

# Analysis of Innovation Trends in Energy Storage Safety Technology based on Patent Data

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**Abstract:** Against the backdrop of energy transition and the large-scale development of renewable energy, the significance of energy storage technology has become increasingly prominent. Based on the data of invention patents, this paper analyzes the innovation situation of global energy storage safety technology, providing a reference basis for future patent research and industrial planning in the field of energy storage safety. Through the global and Chinese patent application volumes, the research comparatively analyzes the application situations of the main source countries and main applicants of patents, and analyzes the innovation situation of energy storage safety technology by combining research methods such as technical structure comparison and value degree comparison. The study finds that global energy storage safety innovation is in a relatively active period. China takes the leading position in the total amount of patent applications, but the proportion of patents with high value is low, and it still lags behind South Korea and the United States. Currently, the main research directions in this field worldwide mainly include battery monitoring and status monitoring, battery protection, fire detection and alarm, fire extinguishing systems, and battery pack structure design.

**Keywords:** Energy Storage Technology; Patent Analysis; Safety; Fire Safety.

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## 1. Introduction

In the current context of global energy transition, with the large-scale development of renewable energy and the continuous increase in the demand for flexibility in the power system, the importance of energy storage technology has become increasingly prominent [1]. Energy storage technology and industry are the keys to building a modern energy system, driving the upgrade of the entire industrial chain, and enhancing the stability of the power grid. They are of great significance for achieving carbon emission reduction, enhancing the national energy competitiveness, and shaping the future energy pattern.

Countries around the world have successively introduced relevant strategies for energy storage technology and formulated a series of policies for the deployment of energy storage technology to promote the development of energy storage facilities. The United States is one of the earliest countries to develop the energy storage industry. Since the 1980s, it has continuously focused on the application potential of energy storage technology in the power system. Nowadays, it has achieved remarkable development in electrochemical energy storage, especially focusing on the wide application of lithium-ion battery technology. In 2011, the US Department of Energy released the "2011 - 2015 Energy Storage Battery Plan", and in December 2020, it released the "Energy Storage Grand Challenge Roadmap". Centering on the three key challenges of domestic innovation, domestic manufacturing, and global deployment in the United States, it proposed 28 specific measures covering five major aspects including policies and evaluation, technology research and development and transformation, workforce development, production and manufacturing, and supply chain, and clarified the phased development goals of the energy storage industry. Since 2020, the European Union has intensively introduced a series of development strategic plans and technology roadmaps for the battery energy storage industry, continuously enhancing the strategic position of new

energy storage, and planning to consolidate the EU's dominant position in forward-looking technology research and development and establish a battery supply chain system. For example, in March 2020, the European Commission released "Batteries 2030+", clarifying the long-term development plan of the European battery industry; in December 2020, the European Technology and Innovation Platform of the European Commission released the "Battery Research and Development Strategy", vigorously promoting the research and development and innovation of the battery value chain to enhance the global competitiveness of the battery industry; the European Commission has introduced new battery regulations, emphasizing the sustainability, low carbon, and safety of the entire battery life cycle, etc. In addition to the United States, the European Union, etc., South Korea, Japan, the United Kingdom, Australia, etc. have also promulgated hydrogen energy-related strategies [2]. Overall, with the positive role of energy storage technology in the integrated utilization of renewable energy, the energy storage market shows an explosive growth trend. Major economies around the world are all making strategic layouts in the field of energy storage. Although China has not introduced a national strategy for energy storage, it has also promulgated a series of policies related to energy storage to promote the development of the Energy Storage industry.

