Chapter 2

Literature Review

The researcher has studied concepts, theories and related research used to determine the research guidelines as follows:

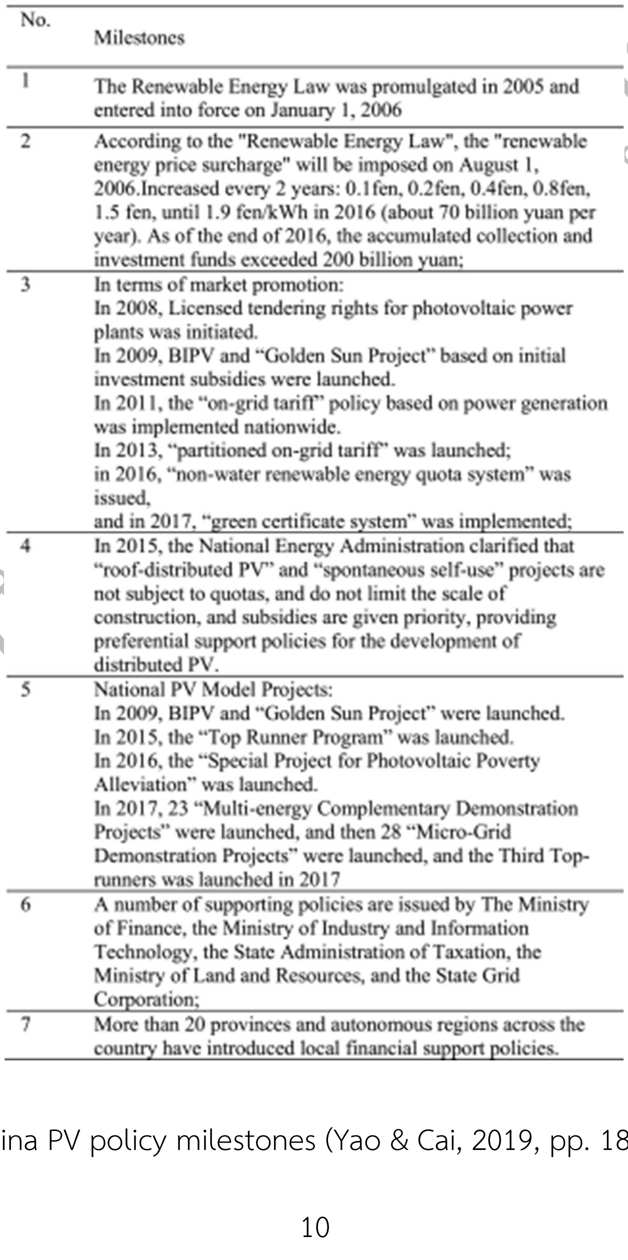
The Development Status and Problems of China's Photovoltaic Industry

The Chinese photovoltaic industry developed robustly in the past, which laid a strong foundation for its healthy growth. Various national policies and measures, such as the Implementation Plan on Promoting the High-Quality Development of New Energy in the New Era (Forwarded by the General Office of the State Council to the National Development and Reform Commission and the National Energy Administration, 2022) and the "Fourteenth Five Year" Renewable Energy Development Plan (National Development and Reform Commission of the People's Republic of China, 2021), were continuously implemented. As a result, the Chinese photovoltaic industry developed vigorously and established a solid groundwork for its healthy development.

Chinese PV companies aimed to strengthen their global competitiveness by improving their technological advancements and lowering production costs. Nevertheless, they were challenged by unpredictable policies such as the sudden announcement of the "531" policy, which sought to control the solar sector's excessive growth by speeding up the elimination of subsidies (Tu, et al., 2019, pp. 404-417). Furthermore, the Chinese photovoltaic industry still faced several issues, including a substantial subsidy gap, increasing curtailment of PV power generation, the manufacturing industry's lack of competitiveness, high land tax, and expenses of photovoltaic power stations, and an incomplete standard system (Yao & Cai, 2019, pp. 181051-181060).

