Industry Chain and Technology Trends in China's Solid-state Battery Industry

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Abstract. Solid-state battery is different from traditional lithium-ion battery, which is a kind of battery using solid electrode and solid electrolyte, and it has the advantages of high safety, long life, high charging and discharging efficiency, good high temperature resistance, simple assembly and processing, and easy to scale up. This paper first analyzes the industrial chain of solid-state batteries in China and the stakeholders in the process of industrial development, and finally draws a technology roadmap for the development of China's solid-state battery industry based on industrial characteristics. In the future, along with energy transformation and national policy support, the focus should be on solid state electrolytes for solid state batteries, and gradually realize the development path of solid state battery electrolytes from liquid state of traditional lithium-ion batteries to solid-liquid hybrid, gel, solid state, and all-solid state.

1. Introduction

Nowadays, energy shortage, competition for resources and environmental pollution caused by excessive use of energy are threatening the survival and development of human beings. The active development of practical and efficient new energy, the use of technology and rational use of new energy is an important way to promote energy conservation and emission reduction, improve the energy structure, and promote the development of social and economic development. Therefore, the United States, Canada, Japan and the European Union are actively developing new renewable energy sources such as solar energy, wind energy, ocean energy (including tidal energy and wave energy), or turning their attention to new fossil energy sources such as submarine combustible ice (hydrated natural gas). At the same time, fuels such as hydrogen and methanol have received a lot of attention as alternatives to gasoline and diesel. Finding alternative energy sources and improving energy efficiency have become the fundamental demands and solutions to the global energy crisis. China is even vigorously developing new energy vehicle industry to promote energy transformation.

With the continuous promotion of new energy vehicles, new energy vehicle batteries have been flourishing as the three core components. At this stage, the first choice of vehicle power battery is the traditional lithium-ion battery, i.e., liquid electrolyte lithium-ion battery. According to the different cathode materials, traditional lithium-ion batteries are divided into two categories: lithium iron phosphate batteries and lithium cobalt batteries. Although the traditional lithium-ion battery has its own advantages, he usually uses organic liquid electrolyte and gel electrolyte, there are volatile, flammable, explosive and other safety hazards. Therefore, scholars have sought to develop a new type of power battery with higher safety and longer range, such as solid-state batteries. Solid-state batteries are a new type of high-safety lithium secondary batteries that replace the liquid electrolyte in traditional lithium-ion batteries with a non-flammable solid electrolyte, in which lithium ions are embedded and dislodged between the positive and negative electrodes and exchange charge with electrons to achieve electrical and chemical energy conversion.
Solid-state batteries have a series of unique advantages such as high safety, long life, high charging and discharging efficiency, good high temperature resistance, simple assembly and processing, and easy to scale up. [1, 2] Solid-state batteries not only open up the possibility of economic, reliable and lightweight development of power batteries, but also make it the future development direction of power batteries and play an important role in promoting the development of new energy industries such as new energy vehicles and battery energy storage in the future. In order to implement the State Council's decision to develop strategic emerging industries and strengthen energy conservation and emission reduction, accelerate the cultivation and development of the energy-saving and new energy vehicle industry, and promote the healthy and orderly development of the all-solid-state lithium battery industry, China has introduced a number of support policies, providing an opportunity for the development of solid-state battery technology. [3-5]

China's policy not only makes clear requirements for the development of power batteries in terms of technical indicators, but also has important implications for strengthening the cooperation among universities, research institutions and key supporting enterprises. In addition, a series of industrial plans are the guideposts for the rapid development of the solid-state battery industry, so it is valuable for the development of new energy industry and energy upgrading to clarify the industrial chain and the trend of technology evolution of solid-state batteries in China.

2. Solid state battery industry chain

China's solid-state battery industry is mainly in the R&D stage, and the R&D system has basically achieved full industry chain coverage. The whole industry chain can be divided into three major areas: upstream raw materials, midstream key materials (cathode materials, anode materials, electrolyte, diaphragm and other materials), and downstream battery assembly and battery applications. Nowadays, China has basically realized the full coverage of the solid-state battery industry chain, as shown in Figure 1.

