Blue Book of China's Concentrating Solar Power Industry 2024

China Solar Thermal Alliance
CSP Committee of China Renewable Energy Society
Zhongguancun Xinyuan Solar Thermal Technology Services Center

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Chapter I Overview of Concentrating Solar Power

1.1 Principles of concentrating solar power systems

Concentrating solar power (CSP) systems, also known as solar thermal electricity (STE) systems, are systems that generate electricity by converting solar energy into thermal energy and then converting heat (thermal energy) to work [1]. A CSP plant usually consists of a solar collection system, a heat storage and exchange system, and a heat-work-electricity conversion system.

Depending on solar concentration modes, commercially applied CSP systems can be classified into four main types, namely, solar tower systems, parabolic trough CSP systems, linear Fresnel CSP systems, and parabolic dish CSP systems. Solar tower and parabolic dish CSP systems are point-focusing systems, while parabolic trough and linear Fresnel CSP systems are line-focusing systems. CSP systems can use different heat transfer fluids (HTFs) as heat absorbing media. The most common commercial HTFs are binary molten salt (also known as solar salt, which is a binary mixture of 60% sodium nitrate and 40% potassium nitrate in the molten state) and thermal oil (a mixture of biphenyl and diphenyl ether). The operating principles of CSP systems involving different HTFs and solar concentration modes are detailed in the following paragraphs. Solar tower systems using molten salt as the HTF and parabolic trough CSP systems using thermal oil as the HTF are currently the mainstream commercial CSP systems.

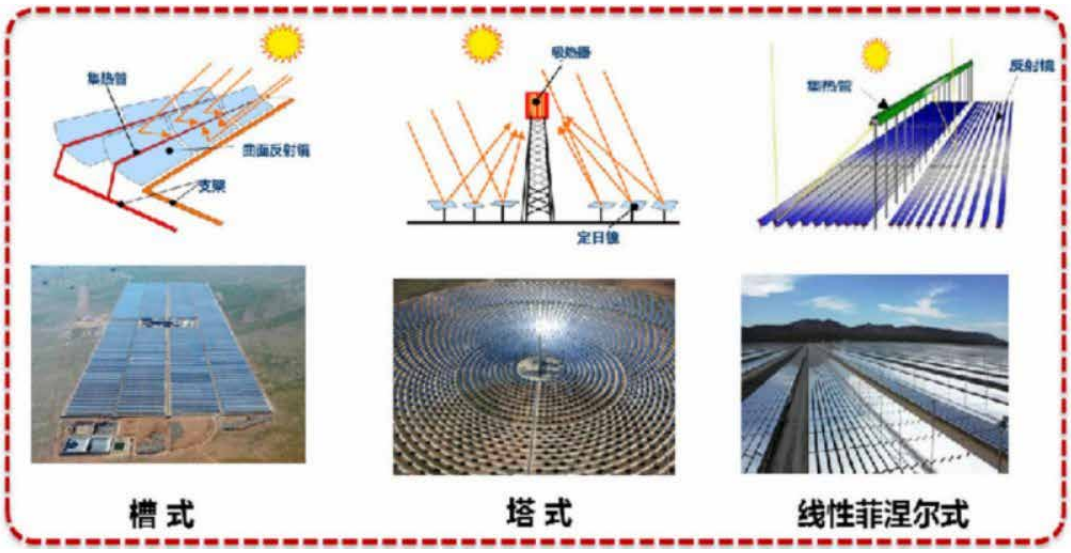


Fig. 1.1-1 Three mainstream modes of solar concentration

A molten salt (MS) solar tower system consists primarily of heliostats, heat absorption tower, solar receivers, high-temperature (hot) and low-temperature (cold) MS storage tanks, steam generators, and turbine-generator unit (TGU). The basic operating principle of such systems is described below. The heliostats arranged around the heat absorption tower track the sun, reflect and focus beams of sunlight onto the central solar receiver at the top of the heat absorption tower. The low-temperature liquid solar salt is transferred by the cold salt pump to the central solar receiver to absorb

heat, and then the hot MS is routed to the hot salt tank for storage. When electricity generation is required, the hot MS is transferred to the steam generator and exchanges heat with water, generating high-temperature and high-pressure (HTHP) steam. The HTHP steam drives the TGU to generate electricity. After releasing heat in the steam generator, the MS is routed to the cold salt storage tank and then recirculated to the central solar receiver to absorb heat. The process described above is repeated during electricity generation. In a MS solar tower system, the thermal energy storage (TES) unit separates the solar concentration and electricity generation units, and the MS serves as both HTF and TES medium.

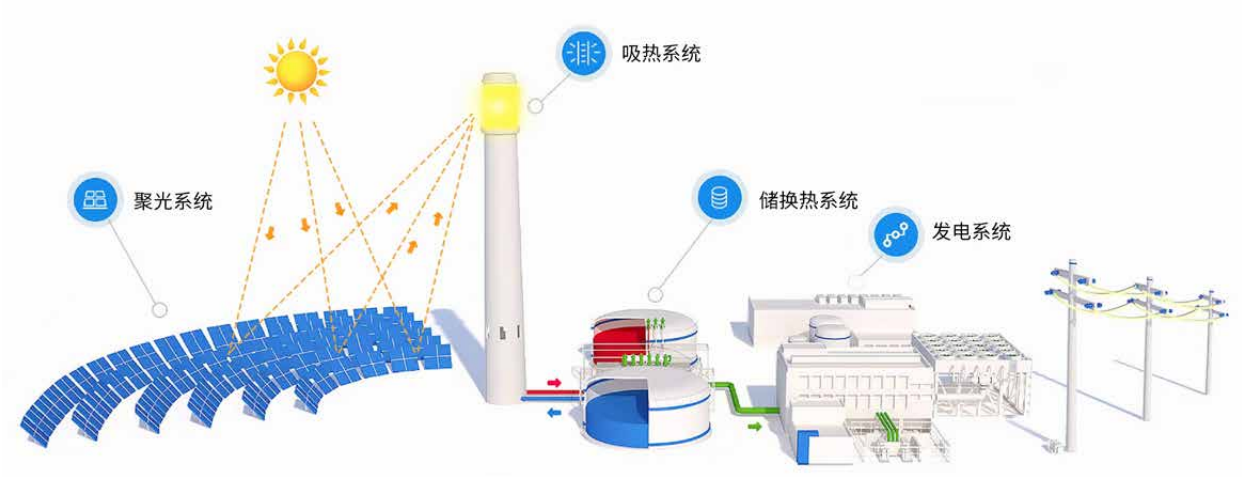


Fig. 1.1-2 Schematic diagram of an MS solar tower system (Source: Cosin Solar)

A parabolic trough CSP system using thermal oil as HTF mainly consists of parabolic trough collectors (which are composed of solar concentrators and receiver tubes), an MS heat storage and exchange system, a thermal oil/steam generation system, and TGU. The parabolic trough collectors are connected both in series and in parallel and arranged in modules, forming a collector field. The basic operating principle of a parabolic trough CSP system is detailed below. The solar concentrators track the sun and reflect sunlight onto the receiver tubes arranged along the focal line to heat the HTF in these tubes. The produced thermal energy is transferred via the HTF/molten salt heat exchanger to the storage tank. When required, the HTF is heated by hot molten salt and transferred to the steam generator, where it undergoes heat exchange, producing steam for electricity generation. The HTF heated in the solar collection system can be directed routed to the oil/steam generator, and the steam generated by the steam generator drives the TGU to do work and generate electricity. The low temperature and low-pressure (LPLT) steam from the TGU is condensed into liquid water in the condenser, and the liquid water is returned to the thermal oil (HTF) steam generator where it absorbs heat from the HTF and evaporates into steam again. After releasing heat in the HTF steam generator, the cold HTF is routed back to the receiver tubes for heating, thus forming a closed circulation loop. Similar to the case of MS solar tower systems, the solar collection and electricity generation units in the TES block of a parabolic trough CSP plant are decoupled, thus eliminating the impact of fluctuations in solar radiation on the stability of TGU output and enabling the plant to be connected to the grid and engage in electricity dispatch without reliance on solar radiation.

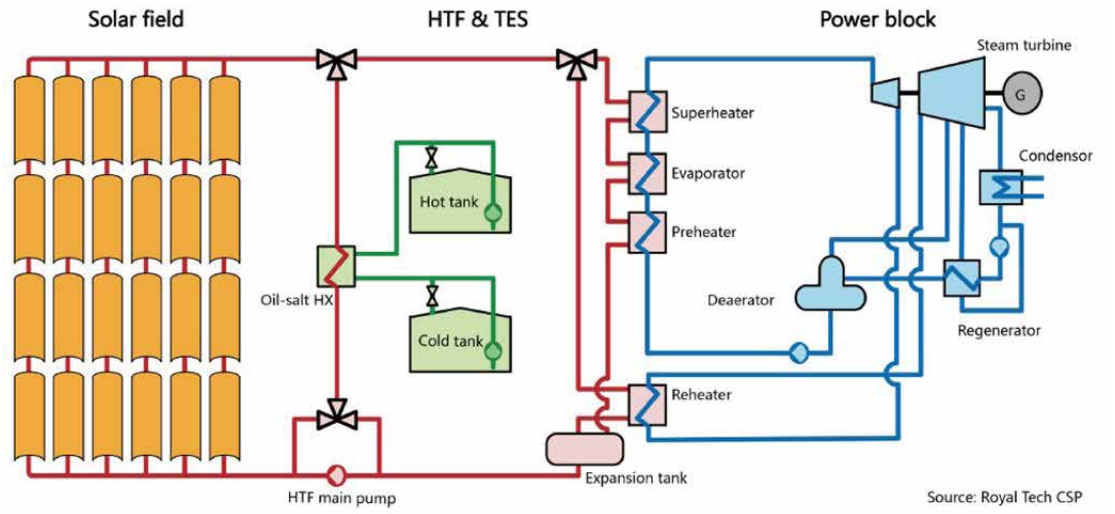


Fig. 1.1-3 Schematic diagram of a parabolic trough CSP system (conventional process) (Source: Royal Tech CSP)