The "Guiding Opinions on Promoting the Development of the Energy Electronics Industry" jointly issued by six departments including the Ministry of Industry and Information Technology of China proposed to strengthen the industrialization technology research of new energy storage batteries and promote the large-scale application of advanced energy storage technologies and products. The "Notice on Further Accelerating the Construction of the Electricity Spot Market by the National Development and Reform Commission and the National Energy Administration" encourages new types of entities to participate in the electricity market, promotes the role of new types of entities such as energy storage in peak shaving and valley filling and

optimizing power quality, and explores new methods such as "new energy + energy storage". The "Construction Guide for the New Energy Storage Standard System" of the National Standards Committee proposed to accelerate the formulation and revision of relevant standards and conduct pre-research on energy storage power station safety standards, etc. At the local level, the energy plans for the "14th Five-Year Plan" in various regions have been successively introduced, clarifying the development goals of energy storage. As of 2023, 24 provinces and cities across the country have clarified the construction goals of new energy storage during the "14th Five-Year Plan" period, with a total scale of 70.65 million kilowatts, far exceeding the target of 30 million kilowatts proposed by the National Energy Administration by 2025.

However, the wide application of energy storage facilities has also brought many safety challenges. Among the energy storage safety issues, the most concerned one is fire safety. On the one hand, the centralized deployment of a large number of energy storage devices makes the fire risk more complex and concentrated, and any failure in any link may lead to serious consequences. On the other hand, key components such as batteries in energy storage power stations may experience dangerous situations such as thermal runaway during operation, posing a potential threat to personal safety and property safety [3]. As shown in Table 1, battery energy storage fire safety accidents occur from time to time worldwide, causing significant property losses.

**Table 1.** Incomplete statistics of global energy storage-related accidents

No.	Country	Accident	Time	Brief Description of Losses
1	Japan	Sodium-Sulfur Battery Fire Accident in Ibaraki Prefecture, Japan	2011.9	The fire burned for two consecutive weeks
2	China	The fire and explosion accident at Beijing Dahongmen Energy Storage Power Station	2022.4	One person died, two firefighters sacrificed, and one firefighter was injured. The direct property loss from the fire was 16.6081 million yuan
3	United States	Fire at KTV Lithium Battery Energy Storage Station in San Buenaventura, California, USA	2024.5	The fire lasted for six days and produced a large amount of toxic and harmful gases.
4	South Korea	Fire at a Lithium Battery Factory in Hwaseong City, Gyeonggi Province, South Korea	2024.6	Resulted in 23 deaths, including 17 Chinese workers. 8 injuries
5	Germany	The fire of energy storage batteries of Suncycle Company in Germany (three times)	2024.8	The loss is estimated to be 30,000 euros

The fire safety issue of energy storage systems has become a key bottleneck for the large-scale promotion of battery energy storage. As battery energy storage systems expand from demonstration applications to commercialization, there is an urgent need for the research and development of fire protection technologies for energy storage systems [4]. Patent data resources are globalized, standardized, and easily accessible, integrating multiple types of information. They are the best intelligence source for studying energy storage safety technology. This can help clarify the evolution direction of energy storage safety technology and provide a basis for formulating technology development strategies. It helps promote the orderly development of the energy storage safety industry, enhance the level of energy storage safety, and facilitate the low-carbon transformation of the energy structure. It is of great significance for achieving the "dual carbon" goals and provides strong support for the top-level design and planning in the field of energy storage safety.

## 2. Overview of the Development of Energy Storage Safety Patent Technology

The data of this study comes from the incoPat patent database. The analysis objects are patent applications in the global hydrogen energy field from January 1, 2003 to December 31, 2022. The retrieval time is July 10, 2023, and a total of 2,933 patent families were obtained.

The number of patent applications for global energy storage safety technology has shown a significant growth trend since 2005, and this growth has been particularly evident after 2016. From only 3 patent applications