China's rapid expansion in the photovoltaic (PV) sector was accompanied by a range of challenges. There was an uneven distribution of installed capacity across the country, and the manufacturing and application ends were geographically mismatched, as were the provinces that generated and consumed electricity. The growth rate of renewable energy, including PV, exceeded the national rate of electricity consumption growth, resulting in a significant shortage of energy funds. Large-scale curtailment of PV power generation and the absence of subsidies were increasing concerns. Furthermore, the introduction of the "531" policy caused significant disruption to the industry, placing short-term pressure on enterprises. As a result, the PV industry was experiencing a new adjustment period.

The state's policies that supported the photovoltaic industry primarily included five aspects: 1) government incentives, 2) grid support, 3) operational supervision, 4) technical support, and 5) financial support. In the early stages of China's PV industry, the government mainly issued incentive policies and provided technical support to enhance innovation capabilities and provide "soft" power for industry development. The government continued to offer substantial financial and tax support to the photovoltaic industry, which was a crucial force in stimulating industrial development (Yao & Cai, 2019, pp. 181051-181060). The milestones of PV policies were summarized in Figure 2.1.



No.	Milestones
1	The Renewable Energy Law was promulgated in 2005 and entered into force on January 1, 2006
2	According to the "Renewable Energy Law", the "renewable energy price surcharge" will be imposed on August 1, 2006.Increased every 2 years: 0.1fen, 0.2fen, 0.4fen, 0.8fen, 1.5 fen, until 1.9 fen/kWh in 2016 (about 70 billion yuan per year). As of the end of 2016, the accumulated collection and investment funds exceeded 200 billion yuan;
3	In terms of market promotion: In 2008, Licensed tendering rights for photovoltaic power plants was initiated. In 2009, BIPV and “Golden Sun Project” based on initial investment subsidies were launched. In 2011, the “on-grid tariff” policy based on power generation was implemented nationwide. In 2013, “partitioned on-grid tariff” was launched; in 2016, “non-water renewable energy quota system” was issued, and in 2017, “green certificate system” was implemented;
4	In 2015, the National Energy Administration clarified that “roof-distributed PV” and “spontaneous self-use” projects are not subject to quotas, and do not limit the scale of construction, and subsidies are given priority, providing preferential support policies for the development of distributed PV.
5	National PV Model Projects: In 2009, BIPV and “Golden Sun Project” were launched. In 2015, the “Top Runner Program” was launched. In 2016, the “Special Project for Photovoltaic Poverty Alleviation” was launched. In 2017, 23 “Multi-energy Complementary Demonstration Projects” were launched, and then 28 “Micro-Grid Demonstration Projects” were launched, and the Third Top-runners was launched in 2017
6	A number of supporting policies are issued by The Ministry of Finance, the Ministry of Industry and Information Technology, the State Administration of Taxation, the Ministry of Land and Resources, and the State Grid Corporation;
7	More than 20 provinces and autonomous regions across the country have introduced local financial support policies.

Figure 2.1 China PV policy milestones (Yao & Cai, 2019, pp. 181051-181060)

Following the implementation of the 531 policies, the policies were adjusted as follows: 1) the industry and energy structure were restructured; 2) electricity prices, including on-grid tariffs, electricity subsidies, and user tariffs, were lowered; 3) all photovoltaic projects were subjected to quota control; and 4) subsidies were phased out, and grid parity was enforced.

In 2015, the National Energy Administration proposed the "Top-Runner" program for photovoltaic power generation and the construction of Top Runner bases. Through market support and experimental demonstrations, the projects accelerated the promotion of photovoltaic power generation technology and industrial upgrading, speeding up the application and transformation of technological achievements into the market. The cost of photovoltaic power generation decreased, the price of electricity was reduced, subsidies were reduced, and grid parity was finally achieved. Currently, a total of 22 Top runner bases' bidding work has been completed, with a scale of 13 GW. Among them, the first Top-runner in 2015 and the second Top-runner in 2016 were basically completed and connected to the grid (Yao & Cai, 2019, pp. 181051-181060).

The national advanced technology pioneer base of Datong coal mining subsidence area in Shanxi Province, China, was officially approved and became the first demonstration project of Top-runner. The total installed capacity of Datong Top-runner base was 3GW, which was implemented over three years. The first-phase construction scale was 1GW and began in September 2015, with all connections completed before June 30, 2016. In 2015, Top-runner advanced technology products achieved the following indicators: the photoelectric conversion efficiency of polycrystalline silicon cell modules and monocrystalline silicon cell modules reached 16.5% and over 17%, respectively (Yao & Cai, 2019, pp. 181051-181060).