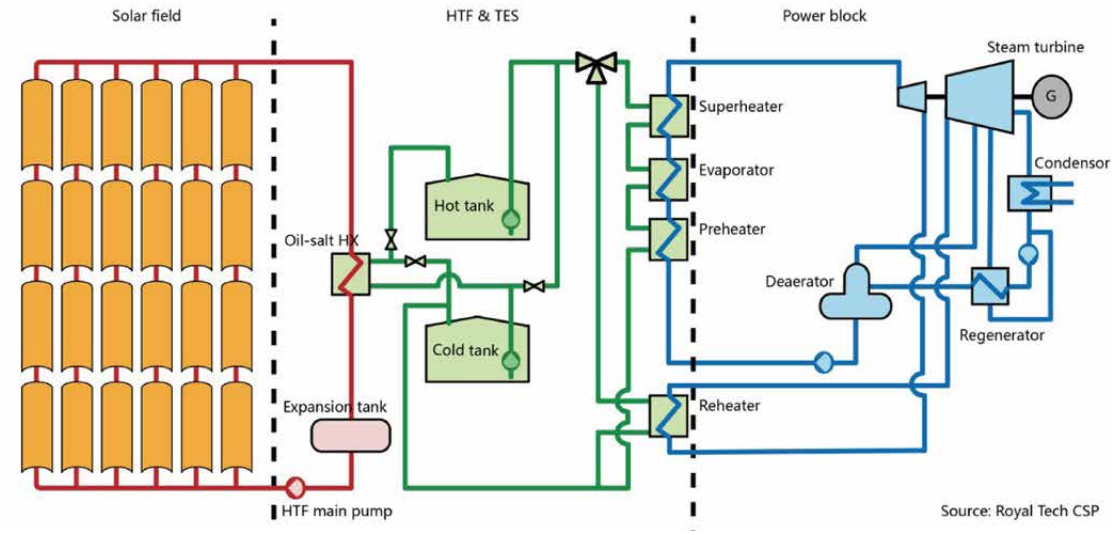


Fig. 1.1-4 Schematic diagram of a parabolic trough CSP system (decoupled process) (Source: Royal Tech CSP)

In a parabolic trough CSP system, the molten salt used can also serve as the HTF. The operation process of parabolic trough CSP systems is described below. The parabolic trough collectors track the sun and collect solar energy to heat the molten salt flowing in receiver tubes. The molten salt that has absorbed heat is stored in the hot salt tank. When electricity generation is required, the molten salt stored in the hot salt tank is transferred to the steam generator, where it releases heat and exchanges heat with water, producing superheated steam that drives the TGU to generate electricity. After heat exchange, the cold molten salt is transferred to the cold salt tank for storage.

An MS linear Fresnel CSP system consists of linear Fresnel collectors (LFCs) that form a Fresnel collector field, hot and cold salt storage tanks, steam generator, and TGU. The Fresnel collector field comprises primary reflectors, secondary reflectors, and receiver tubes. The basic operating principle of a linear Fresnel CSP system is described below. Multiple rows of reflective mirrors (reflectors) are compactly arranged, forming a quasi-parabolic structure. The primary reflectors, which can automatically track the sun, reflect direct solar radiation (beams) onto the secondary

reflectors above them, while the secondary reflectors reflect and focus solar beams onto the vacuum receiver tubes. The solar energy concentrated in the vacuum receiver tubes heats the molten salt in these tubes, and the heated (hot) molten salt is stored in the hot salt tank.

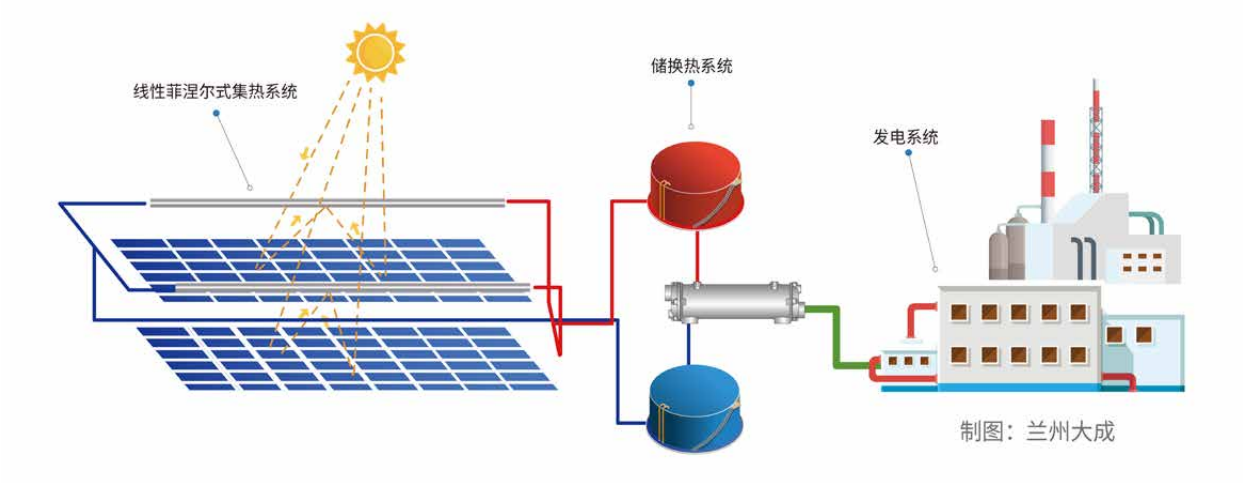


Fig. 1.1-5 Schematic diagram of an MS linear Fresnel CSP system (Source: Lanzhou Dacheng)

CSP systems convert solar energy to thermal energy and generate electricity by heat-work conversion through thermodynamic cycles. The driving force of thermodynamic cycles is the thermal energy of the working fluid in solar collectors. The temperature of such working fluid determines both the photothermal conversion efficiency and the heat-work conversion efficiency. It is the most important factor that determines the efficiency and cost of CSP systems. Fig. 1.1-6 shows the development roadmap for CSP technologies classified into various generations based on such temperature, which basically correspond to the generations of CSP technologies published by the U.S. Department of Energy (DOE).

	1st generation	2nd generation	3rd generation	4th generation
Efficiency	12%	20%	30%	35%
Receiver temperature	230-430℃	375-530℃	650-950℃	800-1100℃
Medium	Water/thermal oil	Nitrate/liquid metal	Air/foam ceramics	Carbonate/chlorides / ceramic granules
2006-2010	1MW Demonstration	0.1MW Experimental	1MWt Experimental	0.02MWt Conceptual design
2011-2015	10MW Demonstration	10MW Demonstration	5MWt Demonstration	1MWt Experimental
2016-2020	100-1000MW Commercial	100MW Commercial	1MW Demonstration	10MWt Demonstration
2021-2025		1000MW Commercial	5MW Demonstration	1MW Demonstration
2026-2030			100MW Commercial	10MW Commercial

Fig. 1.1-6 CSP Technology Development Roadmap

The roadmap above was prepared in 2004 and still has value as a reference. The yellow areas in the figure represent demonstration-level technologies, the areas above the yellow areas represent laboratory technologies, and those below the yellow areas represent commercial technologies. Temperature refers to the collector temperature, medium refers to the heat absorbing medium of solar receiver, and efficiency refers to the overall system efficiency from solar energy to electricity at the design point. The electricity generation capacity of the first-generation and second-generation CSP systems in 2024 can reach the 1,000 MW level. In principle, the single-unit capacity of CSP projects actually launched in the second half of 2024 should be no less than 200 MW and is expected to reach 350 MW. The power of the fourth-generation CSP systems with 800°C heat-absorbing medium and supercritical CO2 solar thermal power systems put into operation for electricity generation in 2024 is 0.2 kW [2]. Current CSP technology developments are basically consistent with the roadmap above. It is to be noted that, from the perspective of thermodynamic efficiency, the temperature of the solar collector field is the core indicator of thermodynamic efficiency. The 565°C molten salt linear Fresnel CSP, molten salt parabolic trough CSP, and molten salt solar tower technologies are all second-generation technologies.

The optical concentration ratio of a solar concentrator field is the most important parameter that affects the temperature and efficiency of solar concentration. It is the ratio of the average radiant power density on the aperture area of the solar receiver (kW/m2) to the direct normal irradiance over the aperture of the solar concentrator field (kW/m2). Generally, the higher the concentration ratio of the solar concentrator field, the higher the solar collection efficiency that the CSP system can achieve, and the higher the electricity generation efficiency of the system. Dish-Stirling CSP systems have the highest concentration ratio, ranging between 600 and 3,000, and the concentration ratios of solar tower, linear Fresnel and parabolic trough CSP systems are 300-1,000, 150, and 80-100, respectively. The CSP system efficiency is the product of solar collection efficiency and thermoelectric efficiency. When the concentration ratio is determined, simply increasing the solar collector temperature may not necessarily improve the system efficiency, but instead it may reduce the solar energy-electricity conversion efficiency. For a fixed concentration ratio, as the operating temperature of the solar receiver increases, the thermal (heat engine) efficiency will increase, but the solar collection efficiency will decrease, due to which a "saddle point" will appear on the system efficiency curve. Therefore, the the solar energy-electricity conversion efficiency can only be improved by increasing the concentration ratio and solar collector temperature in a coordinated manner, as shown in Fig. 1.1-7.

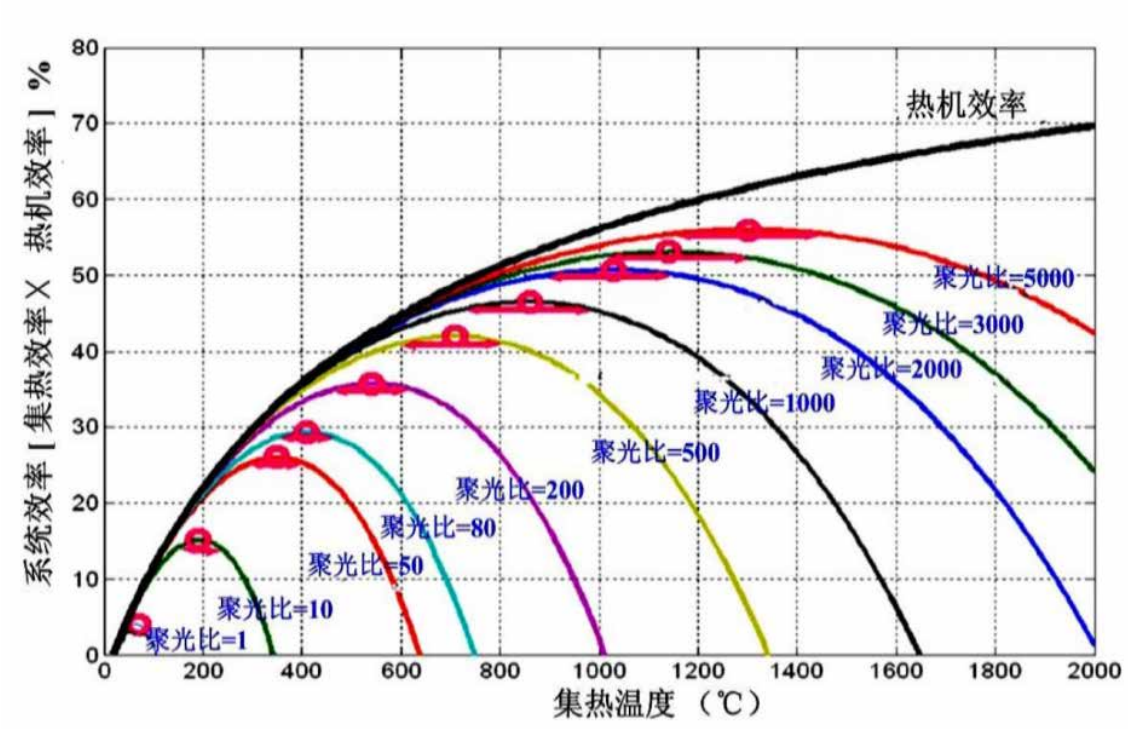


Fig. 1.1-7 Relationship between the CSP system efficiency and the solar collector temperature and concentration ratio

1.2 Role and positioning of CSP

Since the initiation of the "11th Five-Year Plan", China's CSP technologies, research, equipment and products have been developing rapidly. In the 14th Five-Year Plan for Renewable Energy Development (NDRC Energy Document No. [2021] 1445) jointly issued by the National Development and Reform Commission (NDRC), National Energy Administration (NEA), Ministry of Finance (MOF), Ministry of Natural Resources (MNR), Ministry of Ecology and Environment (MEE), Ministry of Housing and Urban-Rural Development (MOHURD), Ministry of Agriculture and Rural Affairs (MARA), China Meteorological Administration (CMA), and the National Forestry and Grassland Administration (NFGA), it is clearly stated that China will orderly promote the development of CSP with long-term TES capability; for regions with high-quality resources such as Qinghai, Gansu, Xinjiang, Inner Mongolia, and Jilin, build CSP plants with long-term TES capability, fully leverage the capabilities of CSP plants in thermal energy storage, load regulation and provision of support for power systems, promote the construction and operation of CSP, wind power, and PV hybrid power plants, and improve the stability and reliability of renewable power generation systems. Developing CSP can ensure renewable energy consumption and promote the integration of renewable power generation systems into the power grid on a larger scale [3].