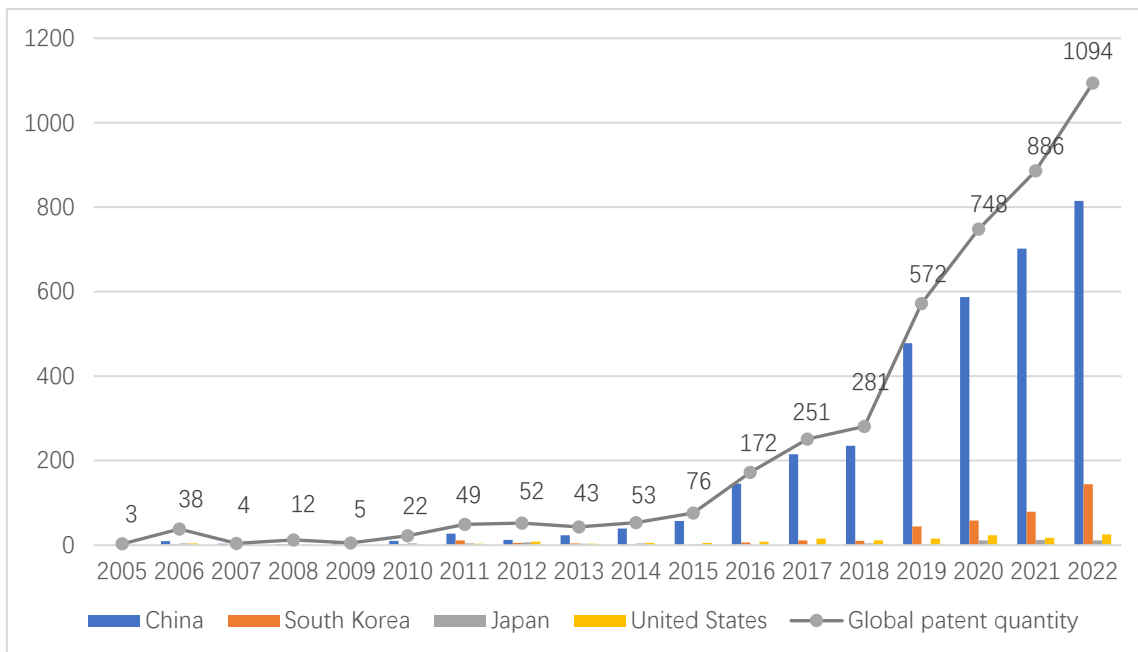
worldwide in 2005, this number soared to 1,094 in 2022, reflecting the rapid development and active technological innovation in the field of energy storage technology. Especially in China, the number of patent applications increased from 145 in 2016 to 815 in 2022, indicating China's rapid development and technological accumulation in this field. These data not only reveal the global development trend of energy storage safety technology but also highlight China's leading position in this field.

The patent application situations of various countries present obvious differences. China, with its absolute advantage in the number of patents, has become the leader in this field. From 0 patent applications in 2005 to 815 in 2022, China's development speed and scale far exceed those of other countries. In contrast, although South Korea, Japan, and the United States also have steady growth, there is a large gap in quantity compared with China. For example, South Korea increased from 6 in 2016 to 144 in 2022, Japan increased from 0 in 2016 to 11 in 2022, and the United States increased from 8 in 2016 to 25 in 2022. These data reflect China's concentrated investment and rapid development in the field of energy storage technology, and at the same time, show the efforts of other countries in catching up.

Based on the changes in the number of patents, it can be judged that the development of energy storage safety technology has undergone a transformation from basic research to application and commercialization. In the early stage, energy storage technology mainly focused on basic research, and the number of patent applications was relatively small. However, with technological progress and the growth of market demand, energy storage technology began to transition to the application and commercialization stages.

Especially after 2016, the significant increase in the number of patent applications indicated that energy storage technology has begun to be widely adopted in practical applications and gradually achieved commercialization. This transformation is not only due to the improvement of technological maturity but also closely related to the global pursuit of a sustainable energy system. 2016 and 2017 were the key years when the number of patent applications for energy storage safety technology increased significantly. The

global number of patent applications was 172 in 2016, and this number increased to 251 in 2017, with a growth rate of 45.93%. This growth is likely related to the global increase in demand for renewable and clean energy and is also closely related to the rapid development of the electric vehicle market. In addition, the number of patent applications in 2021 and 2022 reached 886 and 1,094 respectively, showing the rapid development of energy storage safety technology and the high attention paid to this technology by the market.



