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Pumped Storage Industry–Development Opportunities for Manufacturing Enterprises and a New Growth Pole for the Chinese Economy

Zhou Li*

Tianjin BENEFO Machinery Equipment Group Co., Ltd., China

**Author to whom correspondence should be addressed.*

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Abstract: In the context of the accelerated global transition to green and low-carbon energy, China's energy structure is undergoing profound changes. As of early 2025, the installed capacity of wind and photovoltaic power in China has exceeded 1.4 billion kilowatts, accounting for 42.9% of the total installed power generation capacity, historically surpassing thermal power as the largest power source. However, the randomness, volatility, and intermittency of renewable energy generation pose unprecedented challenges to the power system's regulatory capacity. In this context, pumped storage, as the most technically mature and economically advantageous large-scale energy storage method, is experiencing explosive growth, providing strategic opportunities for the transformation and upgrading of manufacturing enterprises.

Keywords: Pumped storage; Manufacturing upgrade; Industrial synergy; Green economy

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1. Introduction

1.1. Technical principles and industry positioning

Pumped storage power stations achieve large-scale, high-efficiency storage of electrical energy through the mutual conversion of mechanical energy from water and electrical energy from the power system. Their working principle involves pumping water from a lower reservoir to an upper reservoir for storage during periods of low electrical load. During peak load periods, the stored water is released from the upper reservoir to the lower reservoir for power generation, effectively regulating the supply and demand contradiction in the power grid. This "power bank" operating mechanism makes pumped storage the most technically mature, economically optimal, and flexible power source with large-scale development potential.

Compared to traditional energy storage technologies, pumped storage has three core advantages: Firstly, ultra-long service life, with a design life of over 50 years, far exceeding the 10–15 years of electrochemical energy storage; Secondly, large-capacity regulation capability, with a single station's installed capacity reaching up to

1 million kilowatts; Thirdly, low life cycle costs, with a levelized cost of electricity that is only 1/3 to 1/2 of that of electrochemical energy storage. In building a new power system with renewable energy as the mainstay, pumped storage has become an indispensable technical support for ensuring the safe and stable operation of the power grid [1].

1.2. Development scale of China's pumped storage industry

China's pumped storage industry has entered a "fast track" of development. According to data from the Hydropower and Water Resources Planning and Design General Institute's "Pumped Storage Industry Development Report 2024", as of the end of 2024, China's total installed capacity of pumped storage in operation reached 58.69 million kilowatts, ranking first in the world for nine consecutive years, far surpassing Japan's approximately 23 million kilowatts and the United States' approximately 22 million kilowatts [2]. More importantly, the total installed capacity of pumped storage power stations approved and under construction nationwide is about 200 million kilowatts, forming a "double growth" pattern of both operational and under-construction scales.

From a regional perspective, East China has the largest installed capacity, followed by North China and South China. This layout is highly compatible with China's energy consumption centers, effectively supporting regional power supply security and low-carbon transformation. For example, in the South China Power Grid, the pumped storage multi-plant station centralized control center located in Panyu, Guangzhou, controls six pumped storage power stations in the Guangdong-Hong Kong-Macao Greater Bay Area, covering nearly one-sixth of the country's pumped storage equipment. In 2024, the number of calls and duration of pumped storage units in the region exceeded 40,000 and 110,000 hours, respectively, driving a 36% year-on-year increase in renewable energy generation[3].

1.3. Policy drivers and development planning

National policies provide strong support for the pumped storage industry. The "Medium and Long-Term Development Plan for Pumped Storage (2021–2035)", released in 2021, clarifies the ambitious goal of "reaching a total installed capacity of 120 million kilowatts by 2030 and 420 million kilowatts by 2035". The "Energy Law of the People's Republic of China", which officially came into effect in 2025, further proposes "the state shall reasonably plan and actively and orderly develop and construct pumped storage power stations". Reform of the electricity pricing mechanism is also being promoted simultaneously. In 2021, the National Development and Reform Commission issued the "Opinions on Further Improving the Price Formation Mechanism for Pumped Storage", establishing a two-part electricity pricing model to provide income security for industry investment.

Table 1. Medium and long-term development planning goals for China's pumped storage industry

Timeline	Installed capacity target	Annual power generation potential	New energy integration capacity
2025	~80 GW	> 20 TWh	~150 GW
2030	120 GW	> 30 TWh	~300 GW
2035	420 GW	> 100 TWh	Meets large-scale development needs for high-penetration renewable energy

2. Analysis of the economic value of the pumped storage industry

2.1. Investment stimulation and economic growth effects

The pumped storage industry is emerging as a new engine for driving effective investment. The investment scale

of a single pumped storage power station typically ranges from billions to tens of billions of yuan. For example, the Huangcaoyuan Pumped Storage Power Station in Dai County, Shanxi Province, has an installed capacity of 1.4 million kilowatts and a total investment of 10.99 billion yuan. The nine 10-million-kilowatt-class pumped storage power station clusters under construction in Guangdong and Guangxi have a total investment of nearly 70 billion yuan [4]. Industry predictions indicate that during the "14th Five-Year Plan" period, the total investment scale of China's pumped storage industry will exceed one trillion yuan, providing strong support for economic growth.