The types of modules used in the Datong Top-runner base and how they compared to new modules adopted in 2015 are as follows. Approximately 60% of the modules used in the 1GW Datong Top-runner base were made of monocrystalline silicon, while the remaining 40% were made of polycrystalline modules. In 2015, the Datong Top-runner base adopted new modules, such as PERC, black silicon, and n-type bifacial modules, as shown in Figure 3. According to CEPRI's statistics, the monocrystalline silicon PERC module accounted for 21%, a significant proportion compared to other new modules (Yao & Cai, 2019, pp. 181051-181060).

By 2016, all tenders for the second "Top-runner" projects had been completed. The leading technical indicators for photovoltaic power generation were not increased from those in 2015, with the photoelectric conversion efficiency of polycrystalline and monocrystalline modules reaching 16.5% and 17%, respectively. However, in 2016, the pace-setter base adopted competitive comparisons, such as bidding and selection, to allocate projects. The national energy administration issued an investment subject preferred scoring standard for the leading base, which rewarded higher scores to companies whose module efficiency exceeded 0.5% and 1% above the leading indicator, to guide enterprises to adopt more advanced technology products. According to incomplete statistics, the proportion of PERC components accounted for 30%, and the proportion of monocrystalline PERC modules was about 80%. Compared to the 21% PERC ratio of Top-runners in 2015, the application ratio and scale of PERC products in 2016 had greatly improved (Yao & Cai, 2019, pp. 181051-181060).

In November 2017, the State Energy Administration announced the list of leading bases for photovoltaic power generation and set higher threshold technical indicators for Top-runner bases compared to previous years. To qualify as a Top-runner base in 2017, the photoelectric conversion efficiency of polycrystalline and monocrystalline silicon cell modules had to be at least 17% and 17.8%, respectively (Yao & Cai, 2019, pp. 181051-181060). The energy administration also specified full-scale efficiency indicators for modules. The conversion efficiency of poly-module and mono-module used in the technology leading base was required to be 19.4% and 20.4%, respectively, to reach the full score standard. In the 5GW application Top-runner and 1.5GW technical Top-runner bidding processes, PERC modules were the preferred choice, with monocrystalline modules being used much more frequently than polysilicon, making up nearly 90% of the application ratio (Yao & Cai, 2019, pp. 181051-181060).

Over the past three years, Top-runner projects significantly improved technological advancements and promoted grid parity. The advantages of state-owned investment enterprises became increasingly prominent, and private enterprise participation declined. In the future, bifacial modules, paired with a tracker system, are expected to become a typical configuration, and be widely used.

In October 2018, a joint document (NDRC Energy [2018] No. 1459) was released by NDRC, the Ministry of Finance, and the National Energy Administration, which clarified that household natural person distributed PV power generation projects filed for construction before and on May 31 and connected to the grid before and on June 30 were included in the nationally recognized scale management scope. The benchmark feed-in tariff and subsidy per kWh remained unchanged, minimizing the negative impact of the 5.31 new Policies on the PV market. This policy revived about 2 GW of household PV projects that completed grid connection before June 30 without affecting investment in PV by residents and small and medium-sized enterprises. We hope to see more relaxed policies for distributed PV, including household PV systems, industrial and commercial building PV projects, and PV+ projects (such as agriculture-complementary solar power, PV-hydro complementary power generation, PV-forestry complementary power generation, PV-husbandry complementary power generation, and agricultural greenhouse projects) (Wang, 2020, pp. 72-82).

China set a target in its Energy Production and Consumption Transition Strategy (2016-2030) to have non-fossil fuels account for 15% of primary energy consumption by 2020 and 20% by 2030, with the aim of reaching peak CO2 emissions by 2030. According to the 2015 China 2050 High Renewable Energy Penetration Scenario and Roadmap Study by the Energy Research Institute and NDRC, the main objectives for energy transition included reaching 15% non-fossil energy consumption by 2020, peaking coal consumption at 2650 billion kg by 2020, peaking total energy consumption at no more than 4500 billion kg by 2025, and reaching 20% non-fossil energy consumption and 9230 billion kg of CO2 emissions by 2030. The study also set targets of reaching 3.4 billion kg of standard coal for total primary energy by 2050, having renewable energy account for over 60% of primary energy consumption and over 85% of total generation by 2050, and increasing the proportion of electric power in primary energy consumption to 62% by 2050. If these targets are achieved, the annual average installed capacity of PV will remain at 70-100 GW from 2020, and PV power generation will grow at a faster rate (Wang, 2020, pp. 72-82).