**Fig 1.** Annual Application Trend of Patents Related to Energy Storage System Safety Technology

The global market's demand for energy storage safety technology continues to grow, and this growth is driven by several factors. Firstly, as the proportion of renewable energy in the energy structure increases, energy storage technology becomes the key to balancing supply and demand and improving system stability. Secondly, the development of smart grids requires energy storage technology to achieve more flexible energy dispatch and management. In addition, the popularity of electric vehicles has also driven the demand for efficient and safe energy storage systems. Different countries and regions seek a balance in technological cooperation and market competition to jointly promote technological progress. With the global pursuit of a sustainable energy system, energy storage safety technology is expected to be more widely applied worldwide.

Based on historical data and current trends, it is expected that the number of patent applications for energy storage safety technology will continue to increase in the coming years. With the maturity of technology and the expansion of application scenarios, patent applications will pay more attention to technological innovation and market adaptability. The challenges faced by technological development include cost control, safety improvement, and environmental adaptability. However, with the global pursuit of a sustainable energy system, energy storage safety technology will also embrace more development opportunities. Especially in the context of global energy transformation and carbon neutrality goals, the importance of energy storage technology will be more prominent and become a key factor in promoting the safe, stable, and sustainable development of the energy system.

### 3. Innovation Subjects of Energy Storage Safety Patent Technology

Among the top 10 leading applicants worldwide, China occupies 6 seats, demonstrating China's strong R&D capabilities and patent layout in the field of energy storage safety technology. South Korea follows closely with 2 seats, and the listing of LG ENERGY SOLUTION LTD and HYUNDAI MOTOR COMPANY particularly reflects South Korea's professional R&D and market competitiveness in battery technology and energy storage solutions.

China's State Grid Corporation of China tops the list with a significant advantage in the number of patents, which not only reflects the company's in-depth research and innovation in energy storage safety technology but also shows its leadership position in the development of smart grids and clean energy technologies. The listing of China Electric Power Research Institute Co., Ltd. and University of Science and Technology of China further proves China's scientific research strength in energy storage technology R&D. The close connection between State Grid Corporation of China and State Grid Company indicates China's emphasis and investment in R&D of energy storage safety technology at the national level. In addition, the emergence of enterprises such as Zefe Intelligent System (Shanghai) Co., Ltd. and Chutian New Energy Co., Ltd. reveals the innovation vitality of enterprises in the field of energy storage safety in China.

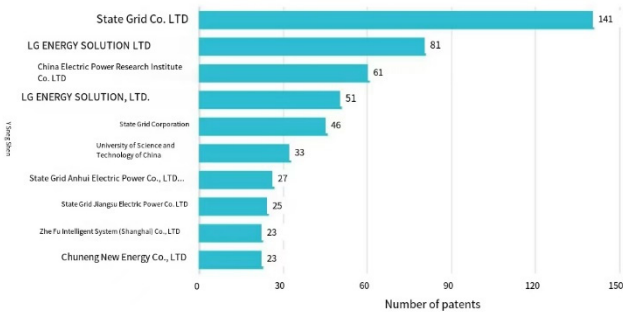


Fig 2. Major Applicants of Patents in Related Fields

References are cited in the text just by square brackets [2]. (If square brackets are not available, slashes may be used instead, e.g. /2/.) Two or more references at a time may be put in one set of brackets [3, 4]. The references are to be numbered in the order in which they are cited in the text and are to be listed at the end of the contribution under a heading References, see our example below.

## 4. Innovation Trend of Energy Storage Safety Technology

### 4.1. Composition of Energy Storage Safety Patent Technology

The research directions of energy storage safety technology mainly include battery monitoring and status monitoring, battery protection, fire detection and alarm, fire extinguishing systems, and battery pack structure design, etc. Battery monitoring collects parameters in real-time to assess the status and detect potential hazards. Battery protection initiates mechanisms to prevent risks when abnormalities occur. Fire detection and alarm can detect abnormalities early and issue alerts. Fire extinguishing systems quickly extinguish fires and reduce losses when fires occur. Battery pack structure design optimizes the arrangement and connection from the physical layout, improves heat dissipation, reduces the possibility of thermal runaway, and facilitates the implementation of fire extinguishing, providing all-round protection for the safe operation of energy storage systems. To obtain the patent situation of the main research directions of energy storage safety technology, this article combines the IPC classification numbers of each research direction with keywords for combination and conducts a secondary search.