This investment stimulation effect is particularly significant in regional economic development. Taking Chengde City, Hebei Province, as an example, relying on the demonstration effect of the Fengning Pumped Storage Power Station (the largest in the world with a total installed capacity of 3.6 million kilowatts), the city has successively started construction on pumped storage projects in Luanping and Longhua. The scale of projects under construction, approved, and newly planned ranks first in Hebei Province. After the Fengning power station is fully operational, its annual power generation will reach 6.6 billion kilowatt-hours, which can satisfy the annual electricity consumption of 2.6 million households. Simultaneously, it will save 480,000 tons of standard coal and reduce carbon dioxide emissions by 1.2 million tons, equivalent to planting 240,000 mu of forests.

2.2. Industrial chain synergy and manufacturing upgrade

The pumped storage industry features a long industrial chain, covering various links such as survey and design, equipment manufacturing, engineering construction, and operation and maintenance. This provides full-chain development opportunities for manufacturing enterprises. Core equipment manufacturing areas include:

(1) High-end special materials: The 1000MPa-grade high-strength hydropower steel developed by Nanjing Iron and Steel Group has solved the stringent requirements of large-scale hydropower projects for ultra-high strength, low-temperature toughness, and weldability of steel, filling a domestic technological gap. This material has been successfully applied to the pressure steel pipes of the Liaoning Qingyuan Pumped Storage Power Station, verifying its reliability and stability under high-pressure environments.

(2) Hydro-turbine generator sets: The low-head diagonal-flow pumped storage pump-turbine unit developed by Tianjin Tianfa Hydropower Company, a subsidiary of Tianjin Baili Equipment Group, has achieved domestic leading performance indicators through structural optimization and hydraulic model innovation. The Yichang Hydropower High-end Manufacturing Industrial Park, jointly established by Zhejiang Fuchun Holding Group and China Three Gorges Corporation, has an initial planned annual production capacity of 10 sets of pumped storage units, which will alleviate the bottleneck of insufficient domestic production capacity.

(3) Smart control systems: The Liaoning Qingyuan Pumped Storage Power Station applies an "unmanned intelligent control" vibration roller and a digital dam intelligent monitoring system, creating a new benchmark for intelligent construction in the pumped storage industry. Nanjing Iron and Steel Group achieves 100% online control of the research and development process and reduces the research and development cycle by 30% through a dual-drive architecture combining an "industrial internet platform + data governance."

2.3. Technological innovation and industrial value-added enhancement

The rapid development of the pumped storage industry has led to significant technological breakthroughs, significantly enhancing the value-added of the equipment manufacturing industry. The 1000MPa high-strength

hydropower steel developed by Nanjing Iron and Steel's hydropower steel team not only fills a domestic technological gap but also achieves international leadership, pushing China's hydropower steel industry to transition from "import dependence" to "global export". It has been successfully applied to projects such as the Rufuji Hydropower Station in Tanzania and the Batang Hydropower Station in Indonesia.

In the field of smart construction, the Qingyuan Pumped Storage Power Station has innovatively applied the rotor stacking process. Through BIM technology modeling and pre-installation, the rotor is stacked in a positive and negative spiral rising manner, ensuring its stability under high-speed centrifugal conditions. Simultaneously, the application of high-precision laser measurement technology and intelligent calibration systems has significantly improved the operating efficiency and reliability of the unit. Nanjing Iron and Steel Group's digital architecture of "One Brain and Three Centers" (Smart Operation Center as the industrial brain, Integrated Ironmaking Center, Integrated Steel and Rolling Center, and Integrated Energy Center) has achieved dynamic optimization across the entire process and value chain, being selected as one of the first excellent smart factories in China.

3. Strategic path for manufacturing enterprises to develop pumped storage

3.1. Industrial chain extension and upgrading practices

Leading manufacturing enterprises are actively deploying in the pumped storage market through technological upgrading and industrial chain integration, forming a diversified development model:

(1) Transformation and upgrading of material suppliers

Nanjing Iron and Steel Group has transitioned from being a traditional steel manufacturer to being a provider of high-end hydropower steel solutions. Its hydropower steel products have been applied to pumped storage power station projects in Liyang, Jiangsu, Jixi, Anhui, Yimeng, Shandong, Changlongshan, Zhejiang, and Wendeng, Shandong. At the end of 2019, Nanjing Iron and Steel exclusively won a 28,000-ton order for the Qingyuan Pumped Storage Power Station in Liaoning, marking the acceleration of its hydropower steel business.