In-depth analysis of China's photovoltaic policy environment in the first half of 2022, as well as the situation of the photovoltaic industry in terms of manufacturing, application, and export, (Wang, 2020, pp. 72-82) discussed the problems faced by China's photovoltaic industry in terms of sales prices at all links of the industry chain, land use for photovoltaic power generation projects, industrial talents, foreign trade, etc. It reflected that China's photovoltaic industry faced constant risks and challenges due to the impact of unexpected factors such as the rebound of domestic COVID-19 and international geopolitical conflicts on China's economic operation. However, in this context, it still maintained a high level of development.

Photovoltaic Silver Paste

PV (photovoltaic) was a new power generation system that used solar energy resources for power generation. Photovoltaic power generation was a technology that used the photovoltaic effect of the semiconductor interface to directly convert light energy into electrical energy (National standard. GB/T 29319-2012 "Technical Regulations for Connecting Photovoltaic Power Generation Systems to Distribution Networks": National standard, 2012). Silver powder was widely used in photovoltaic silver paste due to its good conductivity. Photovoltaic silver paste was composed of a conductive phase, an adhesive phase, and an organic carrier. The conductive phase was the functional phase of photovoltaic silver paste, namely silver powder. According to the front and back of the solar cell, the photovoltaic silver paste was divided into the front silver paste and the back silver paste. The silver powder used was spherical silver powder and sheet silver powder respectively (Zhong, et al., 2015, pp. 6-13).

The market prospect, technical status, and preparation methods of silver powder for photovoltaic silver paste were introduced. The characteristics of various methods were analyzed, and the problems in the silver powder industry and research were summarized and analyzed, along with the direction of future efforts. Zhong Jingming (2015, pp. 6-13) studied the methods and types of spherical silver powder, flake silver powder, and surfactant used in the production of photovoltaic silver paste. Through investigation and analysis, four main characteristics of silver powder for photovoltaic silver paste were summarized, as well as the future direction of efforts in the silver powder industry and technology development.

Silver Powder Morphology

Silver powder was the powdered material of metallic silver, which was the main raw material for making conductive silver paste. It had a high specific surface area and strong sintering activity. It was mainly used as a conductive filler in high-temperature sintered silver paste.

1. Effect of silver powder morphology and particle size on the performance of lead-free conductive silver paste

The effect of silver powder on the resistivity and adhesion of the film after sintering of lead-free conductive silver paste was studied through different morphology, particle size, and grading of silver powder. The average particle size was 0.50, 0.91, 2.09, 3.36 μm spherical silver powder, and 4.3 μm flake silver powder. First, five kinds of silver powder were prepared into lead-free conductive silver paste respectively. The silver powder with the best performance of silver paste was selected, and then lead-free conductive silver paste was prepared by combining this silver powder with nano-silver powder and flake silver powder. The morphology of the sintered silver film of the slurry was observed by scanning electron microscope (SEM), the resistivity of the sintered silver film was measured by a four-probe tester, and the adhesion of the sintered silver film was measured by tensile test (Teng, et al., 2016, pp. 58-63).

The particle size and morphology of silver powder affected the microstructure and compactness of the sintered film, thus influencing the conductivity of the silver film. However, from the perspective of silver powder morphology, the volume resistivity of flake silver powder with the same quality was generally lower than that of spherical silver powder. This was because the contact between flake silver powder particles was surface contact or line contact, which was larger than the point contact contact surface of spherical silver powder, and the flake silver powder was arranged in a flake structure with good fluidity between particles, which was more conducive to the compactness of silver paste sintering and better conductivity (Teng, et al., 2016 , pp. 58-63). Due to the surface effect and small size effect of nano-silver powder, using nano-silver as a conductive filler could improve conductivity and thermal conductivity, reduce the amount of silver, and reduce production costs. Therefore, this paper mainly studied the influence of silver powder with different particle size and morphology on the resistance and adhesion of conductive silver paste and prepared conductive silver paste with excellent performance.