![Figure 1 Solid-state battery industry chain](image)

2.1. Upstream: raw materials

The research and development of solid-state batteries and lithium-ion batteries are based on the same technology, so there is little difference between the two in terms of raw materials. The focus of R&D in China's solid-state battery industry is mainly on finding suitable solid-state electrolytes, and the raw materials commonly used in solid-state batteries currently include: lithium, cobalt, manganese, nickel, carbon, silicon, copper and aluminum. These materials can be used as raw materials for the production of battery components such as electrode materials, encapsulation materials, power management, integrated systems, cells and power management components for solid-state batteries.
2.2. Midstream: key materials
The midstream key materials of solid-state batteries mainly include cathode, electrolyte and cathode, and all structures are composed of solid-state materials.[4, 6]

- **Anode materials:** The anode of all-solid-state battery generally adopts composite electrode, which includes solid electrolyte and conductive agent in addition to electrode active material, and plays the role of transferring ions and electrons in the electrode. Oxide anodes such as LiCoO2, LiFePO4 and LiMn2O4 are more commonly used in all-solid-state batteries.

- **Negative electrode materials:** mainly metal Li negative electrode materials, carbon group negative electrode materials, oxide negative electrode materials. Among them, metal Li cathode materials become one of the most important cathode materials for all-solid-state batteries because of its high capacity and low potential.

- **Electrolyte:** There are mainly polymer solid state electrolyte, oxide solid state electrolyte, oxide crystalline solid state electrolyte and sulfide glass and glass-ceramic solid state electrolyte. [6, 7]

2.3. Downstream: application areas
Solid-state batteries have the characteristics of high energy density, high safety, light weight and strong cycling ability, and have the prospect of wide application. At present, the main task of Chinese solid-state battery enterprises is to find suitable solid-state electrolyte materials and make batteries that can be commercially applied, which is still some distance away from commercial mass production and commercial application. Among the application fields, the target application areas of solid-state batteries mainly include: consumer electronics, electric transportation and industrial energy storage. Among them, solid-state batteries used in industrial energy storage can serve as a buffer between multiple power sources and stable power demand, increasing the power generation capacity of unstable power sources like wind and solar. Energy storage systems are particularly effective for renewable energy providers, grid companies and end users. Solid-state battery energy storage systems can be used in all parts of the power supply value chain to convert intermittent renewable power sources such as wind and solar into stable power output.

3. Stakeholders in China's solid state battery industry
China has strong advantages in developing the battery industry for new energy vehicles, with strong financial and policy support from the government, strong energy enterprises, and abundant talents, and the hardware and software conditions in all aspects have laid a good foundation for the rapid development of the battery industry. Since the 1970s, Chen Liquan, a physicist at the Chinese Academy of Sciences, started the research of solid electrolyte and solid state battery in China. China's solid-state battery industry has multiple stakeholders, including the national government, local governments, research institutes, enterprises and institutions, as well as upstream and midstream raw material suppliers and downstream battery assembly enterprises, and the application areas of solid-state batteries are mainly in consumer electronics, electric transportation and industrial energy storage.

3.1. In terms of government clusters
China's central government, guided by the national electric vehicle industry and energy storage industry strategy, has introduced a series of policies to promote the development of solid-state battery industry, forming a policy system of strategic planning, technical standards and industry norms. Local governments also rely on central government policies and actively launch policies that meet local conditions. Among them, Beijing, Shanghai, Shenzhen, Chongqing, Hangzhou and other municipal governments have issued a number of notices to promote the development of the battery industry.

3.2. In terms of industrial clusters
The current battery industry cluster is mainly composed of research institutes, enterprises and institutions, as well as enterprises at various nodes of the industry chain. Among them, China's battery industry has already invested a certain scale in scientific research, including a number of research institutes and enterprises and institutions.
The research results of scientific institutions are more prominent in the Chinese Academy of Sciences and its affiliated institutes, the 18th Institute of Electronic Science and Technology of China, University of Science and Technology Beijing, Beijing University of Technology, Tsinghua University, Tsinghua University Shenzhen Graduate School, Peking University, Central South University, Nanjing University, etc. The research progress is reflected in the research of positive and negative electrode materials for batteries, the research of electrolyte materials, the improvement of interface problems, the in addition, a series of research results have been achieved in polymer electrolyte, oxide and sulfide electrolyte, interface and electrode. In addition, Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences has conducted research in the field of power lithium battery technology, from new positive and negative electrode materials, graphene preparation and application, high energy density power lithium batteries and new concept power batteries.

4. China solid state battery industry technology roadmap

According to the analysis and generalization of the literature[5, 6, 8], the following characteristics of China's all-solid-state battery industry technology route: 1) from the electrolyte point of view, the liquid content in the cell decreases year by year, and the liquid electrolyte is gradually transformed into a solid-liquid mixed electrolyte, and finally replaced by an all-solid-state electrolyte; 2) the content of lithium metal in the negative electrode of the battery gradually increases, and finally reaches an all-solid-state battery with pure lithium metal as the negative electrode material. 3) the positive electrode of the battery is transformed from lithium iron phosphate into lithium iron phosphate, ternary and other materials gradually transformed into an all-solid-state battery with sulfur and air as the cathode material. Meanwhile, China's all-solid-state battery industry technology roadmap is summarized through interviews with several domestic battery industry experts, as shown in Figure 2.