In the Notice of the General Department of the National Energy Administration on Promoting the Large-scale Development of Solar Thermal Power (March 2023), the role and positioning of CSP are clearly defined, and it is clearly stated that it is necessary to fully understand the significance of large-scale development of CSP; CSP has dual functions of peak shaving and energy storage, can provide long-term peak shaving capacity and moment of inertia in the power system, and has the potential to serve as both peak-shaving and basic power in some regions; the CSP industry has a long chain and can drive the development of multiple traditional and emerging industries and become a new growth

driver for China's new energy industry. As stated in Chapter IV of the document, where conditions permit, provinces and regions are encouraged to enact financial, pricing, land, and other policies supporting the large-scale development of the CSP industry as soon as practicable, plan the construction of 1,000 MW-scale and 10,000 MW-scale CSP plants in advance, and take the lead in developing CSP industry clusters [4].

In Article 8 of the Opinions of the Central Committee of the Communist Party of China and the State Council on Accelerating the All-round Green Transformation of Economic and Social Development issued on July 31, 2024, it is proposed to scientifically deploy pumped hydro energy storage, new energy storage, and CSP plants to improve the safe operation and comprehensive regulation capabilities of the power system [5].

According to Article 25 of the Energy Law of the People's Republic of China effective on January 1, 2025, China promotes the development and utilization of wind and solar power and the construction of both centralized and distributed systems, strives to accelerate the construction of wind power and PV power plants, supports the development and utilization of distributed wind power and PV power generation systems in the vicinity, develops offshore wind power in a reasonable and orderly manner, and actively develops the CSP industry [6]. This provides fundamental support for the development of the CSP industry.

This Blue Book analyzes the current challenges and barriers faced by China's CSP industry from a global perspective and explores ways to establish a model for the development of the CSP market and industry chain with guaranteed quality, supported by law, based on technologies, and guided by policies.