In addition, the conductive silver paste with excellent performance was prepared by studying the influence of silver powder with different particle size and morphology on the resistance and adhesion of the conductive silver paste. The average particle size was 0.91 μm. The silver paste prepared by m spherical silver powder had the lowest resistivity, uniform, and dense adhesion, could form a close conductive network, and had good conductivity. At 0.91 μm spherical silver powders with an average particle size of 0.1 μm, nano-silver powder was helpful to improve the compactness of the silver electrode (Teng, et al., 2016, pp. 58-63).

2. Controllable preparation and scale-up experimental study of micro and nano silver powder

Micro-nano-silver powder was an important industrial raw material. China's micro-nano-silver powder primarily depended on imports, so there was an urgent need to develop a new technology for preparing micro-nano-silver powder with a simple process, environmental protection, low cost, high product yield, and controllable morphology. In this paper, spherical and dendritic silver powders were prepared by chemical reduction in an aqueous phase system (Zhe, 2014, pp. 454-456). Single crystal silver powder was prepared by a mechanical phase system. The effects of the preparation parameters of three kinds of silver powder, such as reducing agent, dispersant, control agent, stabilizer, complexing agent, reaction temperature, and time, pH value, on the average particle size, particle size distribution, sphericity, compaction density, and direct yield of silver powder were discussed, and the preparation process was optimized.

Zhe Zhao (2014, pp. 454-456) studied the effect of dispersant and pH value, and determined the preparation process of dendritic silver powder. The results showed that during the preparation of single crystal silver powder, it was determined that the mass ratio of dispersant was 1.25% PVP 1.3 million, and the mass ratio of the control agent copper chloride was increased from 0.03% to 0.3%. The average particle size could be controlled to be 0.8 μm to 1.4 μm for single crystal silver powder at 110°C. The average particle size of silver powder prepared at pretreatment temperature and reaction temperature of 140°C for 2 hours was 0.8 μm to 1.4 μm. The particle size distribution was narrow, and the particle size decreased with the prolongation of pretreatment time.

Through the chemical reduction method, spherical silver powder and dendritic silver powder were successfully prepared using an aqueous phase system, and single crystal silver powder was prepared using an organic phase system. The process parameters were discussed and analyzed according to the preparation plan for each kind of silver powder. The formula for various kinds of silver powder was optimized, and stepwise amplification experiments of different multiples were conducted for three kinds of silver powder (Zhe, 2014, pp. 454-456).

Micro-nano-silver powder holds a crucial position as an industrial raw material, given its numerous applications in various industries. In the context of China, the heavy reliance on imported micro-nano-silver powder emphasized the pressing need to develop a new technology for its production. This technology had to be characterized by a simple process, environmental friendliness, cost-effectiveness, high product yield, and the ability to control the morphology of the silver powder.

In this research endeavor, we embarked on a comprehensive exploration of different approaches to produce micro-nano-silver powder. Spherical and dendritic silver powders were meticulously prepared via chemical reduction in an aqueous phase system, as documented in the work of Zhe Zhao in 2014. Simultaneously, single crystal silver powder was synthesized using a mechanical phase system. Our investigation delved into the various preparation parameters for these three types of silver powder, encompassing the selection of reducing agents, dispersants, control agents, stabilizers, complexing agents, reaction temperatures, reaction times, pH values, and other factors. The primary focus was on understanding how these parameters influenced critical properties such as the average particle size, particle size distribution, sphericity, compaction density, and the direct yield of silver powder. This meticulous analysis was pivotal in optimizing the preparation process for these diverse types of silver powder.

Through a systematic application of the chemical reduction method, we successfully prepared spherical silver powder and dendritic silver powder using an aqueous phase system, while single crystal silver powder was produced using an organic phase system. The distinct characteristics of each silver powder type were meticulously addressed through a methodical examination of the process parameters. The formulation for each kind of silver powder was optimized, and stepwise amplification experiments were conducted at varying multiples for the three types of silver powder, building a robust foundation for future research in this domain (Zhe, 2014, pp. 454-456).

