and frequency of extreme weather events	Climate change may lead to sea level rise, change of rainfall and fresh water level, increased extreme weather events, and resource shortages. Long-term drought may cause Tianqi Lithium to suffer water shortage in operation. Extreme weather events (wind) and sea level rise will disrupt the ocean transportation of Tianqi Lithium.	Medium	Low	• Develop emergency response plans for extreme weather events

Opportunities

Type	Category	Opportunity Description	Possibility	Influence	Countermeasures
Resource efficiency	Energy efficiency	The refining of lithium salt is an energy-intensive process which mainly consumes electricity for E-drive equipment powering and natural gas for roasting and chemical treatment. As the most attainable deliverable of emission reduction, energy efficiency projects can help companies save energy costs remarkably while reducing greenhouse gas emissions.	High	Medium	• Set up budget for energy efficiency, carry out energy efficiency projects in various production bases, and link project progress to performance
	Recycling	The production of lithium salt will produce a large amount of lithium slag, which is mainly composed of inorganic lithium compounds, organic solvents, electrolytes and other impurities. Recycling and utilizing the valuable lithium in lithium slag can effectively save resources, reduce environmental pollution, and bring economic benefits.	High	Medium	• Conduct research on the comprehensive recycling and utilization of lithium slag
Products and services	Development and/or expansion of low-emission products and services	Green transportation is the key to global net zero, with the popularization of NEVs as the critical path to decarbonize the transportation sector. Many countries have issued directives on the zero emission vehicle. For example, the EU and Canada have announced plans to ban the sale of CO_2-emitting vehicles by 2035. Lithium is a key positive electrode material for power batteries, and the midstream lithium salt processing companies will see a surge in product demand.	High	High	• Expand production capacity of existing production facilities • Build new production facilities in China and Australia
Market	Entry to new markets	A large number of NEVs will be decommissioned in the near future, and the expired power batteries can either be recycled or reused, both of huge potential. Midstream lithium salt processing companies can enter the lithium battery recycling and regeneration market to refine the positive electrode materials in the end-of-life batteries.	High	Medium	• Cooperate with third parties to establish a company specializing in R&D of resource regeneration technology, as well as recycling and cascade utilization of decommissioned power batteries

Indicators and goals »

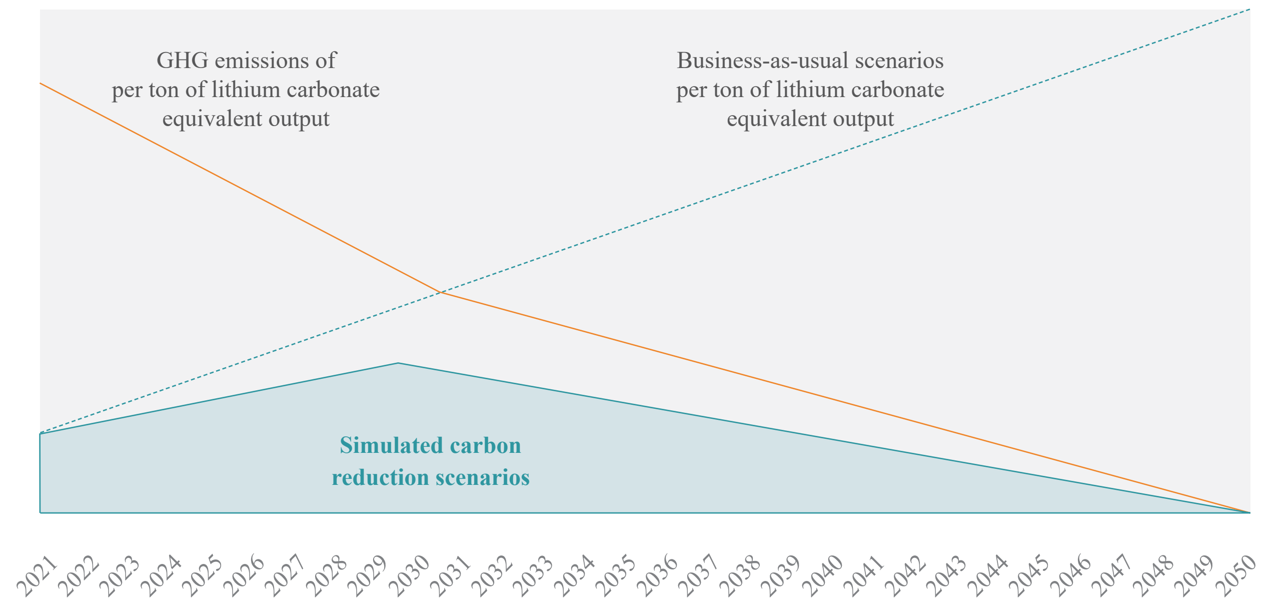


Tianqi Lithium is committed to transparency in climate performance. In the past few years, we have been collaborating with trustworthy institutions to understand our performance of greenhouse gas emissions and important opportunities of emission reduction.