1.3 CSP-related policies enacted in 2024

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
1	Notice of the National Government Offices Administration (NGOA) on Arrangements for Energy Resource Conservation and Eco-environment Protection by Public Institutions in 2024	NGOA	Guoguan Energy Document No. [2024] 12	Jan. 29, 2024	Promote the development and utilization of renewable energy resources such as solar energy according to local conditions, expand the scale of "green electricity" utilization, and study the policies for promoting the construction of CSP projects/plants.
2	Notice on Properly Handling Matters related to Mid-term and Long-term Transactions in the Inner Mongolia Multilateral Electricity Trading Market in 2024	Inner Mongolia Autonomous Region Energy Bureau	Inner Mongolia Energy & Power Document No. [2024] 55	Feb. 4, 2024	Power grid companies should define the modes of power generation and purchase for emerging power generation systems such as market-oriented, grid-connected new energy projects (including electricity consumption and generation), virtual power plants, and market-oriented CSP projects in accordance with the requirements of relevant documents.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
3	Notice of the General Office of the Ministry of Industry and Information Technology (MIIT) on Issuing the Guidelines for Building a System of Standards for Carbon Dioxide Peaking and Carbon Neutrality in the Industrial Sector	MIIT General Office	MIIT General Office Document No. [2024] 7	Feb. 21, 2024	Develop standards for technologies and equipment related to the development, transmission, storage, utilization and distributed application of renewable energy sources such as solar energy, and include the national standard titled "Technical Specification for the Evaluation of Project-based Greenhouse Gas Emission Reduction for Solar Energy Utilization" (20220846-T-469) into the List of Existing and Under-Development Standards for Carbon Dioxide Peaking and Carbon Neutrality in the Industrial Sector.
4	Notice on Issuing the Implementation Plan for the Collection and Promotion of National Key Low-Carbon Technologies	MEE General Office, the General Office of the Ministry of Science and Technology (MST), MIIT General Office, MOHURD General Office, the General Office of the Ministry of Transport (MOT), MARA General Office	Huanban Climate Document No. [2024] 2	Feb. 18, 2024	"Key directions" mainly include high-parameter, low-cost CSP technologies and technologies for distributed CHP (combined heat and power) systems. Advanced energy storage technologies mainly include new energy storage technologies such as heat storage (cold storage) technology.
5	Guiding Opinions on Strengthening the Building of Power Grid Peak Shaving, Energy Storage and Intelligent Scheduling Capabilities	National Development and Reform Commission (NDRC), NEA		Feb. 27, 2024	Give full play to the peak-shaving role of CSP, promote the construction of system-friendly renewable-energy power plants, and strengthen the application of high-precision, long-term power prediction technologies and smart centralized control technologies to enable power plants to gain certain grid peak shaving and capacity supporting capabilities.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
6	Guiding Opinions on Accelerating the Promotion of the Green Development of the Manufacturing Industry	MIIT, NDRC, MOF, MEE, People's Bank of China (PBoC), State-owned Assets Supervision and Administration Commission of the State Council (SASAC), State Administration for Market Regulation (SAMR)	MIIT Lianjie Document No. [2024] 26	Feb. 29, 2024	Accelerate the establishment and improvement of green product standard, labeling and certification systems covering major industries, investigate the possibility of strengthening government/public procurement of green products, and promote the application of green products such as solar thermal systems, new energy vehicles and ships, and green buildings.
7	Notice on Issuing the Guiding Opinions on Energy Work in 2024	NEA	NEA Development Planning Document No. [2024] 22	Mar. 18, 2024	It is clearly stated in the document that it is necessary to continue to promote green and low-carbon energy transition and high-quality development, ensure energy security, and in particular, do a good job in national CSP planning and layout, and constantly promote the large-scale development of CSP.
8	Notice of the People's Government of Gansu Province on Issuing the Territorial Spatial Plan of Gansu Province (2021-2035)	People's Government of Gansu Province	Gansu Government Document No. [2024] 18	Mar. 25, 2024	Actively explore the modes of construction for CSP projects, plan and implement CSP projects with long-term TES in areas with abundant resources and superior conditions for project construction, promote the construction of "solar thermal + wind and photovoltaic" integrated projects, give full play to the peak-shaving role of CSP, and improve the stability and reliability of renewable-energy power systems.
9	Notice on Several Policy Measures to Support the Green, Low-carbon and High-quality Development of Inner Mongolia	NDRC, MIIT, MNR, MEE, NEA, NFGA	NDRC Environmental Document No. [2024] 379	Apr. 3, 2024	Develop new energy resources with greater efforts; focus on planning and constructing large-scale wind power and PV power bases in the Kubuqi, Ulan Buh, Tengger and Badain Jaran deserts, carry out environmental impact assessments for planned projects simultaneously, take active steps to develop CSP projects; speed up the development of the new energy sector; develop high-quality industry clusters such as solar power, wind power, PV power, hydrogen energy, and energy storage whil ensuring energy consumption.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
	Notice on Issuing the 2024-2025 Energy Conservation and Carbon Reduction Action Plan	State Council	State Council Document No. [2024] 12	May 23, 2024	Focus on controlling the consumption of fossil fuels, strengthen carbon intensity management, and launch special campaigns for energy conservation and carbon reduction in different fields and industries. This policy will help promote the development of renewable energy resources such as CSP in order to achieve the goals of carbon dioxide peaking and carbon neutrality.
10	Notice on Conducting Pilot Survey of Wind and Solar PV Power Generation Resources	NDRC, NEA, MNR, MEE, CMA, NFGA	NEA New Energy Document No. [2024] 43	Jun. 6, 2024	Pilot areas should conduct the survey based on their own resource endowments. Areas where conditions permit may extend the scope of survey to solar PV energy and other renewable energy resources for power generation within within their jurisdiction, such as offshore wind, offshore solar PV and ocean energy resources.
11	Opinions of the Central Committee of the Communist Party of China and the State Council on Accelerating the All-round Green Transformation of Economic and Social Development	CPC Central Committee, State Council	State Council Gazette No. [2024] 12	Jul. 31, 2024	Strengthen the connection and integration of clean energy bases, resources for regulation, and power transmission lines in terms of scale/ capacity, spatial layout, and construction pace, scientifically deploy CSP projects, and improve the safe operation and comprehensive regulation capabilities of the power system.
12	Notice on Issuing the Action Plan for Accelerating the Construction of a New Power System	NDRC, NEA, National Data Administration (NDA)	NDRC Energy Document No. [2024] 1128	Aug. 6, 2024	Explore modes for the stable supply of green power through joint operation of CSP, wind and solar PV power plants.
14	Notice on Issuing the Encouragement List and Negative List for Business Development of Financial Leasing Companies and Positive List for Project Company Business	National Financial Regulatory Administration (NFRA)		Aug. 16, 2024	The encouragement list is oriented to national strategic needs and includes important equipment and major technical equipment such as CSP, pharmaceutical research and development, and ships in 27 industries including the new energy industry.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
13	Detailed Rules for the Implementation of CSP-Wind-PV Hybrid Power Generation Projects in Inner Mongolia Autonomous Region (Issued for Comment)	Inner Mongolia Autonomous Region Energy Bureau	Inner Mongolia Energy Document No. [2024] 17	Aug. 12, 2024	CSP-wind-PV hybrid power generation systems should be constructed of "long-term TES CSP + wind power + PV + electric heating (+ supplementary firing) units, scheduled in a unified manner, and operated in a coordinated manner. A CSP-wind-PV hybrid power generation system should be connected to the public power grid as a whole, with a clear physical interface with the power grid. In a CSP-wind-PV hybrid power generation system, the installed capacity of the CSP unit shall generally be no less than 200 MW, and its TES time and mirror field area shall be determined according to the needs of CSP and PV load regulation (in principle, the TES time shall be no less than 6 hours, and the mirror field area shall be no less than 8 m^2/kW). A CSP-wind-PV hybrid power generation system should operate as a whole to generate electricity, its power output should folllow the grid load profile to the maximum extent possible and shall generally be no less than 75% of its capacity, and its ability to follow the grid load profile shall be estimated based on the ratio between the annual cumulative totals of the normalized annual hourly output curve and the normalized grid load profile. During the evening peak period (17:00-22:00), the peak output/capacity of a CSP-wind-PV hybrid power generation system shall be no less than the sum of the rated capacity of the CSP unit and the confidence capacity of the wind power generation unit. The CSP-wind-PV capacity ratio of a CSP-wind-PV hybrid power generation system can be 1:2:0, 1:1.5:1 or 1:1:2, subject to the decision made by the owner based on actual conditions. For CSP-wind-PV hybrid power generation systems, the output/capacity of the CSP unit can be improved by supplementary firing, and the electricity generation contributed by supplementary firing shall not exceed 10% of the system's total electricity generation. The carbon dioxide emissions from a CSP-wind-PV hybrid power generation system with supplementary firing shall not exceed 100 g of carbon dioxide equivalent (CO_2e) per kilowatt-hour (kWh). The lines connecting CSP-wind-PV hybrid power generation systems and the public power grid should be constructed by power grid companies, and if an agreement is reached, may be constructed by project investors. The completed lines can be repurchased by power grid companies in due course according to applicable laws and regulations.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
15	Detailed Rules for the Implementation of Operation Management of Grid-connected Power Plants in Northeast China, Detailed Rules for the Implementation of Management of Auxiliary Services of Power Plants in Northeast China	NEA Northeast China Energy Regulatory Bureau	NEA Northeast China Energy Regulatory Bureau Market Document No. [2024] 41	Aug. 21, 2024	The grid-connected subjects on the generation side include thermal power plants, hydropower plants, nuclear power plants, wind farms, PV power plants, CSP plants, and self-provided power plants within the jurisdiction of load scheduling entities at provincial and higher levels in Northeast China. The monthly operation rate for grid-connected thermal power plants, hydropower plants, nuclear power plants, and CSP plants with primary frequency regulation should reach 100%. If the actual monthly operation rate does not meet this requirement, monthly assessments shall be performed at rated capacity × 0.3 cent/10,000 kW for each percentage point of the difference between the actual and specified monthly operation rates.
16	Implementation Guidelines for Digital and Green Transformations	Secretariat of the Office of the Central Cyberspace Affairs Commission, NDRC General Office, MIIT General Office, MNR General Office, MEE General Office, MOHURD General Office, MOT General Office, MARA General Office, General Office of State Administration for Market Regulation (SAMR), NDA Comprehensive Affairs Department		Aug. 24, 2024	Explore modes for the stable supply of green power through joint operation of CSP, wind and solar PV power plants; progressively promote the large-scale application of CSP in small or edge data centers.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
17	Notice on Ensuring the Linkage Between Renewable Energy Green Electricity Certificates and Voluntary GHG Emission Reduction Trading Market	NEA Comprehensive Department, MEE General Office	NEA Comprehensive Department New Energy Notice No. [2024] 124	Sep. 11, 2014	Avoid repeated obtainment of benefits from green electricity certificates (GECs) and CCER (China Certified Emission Reduction Scheme) by renewable-energy power projects. CSP projects that intend to participate in GECs trading shall not apply for CCER for the corresponding amount of electricity. For CSP projects that intend to apply for CCER, after the review and registration of voluntary GHG emission reduction projects are completed, the NEA Electric Power Service Qualification Management Center (Qualification Center) will "freeze" the related GECs and include them into the scope of untraded GECs for the period. After the verification and registration of the reduction in GHG emissions, the NEA Qualification Center will cancel the untraded GECs corresponding to such reduction and disclose related information to the public.
18	Notice on Initiating the Application Process for the Second Batch of Demonstration Projects for Advanced Green and Low-carbon Technologies	NDRC	NDRC Huanzi Document No. [2024] 759	Sep. 20, 2024	Technical requirements for large-capacity, low-cost CSP demonstration projects: The single unit capacity shall be no less than 200 MW, the TES time shall be no less than 6 hours, and the mirror field area shall be no less than 8 m^2/kW. The focus should be placed on supporting projects with a single unit capacity equal to or greater than 300 MW.
19	Shaanxi Province Three-Year Action Plan for Renewable Energy Development (2024-2026)	Shaanxi Provincial Development and Reform Commission	Shaanxi Development and Reform Commission New Energy Document No. [2024] 1603		Areas with good light conditions such as Yulin are encouraged to build CSP plants for peak shaving.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
20	Opinions on Strengthening the Clean and Efficient Utilization of Coal	NDRC, MIIT, MNR, MEE, MOT, NEA	NDRC Operation Document No. [2024] 1345	Sep. 29, 2024	Provided that source of gas supply are finalized, promote the implementation of "coal-to-gas" and "coal-to-electricity" projects according to local conditions, and encourage the use of industrial waste heat, combined heat and power, and clean energy resources such as geothermal energy and solar thermal energy in place of loose coal.
21	Guiding Opinions on Vigorously Implementing Renewable Energy Substitution Actions	NDRC, MIIT, MOHURD, MOT, NEA, NDA	NDRC Energy Document No. [2024] 1537	Oct. 30, 2024	Promote the large-scale development of CSP; accelerate the enhancement of renewable energy resource evaluation, power prediction, and intelligent regulation/control capabilities; strengthen R&D and multi-scenario application of new TES technologies. Promote the application of CSP technologies such as long-term TES power generation, thermoelectric coupling, and medium- and high-temperature heat utilization. Accelerate pilot testing and application; promote deep integration and joint operation of CSP-wind-PV power systems.
22	Energy Law of the People's Republic of China	Adopted at the 12th session of the Standing Committee of the 14th National People's Congress on November 8, 2024, effective from January 1, 2025	/	Nov. 8, 2024	Article 25 China promotes the development and utilization of wind and solar power and the construction of both centralized and distributed systems, strives to accelerate the construction of wind power and PV power plants, supports the development and utilization of distributed wind power and PV power generation systems in the vicinity, develops offshore wind power in a reasonable and orderly manner, and actively develops the CSP industry.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
23	Notice on Issuing the Plan for Xinjiang Power Grid Preferential Power Purchase and Generation in 2025	Xinjiang Uygur Autonomous Region Development and Reform Commission	/	Nov. 25, 2024	The electricity generated by national CSP demonstration projects will be preferentially purchased according to the approved number of kilowatt-hours. The planned amount of electricity in this respect is 198 million kWh.
24	Catalogue of Encouraged Industries in Western China (2025 Edition)	NDRC	Decree No. [2024] 28	Nov. 29, 2024	New encouraged industries in Western China include multiple CSP projects. Yunnan Province: R&D and production of building materials for solar energy utilization and PV power generation applications; construction and operation of wind and solar power plants, recycling of decommissioned wind power, PV power and CSP generation and energy storage equipment. Gansu Province: R&D and manufacturing of renewable energy equipment such as CSP generators, wind turbines, PV battery modules and inverters, and bidirectional chargers; development of solar energy multi-heat-source drying technology; construction, operation and maintenance of CSP systems; construction, operation and maintenance of wind farms; recycling of decommissioned wind power, PV power and CSP generation and energy storage equipment. Xinjiang Uygur Autonomous Region (including the Xinjiang Production and Construction Corps): operation and maintenance of clean energy power plants such as wind, PV,and CSP power plants; manufacturing of CSP systems and components.

No.	Policy	Enacted/issued by	Document No.	Enacted/ issued on	Main content
25	Preliminary Notice of Inner Mongolia Autonomous Region Energy Bureau on the Application Process for CSP-wind-PV Hybrid Projects	Inner Mongolia Autonomous Region Energy Bureau	Inner Mongolia Autonomous Region Energy Bureau New Energy Document No. [2024] 788	Dec. 4, 2024	For a CSP-wind-PV hybrid plant, the installed capacity of the CSP system shall generally be no less than 200 MW, and the TES time and mirror field area shall be determined according to the needs of wind and PV power load regulation (in principle, the TES time shall be no less than 6 hours, and the mirror field area shall be no less than 8 m^2/kW). The output/capacity of the CSP system can be improved by supplementary firing, and the electricity generation contributed by supplementary firing shall not exceed 10% of the plant's total electricity generation. The carbon dioxide emissions from a CSP-wind-PV hybrid plant with supplementary firing shall not exceed 100 g CO_2e/kWh.
26	Notice on Feed-in Tariff Rates for Electricity Generated by CSP Plants in Qinghai Province	Qinghai Provincial Development and Reform Commission	Qinghai Provincial Development and Reform Commission Pricing Document No. [2024] 778	Dec. 31, 2024	For CSP projects that have been constructed separately according to basic construction procedures and included into the annual CSP demonstration (pilot) project development program of Qinghai Province as reviewed and approved by Qinghai Provincial Development and Reform Commission and Energy Bureau for the period from 2024 to the end of 2028, the feed-in tariff rate will be CNY 0.55/kWh (including tax) from the date on which the plant is put into commercial operation. These projects do not participate in power market transactions. State Grid Qinghai Electric Power Company should carry out power scheduling in a reasonable and scientific manner based on the principle of giving priority to green power, give full play to the role of CSP in functions such as electricity peaking, peak shaving, frequency regulation, and backup, and ensurestable and efficient operation of energy/power supply systems in Qinghai Province.
Prepared by CSTA					

1.4 Main characteristics of CSP technologies

1.4.1 Strong continuous power generation and regulation capabilities

According to the operating data of eight commercial CSP demonstration projects in China, the peak shaving depth of CSP units can reach up to 80%; the ramp rate can reach 3%-6% of the rated power per minute, the cold start time is about 1 hour, and the hot start time is about 25 minutes. CSP generators can fully (100%) participate in load balancing and partially replace conventional coal-fired power units, playing an important role in ensuring the safe and stable operation of power grids with a high proportion of renewable energy. The simulations and calculations performed by China Electric Power Planning and Engineering Institute (EPPEI) taking the Xinjiang Power Grid as an example show that, if the capacity of CSP units increases from 1,000 MW to 5,000 MW, the wind and PV power abandonment rate can be reduced by 10.2%-37.6% [7].

It has been proven that CSP plants can contribute to the base load. In Spain, 18 CSP plants operated continuously for three weeks, and Gemasolar, a solar tower plant with 15-hour TES and an installed capacity of 200 MW operated around the clock for 36 consecutive days [8]. In China, the CGN Delingha 50 MW Parabolic Trough CSP Plant operated continuously and stably for 230 consecutive days as of April 23, 2023, setting a record of continuous operating time; the Qinghai SUPCON Delingha 50 MW Solar Tower Plant operated continuously for 13 days; the Shouhang Hi-Tech Dunhuang 100 MW Solar Tower Plant continuously operated for 14 days in September 2023; for the period from June 1, 2023 to May 31, 2024, the CSNP Urat 100 MW Parabolic Trough CSP Plant generated 342.230 GWh of electricity from pure solar thermal energy, setting a new record for pure solar thermal power generation in a complete year, and its annual equivalent full-load operating time reached 3,422 hours.