This research not only addresses the challenges of producing micro-nano-silver powder in a cost-effective and environmentally friendly manner but also offers a valuable resource for further studies and applications within the silver powder industry. It highlights the intricate interplay of multiple factors and parameters, showcasing the potential for precision and control in silver powder production.

3. Influence of size and morphology of silver powder filler on the performance of conductive adhesive

Hao & Zhiyuan (2021, pp. 45-47) filled the same resin matrix with 80% silver powder fillers of different sizes and shapes to make conductive adhesive. They compared the volume resistivity, thermal conductivity, shear strength, and viscosity to study the influence of the size and shape of silver powder fillers on the properties of conductive adhesive. The larger the size of the silver powder, the lower the volume resistivity and shear strength of the conductive adhesive, and the higher the thermal conductivity. The viscosity of the spherical silver powder and the bulk silver powder conductive adhesive decreased with the increase in the size of the silver powder, while the viscosity of the flake silver powder conductive adhesive increased with the increase in the size of the silver powder.

Using the same epoxy resin matrix, domestic micron-sized spherical silver powder, massive silver powder, flake silver powder, and mixed silver powder of flake silver powder and nano-silver powder were used as conductive fillers, and conductive adhesive was prepared by filling according to the same mass ratio. The effects of different sizes and morphologies of silver powder on the volume resistivity, thermal conductivity, shear strength, and viscosity of conductive adhesive were compared and studied to further improve the performance of conductive adhesive. The larger the size of the silver powder, the smaller the volume resistivity and shear strength of the conductive adhesive, and the higher the thermal conductivity. The viscosity of spherical silver powder and block silver powder conductive adhesive increased with the size of silver powder, while the viscosity of flake silver powder conductive adhesive decreased with the size of silver powder.

4. Morphology and particle size control of spherical conductive silver powder

Spherical conductive silver powder with a narrow particle size distribution was prepared by a chemical reduction method, using polyvinyl pyrrolidone (PVP) as a protective agent, ascorbic acid as a reducing agent, and reducing silver ammonia solution, etc. This powder was then characterized by XRD and SEM (Fatang & Wang, 2011, pp. 52-55).

Silver powder was classified according to the average particle size, where Dav (average particle size) < 0.1 μm represented nanometer silver powder, 0.1 μm < Dav < 10.0 μm was classified as silver powder, and Dav > 10.0 μm was categorized as coarse silver powder. The electronic and aerospace industries primarily used micro and nano silver powder, given their specific properties.

The properties of silver particles were mainly determined by their particle size and morphology. Different application fields and industries had varying requirements for the morphology and particle size of silver powder. The prepared micro-nano silver powder included various shapes such as spherical, sheet, rod, linear, and dendritic. The primary preparation methods included chemical methods, such as the chemical reduction method, microemulsion method, ultrasonic synthesis method, and electrochemical method. Among these, the chemical reduction method was the most widely used.

Research results both domestically and internationally indicated that the morphology and particle size of silver powder prepared by the chemical reduction method were affected by numerous factors, including the type and concentration of the precursor, the type and dosage of the reducing agent, the type and dosage of the surfactant, reaction time, reaction temperature, stirring rate, reaction mode, etc. Consequently, controlling the parameters for silver powder prepared by the chemical reduction method was a complex process.

Furthermore, regular spherical conductive silver powder with a narrow particle size distribution and a smooth surface could be prepared by a liquid-phase chemical reduction method, using ascorbic acid as a reducing agent, PVP as a surfactant, and silver ammonia solution as a precursor. The liquid-phase controllable preparation of silver particles could be achieved by adjusting the experimental parameters, such as ammonia dosage, PVP dosage, reactant concentration, and reaction temperature.

5. Production process route and cost, investment cost, construction cycle, and profit of photovoltaic silver paste

The production process route and cost of photovoltaic silver slurry: silver powder, glass powder (or resin), and organic equivalent substances were batched, and then mixed, stirred, and ground in mechanical equipment. The stirring and grinding process parameters were controlled, and the silver slurry was filtered out. Product performance inspection, packaging, and warehousing were also carried out. Overall, photovoltaic silver paste integrated the scientific knowledge of metal, inorganic non-materials, and organic materials. Its preparation involved powder metallurgy, mechanical processing, phase diagram theory, nanotechnology, fluid mechanics, and other technical fields. The production technology barrier was high. The formula proportion, silver powder micro-gloss morphology, glass phase, organic phase preparation and addition methods, production process parameter control, and other key factors were essential in the preparation of photovoltaic silver paste.