As a leading new energy material company with lithium at our core, we believe that we have the scale and influence to facilitate the process towards net zero by 2050, and uphold the responsibility of implementing climate actions. We hereby make a commitment to climate impact mitigation:

Tianqi Lithium will continue to reduce Scope 1 and Scope 2 emissions from the existing scale of its main business by over 42% by 2030 compared to the baseline year . During the period, it will give priority to low-carbon technologies for the newly expanded business scale of its main business, and encourage core suppliers to set the same or higher emission reduction targets and cut emissions from outsourcing of raw materials and services, and upstream transportation in their main business. The ultimate goal is to reduce Scope 1, Scope 2, and Scope 3 emission level of its main business by 50% by 2030 compared to the baseline year, and achieve net zero by 2050.

*Base year: 2021
*Main business: development of hard-rock lithium ores, processing and sales of lithium concentrates, and production and sales of lithium-based chemical products.
*Existing business scale: the scope of business that has reached designed production capacity in the base year.
*Newly expanded business scale: the scope of business that reaches designed production capacity after the base year.
*Emissions: the greenhouse gas accounting results (absolute value) of companies in accordance with GHG Protocol, ISO 14064, and other regulations.
*Emission level: the emission (intensity value) per unit output (economic indicators or physical indicators, such as tLCE, or lithium carbonate equivalent per unit product) of business activities.
**Net zero: the emission reduction quota required to achieve the 1.5°C target in the target year in compliance with the definition and requirements of net zero in ISO Net zero guidelines (IWA 42:2022).



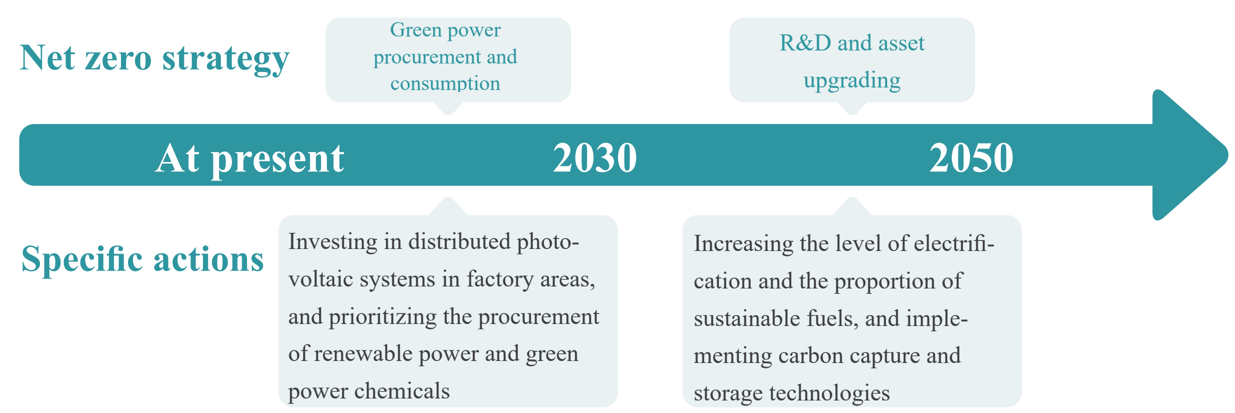
To achieve net zero by 2050, Tianqi Lithium will undertake the following actions in stages:

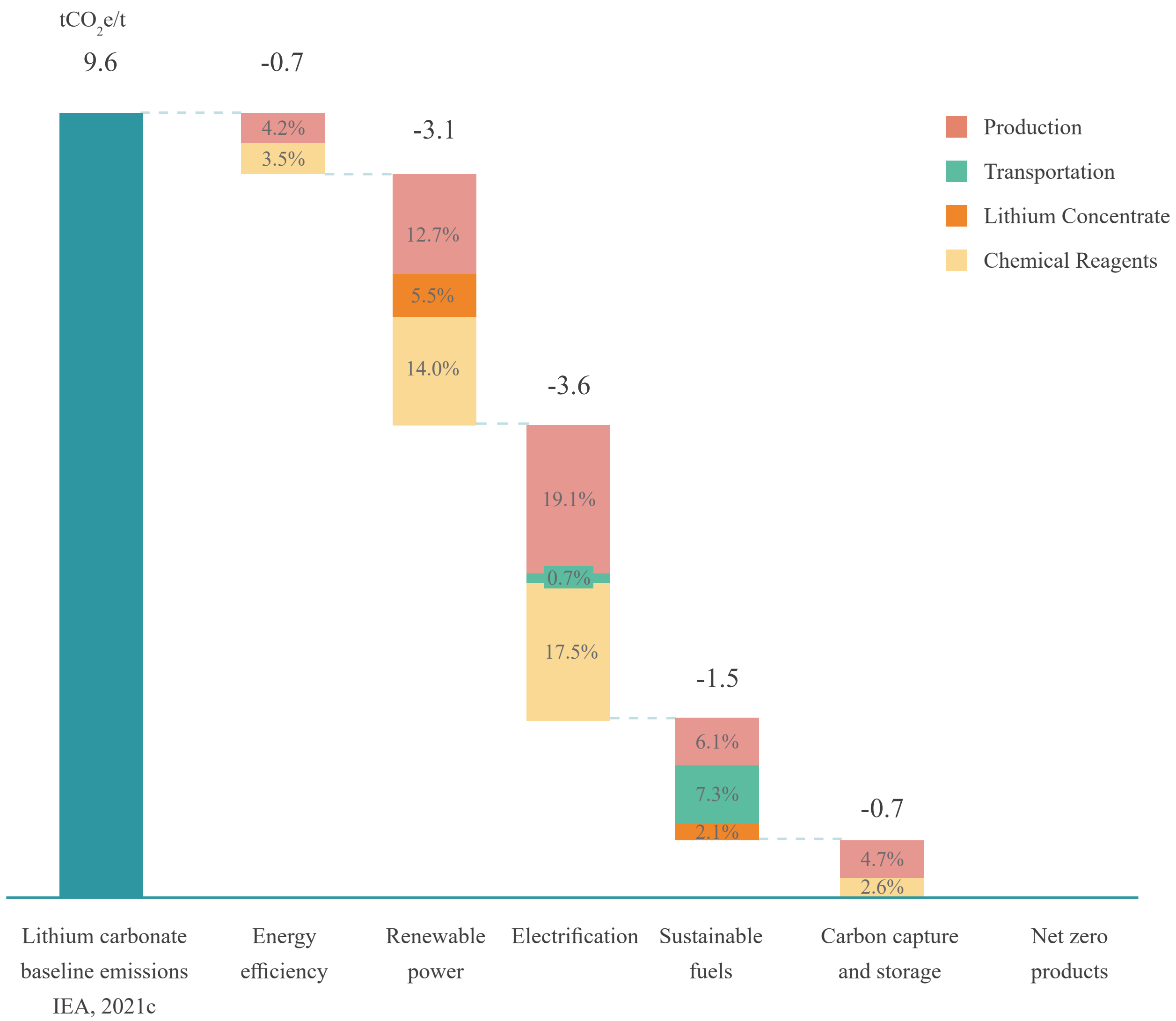
From now until 2030

Tianqi Lithium will focus on the strategy of green power procurement and consumption to enhance energy efficiency and increase the proportion of renewable power. Specific actions include investing in distributed photovoltaic systems in factory areas, and prioritizing the procurement of renewable power and green power chemicals.

From 2030 to 2050

Tianqi Lithium will emphasize R&D and asset upgrading strategies to explore the development of green power thermal steam systems, carbon-neutral natural gas systems, and efficient CO_2 recycling systems. Specific actions include increasing the level of electrification and the proportion of sustainable fuels, and implementing carbon capture and storage technologies.





Although we are committed to net zero by 2050 and mid-term goals, we are aware that external uncertainties may affect our schedule and plans. These uncertainties include the development of key technologies, regional policies and requirements, and decarbonization progress of other industries. We will keep our progress towards targets transparent and update any changes resulting from potential uncertainties in a timely manner.

Special Acknowledgments and List of Editorial Board Members

The White Paper on Sustainable Lithium Industry in Achieving Net Zero White Paper (referred to as the "White Paper") reviews the development history of lithium, analyzes the main opportunities and challenges faced by the industry, and presents strategies from the perspective of the entire industry chain to guide the net zero transition and sustainable development of the lithium industry. At the same time, the White Paper issues a call to actions and initiatives for relevant industry players to jointly achieve net zero of the lithium industry by 2050.

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