Research by the Energy Internet Research Institute of Tsinghua University shows that, with a PV power capacity of 22 GW and a wind power capacity of 7 GW, the Qinghai Power Grid can supply clean power (including the loads in Qinghai and transmitted at UHV to Henan) for three consecutive days during the flood season; and if a CSP capacity of 4 GW is built on the basis of the aforementioned PV and wind power capacities, the Qinghai Power Grid can supply clean power for 30 consecutive days during the flood season, setting a world record [9].

1.4.2 High safety and suitability for large-capacity energy storage

Energy storage safety is an important aspect of large-capacity energy storage. TES (thermal energy storage) with binary molten salts is an energy storage method with a high safety level. For about 50 years since the construction of the THEMIS solar power plant with molten salt (MS) TES in France in 1976, no explosion or other safety accident has occurred at the CSP plants built around the world with a total installed capacity of 7,900 MW. The electricity storage capacity of the Shouhang Hi-Tech Dunhuang 100 MW Solar Tower Plant—an operating solar power tower with the largest single unit capacity in China, has reached 1.7 GWh, and the world's MS TES capacity has reached 1,000 GWh.

1.4.3 Bidirectional grid connection (CSP plants with TES systems)

At CSP plants with MS TES systems, thermal energy can be transferred via the solar collector system and stored in

the MS TES system, and during peak hours, electrical energy on the grid can be converted to thermal energy through the electric heating system and stored for electricity generation. This operation method is very conducive to load balance in the power system and can facilitate power trading. Since 2023, the use of this method has been encouraged for CSP-wind-PV hybrid projects in multiple provinces and autonomous regions, including Jilin, Xinjiang, Qinghai, Gansu, and Inner Mongolia. A number of CSP plus renewable energy power projects are being launched.

China's second-generation CSP plants using molten salts as HTF and first-generation CSP plants using thermal oil as HTF have been put into commercial operation. In 2016, the first 20 CSP demonstration projects with a total installed capacity of 1,349 MW were jointly launched by NDRC, MOF and NEA [10]. The CSP projects launched in China in 2024 include plants with a single unit capacity of not less than 200 MW, and the development of CSP systems with a single unit capacity of 300 MW is encouraged. For the fourth-generation CSP technology, at 19:01 on May 28, 2024, a supercritical CO_2 solar power system using particles as HTF successfully started generating power for the first time in the world. The operating temperature and power of the solar receiver are 700ºC and 1 MW, and the operating temperature, operating pressure and power of TGU are 550ºC, 14 MPa, and 0.2 MW, respectively [2]. For the USA's fourth-generation CSP technology, TGU with operating temperature, operating pressure and power of 500ºC, 14 MPa and 10MW has been completed with the support of DOE and EU's science and technology programs, but the solar receiver and heat exchanger systems have not been completed, and system integration has not been reported. At the 30th SolarPACES Conference held in October 2024, the EU and USA presented research findings on air receivers for the third-generation CSP technology, but there were few results related to system integration.

Solar photovoltaic power generation (Solar PV) is an important form of solar energy utilization. The main differences between CSP and Solar PV are detailed below.

Electricity generation mechanism: A Solar PV power plant employs a heat-to-electricity conversion process that converts solar radiation into thermal energy through solar collectors and generates electricity through TGU, while a CSP plant utilizes a light-to-electricity conversion process that directly converts light energy to electrical energy relying on the photovoltaic effect of solar panels.

Technology maturity: CSP is still in the early stages of commercialization, and its costs are relatively high, while Solar PV is mature and has been commercialized.

Scope of use: CSP is suitable for large-scale applications, especially in areas with good light conditions, while Solar PV is relatively simple, has lower requirements for light conditions, and is more suitable for small-scale and distributed applications.

Readiness for grid connection: CSP plants have stable power output and are easy to connect to the grid, while PV power plants are greatly affected by the intensity of solar radiation and are difficult to connect to the grid.

The characteristics of CSP and Solar PV are shown in Table 1.4-1.

Table 1.4-1 Comparison of the characteristics of CSP and Solar PV

	Solar PV	CSP
Solar irradiance	Global horizontal irradiance (GHI)	Direct normal irradiance (DNI)
Application	Site selection not subject to geographic restrictions, flexible layout, short construction period, easy operation and maintenance	Site selection subject to geographic restrictions, complex system, long construction period, stringent requirements for operation and maintenance
Output characteristics	Intermittent output with fluctuations	Stable output, high flexibility, 24 h continuous power generation
Peak-shaving capacity	Requiring peak-shaving power supply or energy storage station	Peak shaving based on on-grid load requirements
Voltage support capacity	Unable to provide short-circuit capacity support to the power grid	Able to provide short-circuit capacity and voltage support as synchronous generator-based power supply
Frequency regulation capacity	Low frequency support capacity, possibility of system frequency fluctuations caused by intermittent fluctuating output	Able to engage in primary and secondary frequency regulation, provide the moment of inertia, and improve system stability
Harmonics	Harmonics generated by grid-connected inverters	Basically no harmonics
Sub-synchronous oscillations	Tending to cause sub-synchronous oscillations	Able to inhibit sub-synchronous oscillations as synchronous generator-based power supply
Electricity generation under extreme weather conditions	Unable to generate electricity under extreme weather conditions	Able to generate electricity using natural gas, only requiring the use of low-cost spare gas boilers
Electricity generation cost	Relatively low (mature and commercialized, with 0 confidence capacity)	Relatively high (at early stages of commercialization, developing rapidly, with 100% confidence capacity)
Prepared by CSTA		

1.5 Development history of China's CSP industry

The development history of China's CSP industry since the "11th Five-Year Plan" can be divided into clear stages.

Stage 1: Leading role of science and technology, mastery of core technologies

During the "11th Five-Year Plan" and "12th Five-Year Plan" periods, the Ministry of Science and Technology deployed first-generation solar tower and parabolic trough CSP plants and second-generation solar tower plants, MW-class and 10 MW-class

solar tower and parabolic trough CSP plants were constructed, and breakthroughs were achieved in first- and second-generation CSP technologies.

Stage 2: Implementation of demonstration and pilot projects, establishment of the CSP industry chain

At the end of the "13th Five-Year Plan" period, NDRC, MOF, and NEA jointly launched the first CSP demonstration projects with a total installed capacity of 1,349 MW, numerous CSP plants with a total installed capacity of 550 MW were constructed, a preliminary CSP industry chain was established. For 100 MW solar tower plants with 10-hour MS TES, the investment per unit of capacity is CNY 32,000/kW, and the electricity price is CNY 1.15/kWh.

Stage 3: Continuous industrial deployment, industry chain optimization.

In 2023, based on the mastered core technologies and engineering practices and experiences, the General Department of NEA issued the *Notice on Promoting the Large-scale Development of Solar Thermal Power* (NEA General Department New Energy Document No. [2023] 28), proposing to "fully understand the importance of the large-scale development of CSP; CSP has dual functions, namely, peak shaving and energy storage"; it is necessary to launch a number of CSP projects as soon as practicable based on renewable energy bases built in desert and Gobi areas, and desert areas and strive to increase the annual additional CSP capacity in China to about 300 MW during the "14th Five-Year Plan" period [11]. The profits of PV power projects were used to subsidize CSP projects, while CSP projects provided on-grid load support for PV power projects during periods without solar radiation, and the CSP industry chain was improved. In 2023, a number of CSP-PV complementary projects were launched as arranged by NEA, and through project construction, the CSP industry chain was improved and optimized, further reducing costs. For 100 MW CSP plants with 10-hour MS TES, the investment per unit of capacity is CNY 16,000/kW, and the electricity price is CNY 0.76/kWh.

Stage 4: Leveraging of technical advantages, cost reduction and market access

CSP-wind-Pv hybrid projects were constructed, the advantages of CSP in base load support and peak shaving were leveraged, and access to the power market was obtained through electricity spot market transactions. For 300 MW solar tower plants with 10-hour MS TES, the investment per unit of capacity is CNY 14,000/kW, and the electricity price is CNY 0.48/kWh.

Stage 5: Focus on CSP, replacement of thermal power with CSP-wind-PV combination

During the "15th Five-Year Plan" period and the early stage of the "16th Five-Year Plan" period, CSP plants with GW-level single unit capacity will be built as stable sources of power supply that can continuously generate electricity, and wind and PV power plants will be constructed as zero-carbon power sources that can continuously generate and supply electricity at lower costs compared to thermal power plants. For 1,000 MW solar tower plants with 10-hour MS TES, the investment per unit of capacity will be CNY 11,000/kW, and the electricity price will be CNY 0.35/kWh. In addition, demonstration projects for 50 MW supercritical CO_2 power systems will be launched to create space for further reducing electricity prices.

Chapter II CSP Market in China

2.1 China's total installed CSP capacity

CSTA's statistics as of the end of 2024:

1. Installed capacity of completed CSP projects: 838.2 MW, including 481 MW for MS solar tower plants, 191 MW for thermal oil parabolic trough plants, 166 MW for MS linear Fresnel CSP plants, and 0.2 MW for the supercritical CO_2 (Tthe world's first fourth-generation solar thermal power generation system);

2. Installed capacity of ongoing CSP projects: 3,300 MW, 34 projects;

3. Installed capacity of planned CSP projects: 4,750-4,800 MW, 37 projects.

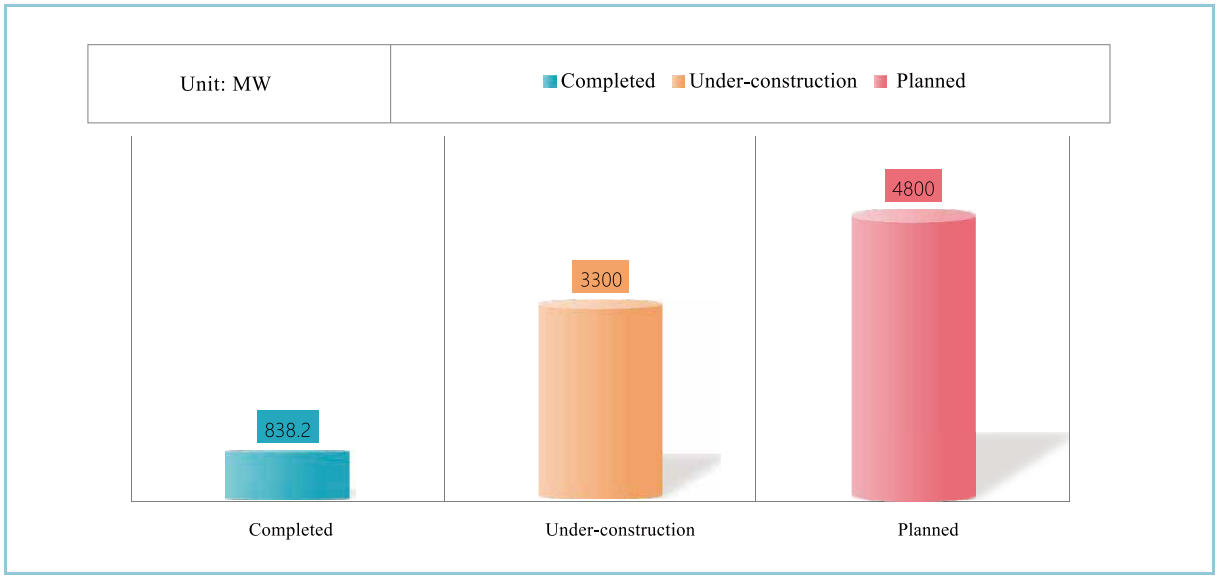


Fig. 2.1-1 Construction Progress of CSP Plants in China (Prepared by: CSTA)