(2) Technological breakthroughs by equipment manufacturers:

Tianjin Baili Equipment Group's Tianfa Hydropower Company successfully won the bid for the Beijing Miyun Baihe Hydropower Station equipment renewal project with its self-developed low-head diagonal flow pumped storage pump-turbine unit, achieving a "second handshake" with the client across half a century. Relying on the synergies within the group's industrial chain, the company has integrated resources such as valves from International Machinery, frequency converters from Liaoning Rongxin, and transformers from TBEA, forming a competitive industrial chain.

(3) Strategic cooperation between system integrators

Zhejiang Fuchun Holdings has quickly entered the pumped storage field through consecutive signings of the "Strategic Cooperation Framework Agreement for the Jiangshan Pumped Storage Power Station Project in Zhejiang" and the "Cooperation Framework Agreement for the Yichang Hydropower High-end Manufacturing Industrial Park Project". The industrial park, built in partnership with the Three Gorges Group and the Yichang Municipal Government, is positioned as an "advanced pumped storage unit manufacturing base, a hydropower station spare parts production base, and a clean energy advanced equipment research and development trial production base", realizing a strategic transition from being a hazardous waste treatment leader to being a clean energy equipment manufacturer.

3.2. Digital transformation and smart construction

Digital technology is profoundly reshaping the manufacturing of pumped storage equipment and the construction model of power stations. The digital research and development system built by Nangang Group has achieved 100% online control of the research and development process, reducing the research and development cycle by 30%. Its "Smart Factory for Personalized Steel Production" project has been selected as a national-level excellent smart factory. Through the deep integration of advanced technologies such as artificial intelligence, 5G, and digital twins with steel manufacturing, it addresses pain points such as difficulties in data management, control, decision-making, and achieving win-win situations.

In the power station construction process, the Liaoning Qingyuan Pumped Storage Power Station applies a digital dam smart monitoring system, establishing a real-time, smart, full-process, and efficient intelligent rolling system for dam filling construction. Key processes such as stator assembly, spiral case hydrostatic testing, seat ring flat grinding, and unit turning are realized with intelligent and visual control, providing data analysis support for high-precision installation [5].

3.3. Green value and comprehensive benefits

The economic value created by pumped storage power stations far exceeds that of power regulation itself, forming a multi-dimensional value system of "economy-society-ecology":

(1) Comprehensive utilization of water resources

The 12 reservoirs of the six pumped storage power stations in the Guangdong-Hong Kong-Macao Greater Region have a total storage capacity of 310 million cubic meters, equivalent to 22 West Lakes. Among them, the lower reservoir of the Shenzhen Pumped Storage Power Station was directly transformed and built on the basis of the Tongluojing Reservoir. The water quality has maintained the second-class standard for a long time, and it can provide about 6 million cubic meters of urban water per year.

(2) Flood control and drought relief regulation

In 2024, the Guangdong Qingyuan Pumped Storage Power Station responded to the requirements of the water conservancy department to release water in spring, effectively alleviating the local water shortage; in the same year, in response to heavy rainfall, the six power stations cumulatively retained more than 290 million cubic meters of floodwater and released nearly 270 million cubic meters of water.

(3) Integration of industrial and cultural tourism

Many pumped storage power stations in the Greater Region have created "special business cards" for industrial and cultural tourism. Shenzhen Power Station has planted more than 4,000 cherry blossoms to attract citizens to enjoy the spring outing; Guangzhou Power Station welcomes thousands of egrets to rest in autumn; Huizhou Power Station utilizes more than 10,000 hectares of Xiangtou Mountain to carry out tree planting tourism. This "green power station + eco-tourism" model has created additional economic benefits and improved the overall return on investment of the project.

4. Policy environment optimization and industry development suggestions

4.1. Analysis of current policies

The current policy system for pumped storage energy industry is centered around the "Medium and Long-Term Development Plan for Pumped Storage Energy (2021–2035)". Supporting documents such as the "Opinions on Further Improving the Price Formation Mechanism for Pumped Storage Energy" and the "Interim Measures for

the Development and Construction Management of Pumped Storage Power Stations" have formed a three-in-one policy framework consisting of planning guidance, electricity price support, and management regulations. The two-part electricity pricing policy (capacity price + energy price) effectively guarantees reasonable returns for investors and stimulates investment enthusiasm among grid enterprises. By the end of 2024, the cumulative installed capacity of pumped storage energy in operation by State Grid will reach 40.26 million kilowatts, with a total capacity in operation and under construction exceeding 94 million kilowatts.