Production cost of photovoltaic silver paste: In 2021, direct materials (silver powder, glass phase, organic phase, etc.) accounted for 99.41% of the production cost of photovoltaic silver paste (including 4.65% of material sales cost), labor cost accounted for 0.24%, manufacturing cost accounted for 0.28%, and logistics-related expenses accounted for 0.07%. Compared to 2016, direct materials accounted for 98.76%, direct labor accounted for 0.61%, and manufacturing costs accounted for 0.63%. The material cost in the silver slurry production process accounted for the largest proportion, while labor and fuel and power costs required for manufacturing accounted for a relatively small proportion. Among the material costs, silver powder cost accounted for over 90%. In the future, reducing production costs mainly involves material costs, especially the reduction of silver powder costs, which is the development direction.

Investment cost of photovoltaic silver slurry production line: According to the relevant announcements released by Suzhou Guzhen, Dike Co., Ltd., and Juhe Co., Ltd., and subject to different factors such as production technology, process, site, and market conditions of each company, the required funds for investing 500,000 kg to 1,700,000 kg of photovoltaic silver slurry production capacity were between 150 million to 270 million RMB, and the investment cost of a single ton of photovoltaic silver slurry production line was between 160,000 RMB and 53,000 RMB.

The construction period of photovoltaic silver slurry was 1-2.5 years. The decline in profits of photovoltaic silver slurry: With the reduction of subsidies in the photovoltaic industry, as well as the significant fluctuations in the price of purchased silver powder, the increase in business risks, and the intensification of industry competition, the gross profit margin of the photovoltaic silver slurry industry decreased. The average gross profit margin of the industry in 2021 was 13.15%, a year-on-year decrease of 9.37% compared to 2020. The average gross profit margin in the past five years had a compound annual decline rate of 8.95%, indicating a significant overall decline.

Competitiveness

The ability of a business to successfully compete in the market and build long-term performance advantages over its rivals was referred to as competitiveness. It involved a variety of elements, including the firm's overall strategic posture, product quality, innovation, cost-effectiveness, customer service, and marketing efficacy. The task of assessing a company's competitiveness was difficult and necessitated a multifaceted strategy.

According to Hitt, et al. (2016, p. 399), "the firm's ability to create, deliver, and capture value in a competitive market environment" was the definition of "firm competitiveness." It included the company's ability to create and maintain a competitive advantage, or superior performance in comparison to other competitors in the market (Barney, 1991, pp. 99-120). Competition extended beyond immediate financial success and involved the capacity to adjust over time to shifting market conditions and produce greater returns (Porter, 1990, pp. 73-93).

According to Hitt, et al. (2016, p. 399), the concept of "firm competitiveness" is fundamental in the realm of business strategy and management. It is defined as the firm's ability to create, deliver, and capture value in a competitive market environment. Firm competitiveness encompasses various dimensions that collectively contribute to a company's success and sustainability. One critical aspect of firm competitiveness is the firm's ability to create and maintain a competitive advantage. Competitive advantage refers to a unique set of strengths and capabilities that allows a company to outperform its rivals and secure a prominent position in the market (Barney, 1991, pp. 99-120). These strengths can include technological innovation, brand recognition, cost leadership, product differentiation, or access to critical resources. Maintaining such an advantage is an ongoing process that demands continuous innovation and adaptation to evolving market dynamics.

Furthermore, competition in today's business landscape extends beyond immediate financial success. It also involves the capacity to adapt over time to shifting market conditions and generate sustainable, long-term returns (Porter, 1990, pp. 73-93). This means that firms must not only focus on short-term profitability but also invest in strategies that enable them to weather market fluctuations and remain competitive in the face of changing consumer preferences, emerging technologies, and global economic shifts.