Table 2.1-1 Summary of Completed CSP Projects in China (as of December 31, 2024)

No.	Project	Power generation time	Solar concentration form	Installed capacity (MW)
1	IEE-CAS Yanqing 1 MW Experimental Solar Tower Plant	August 2012/May 2017	Solar tower/parabolic trough	1
2	SUPCON SOLAR Delingha 10 MW CSP Plant	July 2013/August 2016	Water/molten salt tower	10
3	Lanzhou Dacheng 1 MW Linear Fresnel CHP Plant	October 2015	Linear Fresnel	1
4	Lanzhou Dacheng 1 MWe CSP Distributed CHP Demonstration Project in Lhasa Liuwu	October 2015	Linear Fresnel	1

No.	Project	Power generation time	Solar concentration form	Installed capacity (MW)
5	Shouhang Hi-Tech Dunhuang 10 MW MS Solar Tower Plant	December 2016	Solar tower	10
6	Zhangjiakou No. 1 15 MW Linear Fresnel CSP Plant	May 2018	Similar to linear Fresnel	15
7	CGN Delingha 50 MW Thermal Oil Parabolic Trough CSP Plant	October 2018	Parabolic trough	50
8	Shouhang Hi-Tech Dunhuang 100 MW MS Solar Tower Plant	December 2018	Solar tower	100
9	SUPCON SOLAR Delingha 50 MW MS Solar Tower Plant	December 2018	Solar tower	50
10	PowerChina Gonghe 50 MW MS Solar Tower Plant	September 2019	Solar tower	50
11	Luneng Golmud Multi-energy Complementary 50 MW MS Solar Tower Plant	September 2019	Solar tower	50
12	EnergyChina Hami 50 MW MS Solar Tower Plant	December 2019	Solar tower	50
13	Lanzhou Dacheng Dunhuang 50 MW MS Linear Fresnel CSP Plant	December 2019	Linear Fresnel	50
14	CSNP Urat 100 MW Thermal Oil Parabolic Trough CSP Plant	January 2020	Parabolic trough	100
15	Yumen Xinneng 50 MW MS Beam-down CSP Plant	March 2022	Solar tower	50
16	IEE-CAS Yanqing Experimental Supercritical CO_2 Power Plant	May 2024	Fourth-generation	0.2
17	CNNC Yumen 100 MW CSP+200 MW Wind Power+400 MW PV Power Project	September 2024	Linear Fresnel	100
18	Gansu Akesai (Huidong New Energy) 750 MW CSP+PV Pilot Project	November 2024	Solar tower	110
19	Tibet Zabuye Source-Grid-Load-Storage Integrated Energy Supply Project	December 2024	Parabolic trough	40
Total				838.2
Prepared by CSTA				

Table 2.1-2 Annual Cumulative Installed Capacity of CSP Plants in China

Year	Cumulative installed capacity (MW)
2012	1
2013	11
2014	11
2015	13
2016	23
2017	23
2018	238
2019	438
2020	538
2021	538
Prepared by CSTA	

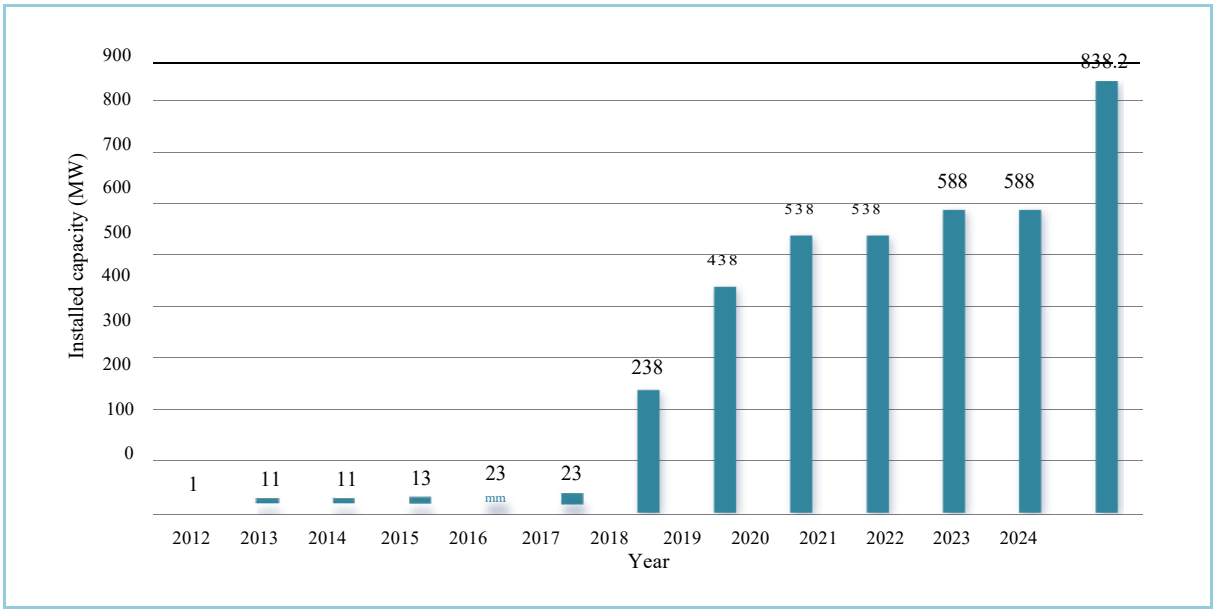


Fig. 2.1-2 Annual Cumulative Installed Capacity of CSP Plants in China (Prepared by: CSTA)

2.2 Global installed CSP capacity

In 2024, a new CSP plant with an installed capacity of 100 MW and a 12-hour MS TES system, namely, the Redstone CSP plant was connected to the power grid in South Africa. It is the first MS solar tower plant in South Africa and is located in Postmasburg near Kimberley in the Northern Cape of South Africa, close to the 75 MW Lesedi PV power plant and 96 MW Jasper PV power plant developed by SolarReserve and its partners. These three power plants

form a PV+CSP complex with a total installed capacity of 271 MW. The REdstone project is South Africa's largest renewable energy investment project to date, and its strategic importance has been recognized by the South African National Energy Association (SANEA).

The total project investment is about ZAR 11.6 billion (equivalent to CNY 5.3 billion), the project owner is ACWA Power, the project EPC contractor is Shandong Electric Power Construction Corporation III, a member of CSTA, and the project is jointly developed by ACWA Power, Central Energy Fund, and Pele Green Energy. The plant was successfully connected to the grid for the first time at 13:19 on September 14, 2024 (local time), with excellent performance parameters and indicators, and all systems operated stably [12].

After the plant is put into operation, it will be able to supply 466 GWh of electricity to the grid and provide clean energy to 210,000 households in South Africa every year. During its construction, the project created more than 2,500 jobs for South Africa, including 650 employees from the local community, and more than 400 local engineers and technicians were trained [13].

Fig. 2.2-1 Redstone CSP Plant (Photo by: Shandong Electric Power Construction Corporation III)

According to CSTA's statistics, as of the end of 2024, the global cumulative installed CSP capacity reached 7,900.2 MW (including the installed capacity of 274 MW of eight parabolic trough CSP plants that were built in the USA in the 1980s and have been decommissioned, with maximum operating time of more than 30 years). The data of global cumulative installed CSP capacity in recent years is given in the table below.

Table 2.2-1 Global Cumulative Installed CSP Capacity

Year	Global cumulative installed CSP capacity (MW)	Remarks
2014	4,584	THEMIS (France), the world's first experimental MS solar tower plant: The construction of the plant started in 1979, and the plant started generating electricity in 1983. CESA-I, the world's first experimental solar tower plant using water as HTF, started generating power in 1979. LS-1 (USA), the world's first experimental parabolic trough CSP plant using thermal oil as HTF, was put into operation in the 1980s. The 110 MW Crescent Dunes Solar Energy Project (USA), the world's first commercial MS solar tower plant, started generating electricity in 2015. SEGS I (USA), the world's first commercial parabolic trough CSP plant with an installed capacity of 13.8 MW, started generating electricity on December 20, 1984. Puerto Errado 2 (Spain), the world's first Fresnel CSP plant using water as HTF with an installed capacity of 30 MW and 0.5-hour TES: The construction of the plant started in April 2011, and the plant was put into operation for power generation and connected to the grid in March 2012. Lanzhou Dacheng Dunhuang 50 MW CSP Plant, the world's first linear Fresnel CSP plant using molten salt as HTF, started generating electricity on December 31, 2019. IEE-CAS Yanqing 0.2 MW Solar Power Plant, the world's first experimental power plant using supercritical CO_2 power cycles, started generating electricity on May 28, 2024.
2015	5,005	
2016	5,082	
2017	5,199	
2018	6,109	
2019	6,590	
2020	6,690	
2021	6,800	
2022	7,050	
2023	7,550	
2024	7,900.2	
Prepared by CSTA		

Table 2.2-2 Comparison of Global and China's Cumulative Installed CSP Capacity

Year	Global cumulative installed CSP capacity (MW)	China's cumulative installed CSP capacity (MW)
2014	4,584	11
2015	5,005	13
2016	5,082	23
2017	5,199	23
2018	6,109	238
2019	6,590	438
2020	6,690	538
2021	6,800	538
2022	7,050	588
2023	7,550	588
2024	7,900.2	838.2
Prepared by CSTA		