However, there is still room for improvement in the policy system: Firstly, the electricity pricing mechanism is not fully streamlined, and how the current two-part electricity pricing can be integrated with the reform of the electricity market remains to be explored; Secondly, high-quality site resources are decreasing, and economically viable sites are becoming scarcer as development progresses; Thirdly, the market-oriented operation mechanism is immature, and the construction of ancillary service markets and capacity markets is lagging.

4.2. Policy optimization suggestions

To promote the high-quality development of the pumped storage energy industry, it is suggested to optimize the policy environment from the following aspects:

(1) Building a differentiated market mechanism

Following the principle of "balancing safety and development", deepen the pilot program for pumped storage energy to participate in market transactions in leading regions of electricity market reform, such as Guangdong and Shandong. Establish a transitional mechanism of "benchmark capacity price + contract for difference", draw on the policies of coal-fired capacity price and new energy mechanisms, set benchmark electricity prices based on resource endowments by region, reduce pricing pressure, and guide cost reduction and efficiency improvement.

(2) Strengthening incentives for technological innovation

Establish a national science and technology special project for pumped storage energy, focusing on supporting the research and development of key technologies such as 1000MPa high-strength steel, variable-speed units, and seawater pumped storage. Provide application incentives for the first set of equipment, such as the successful demonstration of Nanjing Steel's 1000MPa hydropower steel at the Qingyuan power station, which fills a domestic technological gap. Encourage the development of innovative forms such as distributed pumped storage and seawater pumped storage. China's first seawater pumped storage project, the Ningde Fuying Island project, is currently under preparation.

(3) Improving the ecological compensation mechanism

Incorporate pumped storage power stations into the pilot program for realizing the value of ecological products, quantitatively evaluate their ecological service values, such as carbon emission reduction, water conservation, and flood regulation. Referring to the "eco-tourism" model of Shenzhen Pumped Storage Power Station, support the integrated development of "industrial cultural tourism + pumped storage" to expand revenue channels.

(4) Promoting equipment renewal and recycling

Include pumped storage equipment in the scope of support for large-scale equipment renewal actions, and support the replacement of old units. For example, in the 51-year unit renewal of Beijing Miyun Baihe Hydropower Station, Tianjin Baili Equipment Group provided new low-head diagonal flow units, achieving technological leapfrogging. Establish a remanufacturing system for pumped storage equipment

to promote the recycling of core components of decommissioned units.

5. Conclusion

As a critical support for energy transformation and a high-quality carrier for the upgrading of the manufacturing industry, the pumped storage industry is exhibiting tremendous economic value and development potential. Guided by the dual carbon goals, China's pumped storage industry has entered a fast lane of development, with its installed capacity ranking first in the world for nine consecutive years. The policy environment is continuously optimizing, and technological innovations are advancing rapidly. This industry not only directly drives economic growth through trillion-level investment but also promotes breakthrough developments in high-end materials, smart equipment, digital technology, and other fields through the coordination of the entire industry chain, providing strategic opportunities for the transformation and upgrading of manufacturing enterprises.

For manufacturing enterprises, the core value of the pumped storage industry lies in its triple certainty: Firstly, policy support certainty, as the national plan clearly states the formation of 420 million kilowatts of pumped storage capacity by 2035; secondly, market demand certainty, as the surge in renewable energy installations gives rise to rigid regulation demands; and thirdly, technological innovation certainty, as continuous breakthroughs in materials science, digital technology, and smart construction create high value-added space. Successful practices by enterprises such as Nansteel Group, Tianjin Baili Equipment, and Zhejiang Fuchun Holding indicate that through industrial chain extension, technological upgrading, and digital transformation, manufacturing enterprises can fully explore new growth curves in the pumped storage industry.

With the implementation of the Energy Law of the People's Republic of China and the deepening of electricity market reform, the pumped storage industry will usher in a more market-oriented and standardized development environment. In the future, efforts should be made to build a three-in-one industrial ecosystem integrating "technology, market, and policy." Technically, breakthroughs should be accelerated in core areas such as high-strength steel, efficient units, and intelligent control. In the market, exploration should be conducted on a differentiated mechanism of capacity pricing combined with electricity bidding in different regions. Policy-wise, emphasis should be placed on site resource protection and equipment renewal support. Through multi-party collaboration, the pumped storage industry can truly become a "new engine" for the high-quality development of the manufacturing industry and a "stabilizer" for economic green transformation, injecting powerful momentum into Chinese-style modernization.

Disclosure statement

The author declares no conflict of interest.

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