China is one of the largest energy storage markets globally,

with huge energy demand and renewable energy development goals. The technology of fire extinguishing systems occupies a high proportion of 63.49% in patent applications in the field of energy storage safety, which is inseparable from the increased safety risks caused by the expansion of energy storage scale. The structural design of battery packs is crucial for improving the overall performance and safety of energy storage systems, and its patent application accounts for 23.23%. The patent applications for battery monitoring and status monitoring technology, battery protection technology, and fire detection and alarm technology have relatively low proportions, accounting for 1.46%, 3.01%, and 8.82% respectively, and are still in the development stage.

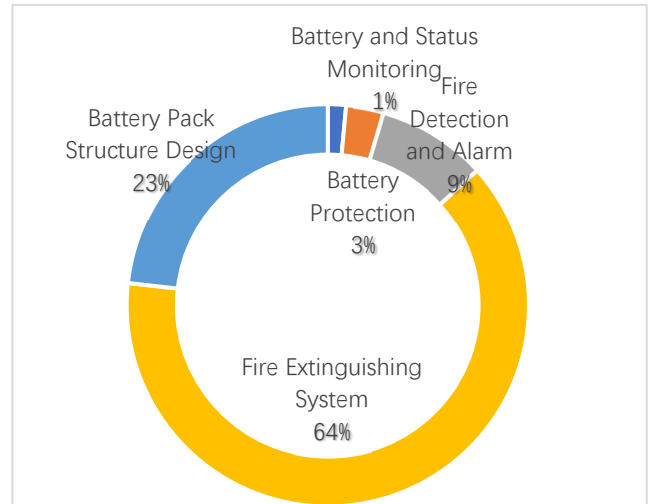


Fig 3. Composition of Relevant Patent Technologies in China

The energy storage application scenarios in South Korea mainly focus on home energy storage and grid energy storage, and its energy storage safety technology is also concentrated in the directions of fire extinguishing systems (48%) and battery pack structure design (40%). Due to the relatively mature development of the home energy storage market in South Korea, many households have installed energy storage systems to improve energy self-sufficiency and cope with electricity price fluctuations. The development of battery pack structure design is more mature than that in China, and the patent applications account for 40% of the total applications.

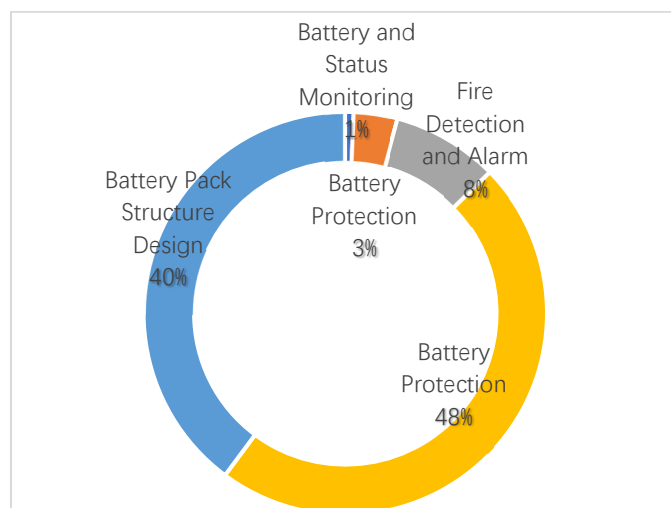


Fig 4. Composition of Relevant Patent Technologies in South Korea

## 4.2. Analysis of Patent Value Degree of Major Applicant Countries

In the field of energy storage safety technology, the analysis of the IncoPat value degree of the major applicant countries reveals the competitiveness of each country. The United States has strong performance in high-value patents in the themes of battery protection and fire extinguishing systems. The proportion of patents with an IncoPat value degree of 10 is as high as 45.24% and 39.81% respectively, highlighting its innovative strength in core technology fields.