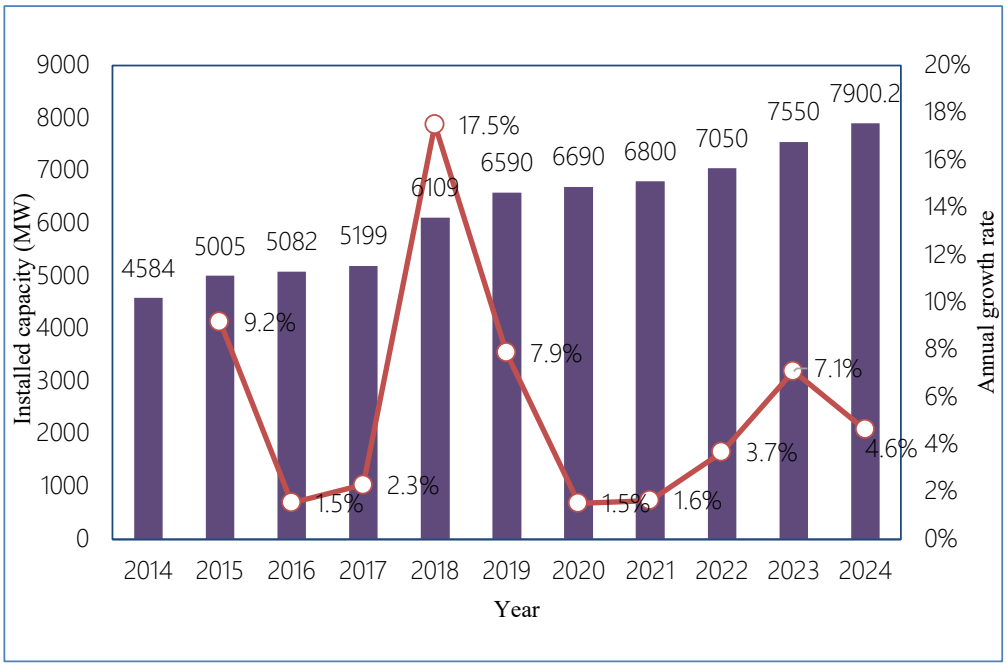


Fig. 2.2-2 Global Cumulative Installed CSP Capacity and Annual Growth Rate (Prepared by: CSTA)

2.3 Proportions of various solar concentration forms of CSP plants

As of the end of 2024, among China's cumulative installed CSP capacity, MS solar tower plants account for about 57.4%, thermal oil parabolic trough CSP plants account for about 22.7%, MS linear Fresnel CSP plants account for about 19.9%, and supercritical CO_2 CSP plants account for about 0.02%.

According to CSTA's statistics, among the global cumulative installed CSP capacity, solar tower plants account for about 21.63%, parabolic trough CSP plants account for about 73.76%, and linear Fresnel CSP plants account for about 4.61%.

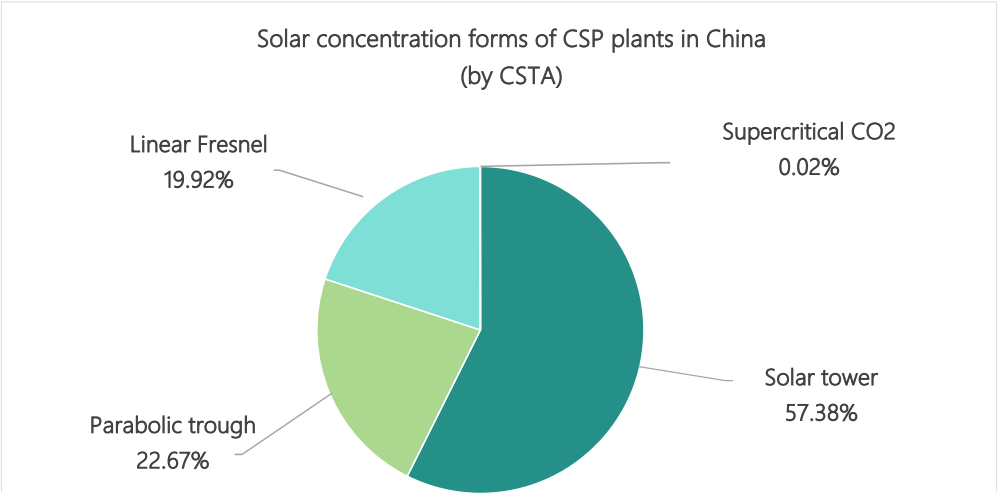


Fig. 2.3-1 Solar Concentration Forms of CSP Plants in China (Prepared by: CSTA)

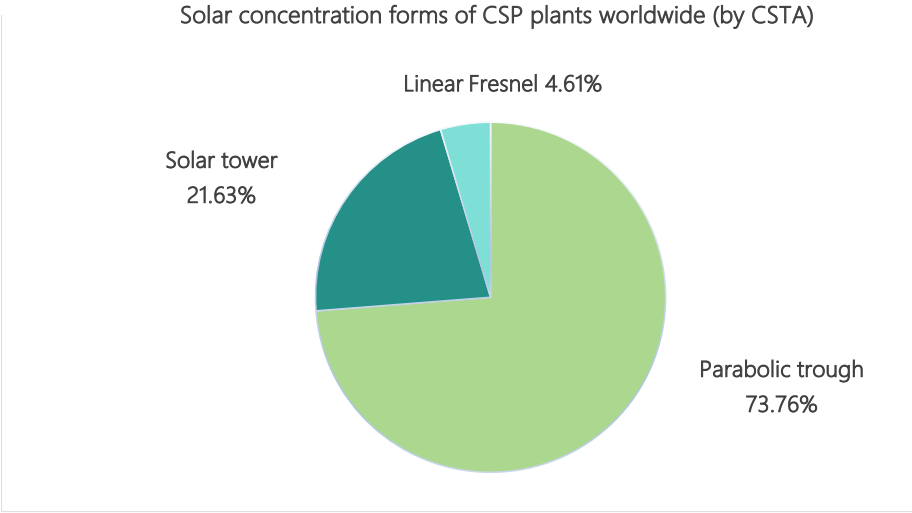


Fig. 2.3-1 Solar Concentration Forms of CSP Plants Worldwide (Prepared by: CSTA)

The comparative analysis shows that solar tower plants account for the majority of CSP plants in China, while parabolic trough CSP plants account for the majority of CSP plants in the world. The main reason is that the earliest commercial CSP plants abroad employed the parabolic trough technology. The nine SEGS power plants built in the USA in the 1980s with a total installed capacity of 354 MW were all parabolic trough-type power plants (without TES systems). Europe's first commercial CSP plant also employed the parabolic trough (with MS TES) technology. In 2007, the Spanish Government enacted Royal Decree 661-2007on the Feed-In Tariffs support scheme to promote the development of CSP technologies [14]. However, financial institutions including banks require that construction projects have reference cases to improve creditworthiness. Therefore, almost all CSP plants built in Spain use parabolic trough collectors.

2.4 New CSP projects put into operation in China

In 2024, a number of CSP projects with a total installed capacity of 250.2 MW (as listed in the table below) were completed and put into operation in China.

Table 2.4 List of New CSP Projects in 2024

No.	Project Name/Owner/Location	Installed Capacity (MW)
1	IEE-CAS Yanqing Experimental Supercritical CO_2 CSP Plant/IEE-CAS/ No. 8 Sun Tower Road, Yanqing District, Beijing (fourth-generation CSP technology)	0.2
2	CNNC Yumen 100 MW CSP+200 MW Wind Power+400 MW PV Power Project/CNNC Yumen Xin'ao New Energy Co., Ltd./Hongliuquan Wind and Solar Energy Storage Demonstration Base in Yumen, Jiuquan City, Gansu Province (second-generation CSP technology)	100

No.	Project Name/Owner/Location	Installed Capacity (MW)
3	Gansu Akesai (Huidong New Energy) 750 MW CSP+PV Pilot Project/Huidong New Energy Co., Ltd. in Aksay Kazakh Autonomous County/10-million-kW CSP Base in Aksai Shili Gobi, Jiuquan City, Gansu Province(second-generation CSP technology)	110
4	Tibet Zabuye Source-Grid-Load-Storage Integrated Energy Supply Project/Baowu Clean Energy (Tibet) Co., Ltd./Southeast of Zabuye Salt Lake, Zhongba County, Shigatse City (second-generation CSP technology)	40
Total		250.2
Prepared by CSTA		

2.5 Ongoing CSP projects

According to CSTA's statistics, as of December 31, 2024, there are about 34 ongoing CSP projects in various provinces and autonomous regions in China (as listed by the governments of these provinces and autonomous regions), with a total installed capacity of 3,300 MW, most of which are expected to be completed in 2025.

Table 2.5 Summary of Ongoing CSP Projects in China

No.	Project Name	Solar Concentration Form	Installed Capacity (MW)
1	Jinta Zhongguang Solar 100 MW CSP + 600 MW PV Project	Solar tower	100
2	Henderson Energy (CTGR) Guazhou 100 MW CSP + 200 MW PV + 400 MW Wind Power Project	Solar tower	100
3	China Longyuan Power Group Corporation Limited 100 MW CSP + 480 MW Wind Power + 120 PV Power Project	MS linear Fresnel	100
4	Gansu Solar Power Generation Co., Ltd Akesai 50 MW High-temerapture MS Parabolic Trough CSP Plant	Parabolic trough	50
5	Bid Section 1 of Hainan and Haixi Bases Qingyu DC Power Project (Phase II)	Solar tower	100
6	Bid Section 3 of Hainan and Haixi Bases Qingyu DC Power Project (Phase II)	Solar tower	100
7	Qinghai Golmud (CTGR) 1,100 MW PV + CSP Project	Solar tower	100
8	CGN Energy Deingha 1,000 MW PV + CSP Project (200 MW PV)	Solar tower	200
9	PowerChina Gonghe 1,000 MW PV + CSP Project	Solar tower	100
10	Jixi Base Lugu Baicheng 1,400 MW Outgoing DC Power Transmission Project - Unit 1	Solar tower	100
11	Jixi Base Lugu Baicheng 1,400 MW Outgoing DC Power Transmission Project - Unit 2	Solar tower	100