Firm competitiveness is a multifaceted concept that encompasses a company's ability to create value, maintain a competitive advantage, and adapt to changing market conditions. It is not solely about financial performance but also about a firm's resilience and capacity to prosper in a dynamic and highly competitive business environment. Understanding these dimensions of competitiveness is essential for businesses seeking sustained success and growth in the modern marketplace.

Measuring business competitiveness necessitated a combination of qualitative and quantitative techniques as well as taking both internal and external factors into account. These were a few methods that were frequently used to gauge a company's competitiveness:

1) Financial Performance Metrics: According to Gupta & Govindarajan (2000, pp. 473-496), financial metrics like return on investment (ROI), return on assets (ROA), and net profit margin offered quantitative assessments of a company's financial competitiveness. These indicators evaluated the company's capacity for resource management and profit generation.

2) Market Share: The market share of a company was its share of the overall market demand divided by its sales or income. It evaluated the company's ability to compete in the market and draw in clients (Hooley, et al., 2005, pp. 18-27).

3) Customer Satisfaction and Loyalty: According to Johnson, et al. (1996, pp. 163-182), customer-centric metrics such as customer satisfaction surveys, customer retention rates, and customer lifetime value were used to gauge a company's capacity to provide value and forge lasting connections with its clients.

4) Innovation and R&D Metrics: A company's innovation competitiveness could be determined by measures of its investment in research and development (R&D), the number of patents, the success rate of new product development, and time-to-market (Danneels, 2002, pp. 1095-1121).

5) Operational Efficiency Metrics: According to Su, et al. (2023, p. 6386), operational competitiveness and cost efficiency were shown by efficiency indicators such as total factor productivity, cost per unit, and cycle time.

Assessing a company's standing in industry rankings and contrasting it with its rivals could offer a relative measure of competitiveness (for example, Forbes Global 2000, Fortune 500). By creating a clear and well-defined strategic plan that matched the firm's resources and competencies with market possibilities and competitive advantages, businesses became more competitive. Analyzing the external environment, comprehending consumer wants, and developing efficient strategies were required for this (Porter, 1996, pp. 85-90).

Additionally, by Continuous Improvement: Making every effort to improve how the business operated. To improve operational efficiency, cut waste, and provide higher value to consumers, implementing quality management systems like Total Quality Management (TQM), Lean Six Sigma, or Kaizen (Dale, et al., 2007, p. 457), and concentrating on Innovation and Research Development: Promoting an innovative culture within the firm by funding R&D initiatives, fostering creativity, and fostering experimentation. Continuous innovation resulted in the creation of novel goods, procedures, and technology, giving businesses an advantage over rivals (Tidd & Bessant, 2018, p. 1840007)

Summary

The research of the above documents was a problem that could not be ignored under the historical conditions of the development and utilization of solar photovoltaic clean energy. The use of solar photovoltaic and other types of energy could greatly reduce mankind's dependence on fossil energy, as well as the environmental pollution caused by the usage process. Scholars focused on how to make more efficient use of solar energy resources and better use of silver powder technology, and they made a detailed analysis from different perspectives, such as policy, technological development, and innovation. From the data collected in this project, it was evident that although many scholars had conducted various studies on the application of silver powder technology, there were also deficiencies and shortcomings in these studies, as follows:

The technical barriers that had to be overcome in silver powder and silver paste were relatively high. China's photovoltaic industry mainly depended on imports in its development, and the development risk was high. In the document "Research on Silver Powder for Photovoltaic Silver Paste," the process and technical conditions had gradually matured after years of development. The time span of this study was long, which may have had a certain impact on the research direction of researchers. According to the methodologies of the documents "Influence of morphology and particle size of silver powder on the performance of lead-free conductive silver paste" and "Morphology and particle size control of spherical conductive silver powder," small experiments were relatively easy, but it was difficult to expand the scale of production of ABC Company, and the conversion cost was high. In the literature "Controllable preparation and scale-up experimental study of micro and nano silver powder," it was difficult to verify the adding ratio of various kinds of silver powder. According to the "Experimental Study on Controllable Preparation and Enlargement of Micro and Nano-silver Powder," there was a problem that the sphericity of spherical silver powder became worse due to the instability in the preparation of spherical silver powder with the increase of magnification; In the subsequent washing process of single crystal silver powder, the sedimentation rate was low, and the problem affecting the yield could not be ignored.