Although South Korea does not have an advantage in the total number of patents, in the theme of battery monitoring and status monitoring, the proportion of its high-value patents reaches 20%, showing the high level of its patent quality. At the same time, the proportion of high-value patents in the theme of fire extinguishing systems in South Korea also reaches 33.77%, indicating that its patent layout in this field is also competitive.

China takes the leading position in the total number of patent applications, but there is still room for improvement in

high-value patents. The proportion of patents with an IncoPat value degree of 9-10 in China accounts for 40.30% in the theme of battery monitoring and status monitoring, 22.94% in the theme of battery protection, and 33.86% and 33.77% respectively in the themes of fire detection and alarm and fire extinguishing systems. Although China has the highest number of patent applications in the theme of battery pack structure design, in terms of the application of high-value patents, compared with the United States and Japan, it still needs to be strengthened.

The comprehensive analysis shows that although China has an absolute advantage in the number of patents, while pursuing quantity, it is urgent to improve patent quality and tackle key core technologies. The performance of the United States and South Korea in high-value patents indicates that the quality and innovation of patents are equally important. Although China leads in the number of patents with an IncoPat value degree of 9, the proportion of high-value patents in the themes of balance management and fire prevention and extinguishing technologies needs to be further increased to enhance global competitiveness.

**Table 2.** Comparative analysis of patent number and value of the main source countries of patent applicants

Patent Technology Theme	China	Korea	United States
Total Number of Patents for Battery Monitoring and Status Monitoring Theme / Piece	62	4	1
Number of Patents with a Patent Value Degree of 10 for This Theme / Piece	2	1	0
Number of Patents with a Patent Value Degree of 9 for This Theme / Piece	25	0	1
Total Number of Patents for Battery Protection Theme / Piece	128	21	21
Number of Patents with a Patent Value Degree of 10 for This Theme / Piece	3	1	18
Number of Patents with a Patent Value Degree of 9 for This Theme / Piece	36	7	1
Total Number of Patents for Fire Detection and Alarm Theme / Piece	375	51	17
Number of Patents with a Patent Value Degree of 10 for This Theme / Piece	12	13	16
Number of Patents with a Patent Value Degree of 9 for This Theme / Piece	138	14	1
Total Number of Patents for Fire Extinguishing System Theme / Piece	2701	285	103
Number of Patents with a Patent Value Degree of 10 for This Theme / Piece	77	49	63
Number of Patents with a Patent Value Degree of 9 for This Theme / Piece	965	82	19
Total Number of Patents for Battery Pack Structure Design Theme / Piece	988	239	79
Number of Patents with a Patent Value Degree of 10 for This Theme / Piece	49	51	57
Number of Patents with a Patent Value Degree of 9 for This Theme / Piece	404	67	10

## 5. Summary

The number of patent applications for global energy storage safety technology has increased significantly since 2005, especially after 2016, reflecting the rapid development and active technological innovation in the field of energy storage technology. The number of patent applications in this field in China has risen sharply, indicating its rapid development and technological accumulation in the field of energy storage safety technology.

Enterprises occupy a dominant position in the research and development of energy storage safety technology. Educational institutions and scientific research units also play an important role in basic research and applied research. Although the number of patent applications by individuals and institutions and groups is small, they also contribute an

important force to the diversity of technological innovation. The research directions of energy storage safety technology mainly focus on battery monitoring and status monitoring, battery protection, fire detection and alarm, fire extinguishing systems, and battery pack structure design. The technology of fire extinguishing systems occupies a high proportion in patent applications in the field of energy storage safety, which is closely related to the increase in safety risks caused by the expansion of energy storage scale.

Although China has an absolute advantage in the number of patents, there is still room for improvement in high-value patents compared with the United States and South Korea. China needs to pay more attention to improving patent quality and tackling key core technologies while pursuing quantity. With the global pursuit of a sustainable energy system, it is expected that energy storage safety technology will be more

widely applied worldwide. At present, the development of patents in battery monitoring and status monitoring technology, battery protection technology, and fire detection and alarm technology in various countries still has great potential. The layout of related technology patents should be accelerated to cope with the challenges of cost control, safety improvement, and environmental adaptability brought about by the rapid development of the energy storage industry.

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