![Figure 2](image-url)

**Figure 2** China's all-solid-state battery industry technology roadmap

The study found that China has strong R&D capability in solid-state batteries at this stage, but needs to make further breakthroughs in key technologies, common technologies and equipment manufacturing technologies for solid-state batteries. The key technologies include: graphene, carbon tube sulfur carbon composite cathode and other technologies; polymer cross-linked nano-composite electrolyte, nanomicrocrystalline glass ceramic electrolyte and other technologies; nano-layer electrolyte protection technology lithium negative electrode, positive and negative material interface modification and other
technologies. Failure to solve key technical problems will lead to a lag in the industrialization of Chinese solid-state batteries, with a lag time of about 3 to 5 years compared to the global solid-state battery industry path.

Overall, China's all-solid-state battery technology is mainly at the primary R&D testing stage, and the overall technology is not yet mature, mass production has not yet been realized, and no complete industrial chain structure has been formed. The development of key battery materials has laid the foundation for the industrialization of high-capacity all-solid-state lithium-ion batteries, however, there are still some urgent problems that need to be solved.

- The conductivity of electrolytes is still low, resulting in poor battery multiplication and low temperature performance, in addition to poor compatibility with high voltage cathodes, and new polymer electrolytes with high conductivity and high voltage resistance need to be developed. Oxide crystalline electrolytes need to further reduce the grain boundary resistance and improve the conductivity. Sulfide solid-state electrolytes are very sensitive to humidity, resulting in harsh preparation conditions and increased costs, so improving the air stability of sulfide electrolytes is an important direction.

- In order to realize the high energy storage and long life of all-solid-state batteries, the development of new high-energy and high-stability positive and negative electrode materials is really necessary, and the best combination of high-energy electrode materials and solid-state electrolytes and safety needs to be confirmed.

- There have been serious problems at the electrode/electrolyte solid-solid interface in all-solid-state batteries, including high interfacial impedance, poor interfacial stability, and interfacial stress changes, which directly affect the performance of the battery. The development of new or optimization of existing electrode materials to reduce the bulk effect, etc. Although there are many problems, in general, the development prospect of all-solid-state batteries is very bright, and it is the trend to replace the existing lithium-ion batteries as the mainstream energy storage power source in the future.

5. Conclusion

The application of solid-state batteries greatly reduces energy consumption and heavy metal pollution, making a significant contribution to the success of environmental protection. At the same time, for safety reasons, there is a huge market demand for all-solid-state batteries. Although all-solid-state lithium batteries have made considerable progress in the past few decades, it will still take some time to realize their large-scale industrialization.

The use of solid electrolyte instead of liquid electrolyte and the development of all-solid-state battery is the fundamental way to solve the safety problem of Li-ion battery. From a theoretical point of view, although the manufacturing equipment of solid-state lithium batteries is quite different from the traditional lithium-ion battery cell preparation equipment, there is no revolutionary innovation. Therefore, the realization of solid-state battery industrialization depends entirely on the breakthrough of specific material technology and battery technology solutions. Once the process breakthrough of key materials, electrode, positive and negative electrodes and electrolyte matching, industrialization can be realized relatively quickly.

At this stage, with the strong support of national policies, many enterprises and research institutes have invested in the R&D process of all-solid-state batteries, with their focus mainly on three aspects: cathode materials, anode materials and solid-state electrolytes. The continuous evolution of the downstream industry of solid-state batteries will certainly promote the development of the solid-state battery industry, especially with the widespread application of new energy electric vehicles, accelerating the innovation of ternary lithium-ion batteries and other batteries, further guiding the development of a new generation of power batteries - all-solid-state batteries in the direction of safety, long life and high temperature resistance. Once there is a breakthrough in core technology, solid-state battery will be widely used in aerospace, consumer electronics, new energy vehicles and other fields, making great contribution to the improvement of national competitiveness.
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Acknowledgments

Special thanks to Prof. Ari Kokko for my help, who come from Copenhagen Business School. And this paper’s financial support was provided by the Fundamental Research Funds for the Central Universities (funding project coded: 2020YJS054). At the same time, this paper also gets the financial support by State Grid Energy Research Institute Co. LTD (funding project coded: B20SK00641).