No.	Project Name	Solar Concentration Form	Installed Capacity (MW)
12	CTGR Hami 1,000 MW CSP + PV Integrated Energy Demonstration Project	MS linear Fresnel	100
13	Datang Shichengzi 1,000 MW CSP + PV Integrated Clean Energy Demonstration Project	MS linear Fresnel	100
14	Luneng Fukang Multi-energy Complementary (and New Energy Market-oriented Grid-connected) Project	Solar tower	100
15	EnergyChina Hami "Solar (Thermal) Energy Storage" Multi-energy Complementary Integrated Green Power Demonstration Project	Solar tower	150
16	PowerChina Turpan City Toksun County CSP + PV Integrated Project	Solar tower	100
17	PowerChina Ruoqiang 100 MW CSP (with TES) + 900 MW PV Demonstration Project	Solar tower	100
18	Tangshan Haitai New Energy Technology Co., Ltd CSP + PV Integrated Project	Solar tower	100
19	SPIC Henan Power Company Limited CSP + PV Integrated Project	Solar tower	100
20	Energy China Zhejiang Thermal Power Construction Co., Ltd CSP + PV Integrated Project	Solar tower	100
21	SDIC Ruoqiang 100 MW CSP (with TES) + 900 MW PV Market-oriented Grid-connected Project	Solar tower	100
22	Xinhua Hydropower Bozhou 100 MW CSP (with TES) + 900 MW New Energy Project	Solar tower	100
23	Jinghe Xinhua New Energy Co., Ltd CSP with TES + New Energy Integrated Project	Solar tower	100
24	Military-Civil Fusion Program 3 GW PV Power Base (Phase I: 100 MW CSP with Compressed CO_2 MS TES + 900 MV PV Integrated Project)	/	100
25	CGN Tibet Ali Snowy Plateau "Zero-Carbon" Photothermal Electricity Storage Demonstration Project	Parabolic trough	50
26	Energy China Lhasa Damxung 250 MW PV + 100 MW CSP Project	Parabolic trough	100
27	Energy China Lhasa Damxung 100 MW CSP + 800 MW PV Integrated Project	Parabolic trough	100
28	Central Southern China Electric Power Design Institute Co., Ltd. of China Power Engineering Construction Group 50 MW Grid-connected CSP + 448 MW PV Multi-energy Complementary Integrated Project in Gamba County, Shigatse City (a project launched in 2024 to ensure energy supply and energy security)	/	50
29	Tibet Development Investment Group Co., Ltd.125 MW PV + 50 MW CSP Integrated Project in Turuo Village, Amdo County	/	50

No.	Project Name	Solar Concentration Form	Installed Capacity (MW)
30	China Huadian Corporation Ltd. Tibet Lhasa Damxung 100 MW CSP + 800 MW PV Multi-energy Complementary Integrated Project	Parabolic trough	100
31	China Huaneng Group Qinghai Company Golmud 500 MW Supercritical CO_2 CSP Integrated Demonstration Project	/	50
32	Bid Section 2 of Hainan and Haixi Bases Qingyu DC Power Project (Phase II)	Solar tower	100
33	Northern Hami 900 MW PV + 100 MW CSP Project	Solar tower	100
34	Tibet Development Investment Group Co., Ltd.100 MW CSP + 800 MW PV Integrated Project in Tushuo, Amdo County	Solar tower	100
Total: 3,300			
Prepared by CSTA			

2.6 Planned CSP projects in China

According to CSTA's statistics, as of the end of 2024, there are 37 planned CSP projects in various provinces and autonomous regions in China (as listed by the governments of these provinces and autonomous regions), with a total installed capacity of 4,750-4,800MW.

Table 2.6 Planned CSP Projects in 2024

No.	Project Name	Project Owner	Project Origin
Gansu Province			
1	CGN Gansu Yumen 700 MW PV + CSP + Wind Power Hydrogen Production Demonstration Project (100 MW CSP + 200 MW PV + 400 MW Wind Power)	CGN Solar Jinchang Co., Ltd.	List of reserved projects for the 3rd batch of wind + Pv power bases in Gansu Province
2	CNNP Rich Energy Co., Ltd 1,600 MW Clean Energy Supply Project (mainly consisting of 900 MW wind power + 700 MW PV power facilities, steam boilers, and a 100,000 m^2 PTC (parabolic trough collector) field)	CNNC Energy (Gansu) Co., Ltd.	List of reserved projects for the 3rd batch of wind + Pv power bases in Gansu Province
3	Jinta County Baishuiquan 700 MW Wind + PV Power Project (100 MW CSP + 400 MW Wind Power + 200 MW PV)	Jinta County Jinxin Industrial Investment New Energy Development Co., Ltd.	Company-level planned project
Qinghai Province			
4	China Energy Engineering Group Jiangsu Power Design Institute Co., Ltd./ Jiangsu Meike Solar Technology Co., Ltd. Gonghe 1,000 MW Source-Grid-Load-Storage Integrated Project	China Energy Engineering Group Jiangsu Power Design Institute Co., Ltd.	2nd batch of large wind + PV power bases/projects in Qinghai Province

No.	Project Name	Project Owner	Project Origin
5	Golmud Utumeiren 3,300 MW Multi-energy Complementary Project (3,000 MW PV + 300 MV CSP, TES capacity: 520 MW/1,000 MWh, 10 MW phase modifier)	China Green Development Group Qinghai New Energy Company	Key market-oriented, grid-connected projects in Qinghai Province in 2021
6	Large-capacity TES Multi-energy Complementary Integrated Project (1,150 MW PV + 200 MW CSP)	Qinghai SUPCON Solar Power Generation Co., Ltd.	One of the former key market-oriented, grid-connected projects in Qinghai Province in 2021
7	Qinghai Haixi Lenghu Wind + CSP + PV Integrated Project	CGN Qinghai Lenghu Wind Power Co., Ltd.	Planned project
8	Zhejiang Zhongguang New Energy Technology Co., Ltd. Delingha 350 MW CSP Project	Zhejiang Zhongguang New Energy Technology Co., Ltd.	CSP demonstration (pilot) projects in Qinghai Province in 2024
9	Cosin Solar Golmud 350 MW CSP Project	Cosin Solar Technology Co., Ltd.	
10	CGN Wind Power Co., Ltd. Dachaidan 350 MW CSP Project	CGN Wind Power Co., Ltd.	
Xinjiang Uyghur Autonomous Region			
11	Xinjiang Chongneng Hami-Chongqing Power Transmission Hami 4,100 MV New Energy Project (2,800 MV wind power + 1,200 MW PV + 100 MW CSP)	Xinjiang Chongneng Power Development Co., Ltd.	Xinjiang Hami-Chongqing UHV DC Power Transmission Project-Coal Power Project Xinjiang Hami-Chongqing UHV DC Power Transmission Project-Coal Power Project 3rd batch of wind + PV power bases/projects 2nd batch of registered renewable energy projects in 2023 Xinjiang Production and Construction Corps 4th batch of market-oriented and grid-connected renewable energy projects in 2024
	Xinjiang Hami-Chongqing Power Transmission Project Channel III Renewable Energy Project (4,200 MW Wind + 1,800 MW PV + 100 CSP)	Xinjiang Huadian Tianshan Power Generation Co., Ltd	
12	Tuha Oilfield Eastern Shanshan Wind + CSP + TES Comprehensive Energy Integrated Project (900 MW PV + 100 MW CSP)	PetroChina Tuha Oilfield Company	
13	Hesheng Electrical Industry (Shanshan) Co., Ltd. 250 MW CSP + 2,100 MW PV Integrated Project	Hesheng Electrical Industry (Shanshan) Co., Ltd.	
14	Datang Hami 13th Division Clean Energy Development Co., Ltd. 200 MW CSP + 1,800 MW PV Integrated Project in Huangtian Farm, Xinxing City, 13th Division	China Datang Corporation Renewable Power Co., Ltd.	

No.	Project Name	Project Owner	Project Origin
Tibet Autonomous Region			
15	CGN Lhasa Umatang 125 MW PV + 50 MW CSP Project	CGN Wind Power Co., Ltd.	Grid-connected projects in 2023 for ensuring energy supply
16	Nagqu City Seni (District) 250 MW PV + 100 MW CSP Project	SDIC Power Holdings Co., Ltd.	
17	Naqu City Nyainrong 125 MW PV + 50 MW CSP Project	SDIC Power Holdings Co., Ltd.	
18	Guangdong Construction Engineering Group 50 MW CSP Project in Zhongba County or Angren County, Shigatse City	Guangdong Construction Engineering Group Co., Ltd	Projects in 2024 for ensuring energy supply
19	Tibet Development and Investment Groupin 50 MW CSP Project in Tushuo, Anduo County, Nagqu City	Tibet Development and Investment Group Co. Ltd.	
20	China Longyuan Power Group 50 MW CSP Project in Nyainrong County, Naqu City	China Longyuan Power Group Corporation Limited	
21	Bid Section 1 of CGN Wind Power Co., Ltd. 50 MW CSP Project	CGN Wind Power Co., Ltd.	
22	Bid Section 2 of China Gezhouba Group 50 MW CSP Project	China Gezhouba Group Mechanical & Electrical Construction Co., Ltd.	
23	Huaneng Tibet Yarlung Zangbo River Hydropower Development & Investment Co., Ltd. 2024 Tibet CSP + PV Project (intended capacity: 50-100 MW CSP + 350-900 MW PV)	Huaneng Tibet Yarlung Zangbo River Hydropower Development & Investment Co., Ltd.	Planned projects
24	Huadian Tibet Energy Co., Ltd. Nagqu City Seni (District) PV + CSP Integrated Project Phase I (50 MW CSP + 120 MW PV + 96 MWh TES)	Huadian Tibet Energy Co., Ltd.	
25	Nagqu City Anduo CSP + Wind + PV Integrated Project & 100 MW CSP Project Phase I	CHN Energy Tibet Electric Power Co., Ltd.	
26	SDIC Nagqu City Seni (District) 250 MW PV + 50 MW CSP Integrated Project	SDIC Tibet New Energy Co., Ltd.	
27	CHN Energy Longyuan Ali New Energy (ALI) Co., Ltd. 125 MW PV + 100 MW Wind + 50 MW CSP Multi-energy Complementary Project in Bailang County, Tibet	CHN Energy Longyuan Ali New Energy (ALI) Co., Ltd.	

No.	Project Name	Project Owner	Project Origin
Inner Mongolia Autonomous Region			
28	Huaneng Wulatehouqi Wind, CSP & TES Integrated Project-300 MW CSP Project	Huaneng Renewables Corporation Limited Mengxi Company Limited	Key projects of Bayannaoer City's third quarter investment promotion in September 2022
29	Huaneng Zhungeer Banner Multi-energy Complementary 100 MW CSP Project	Huaneng Renewables Corporation Limited Mengxi Company	Planned projects
30	Huaneng Alxa CSP-supported Large Clean Energy Export Base	Huaneng Alxa League Renewable Power Co., Ltd.	
31	CSP + PV Integrated System Project of Alxa Renewable Energy Division of Datang (Inner Mongolia) Energy Development Co., Ltd		
32	Alxa Left Banner 200 MW CSP Project	/	Project implemented according to the Detailed Rules for Implementation of CSP, Wind and PV Integrated Projects in Inner Mongolia Autonomous Region (Issue for Comment)
33	Renewable Energy Base in Central and Northern Ordos, Inner Mongolia Autonomous Region – 200 MW CSP Project	China Three Gorges Corporation	Renewable energy bases/ projects
34	Renewable Energy Base in Northeastern Ulanbuhe Desert, Inner Mongolia Autonomous Region - 200 MW CSP Project	Inner Mongolia Energy Group Co., Ltd.	
35	Renewable Energy Base in Tengger, Inner Mongolia - 200 MW CSP Project	China Huadian Corporation Ltd.	
36	Jiuquan Renewable Energy Base in Badain Jaran Desert, Gansu – Reasonable CSP capacity to be provided	China Energy	
Sichuan Province			
37	CGN Renewable Energy 200 MW CSP Project in Aba County, Sichuan	CGN Yanyuan Solar Energy Co., Ltd.	Planned project
Prepared by CSTA			

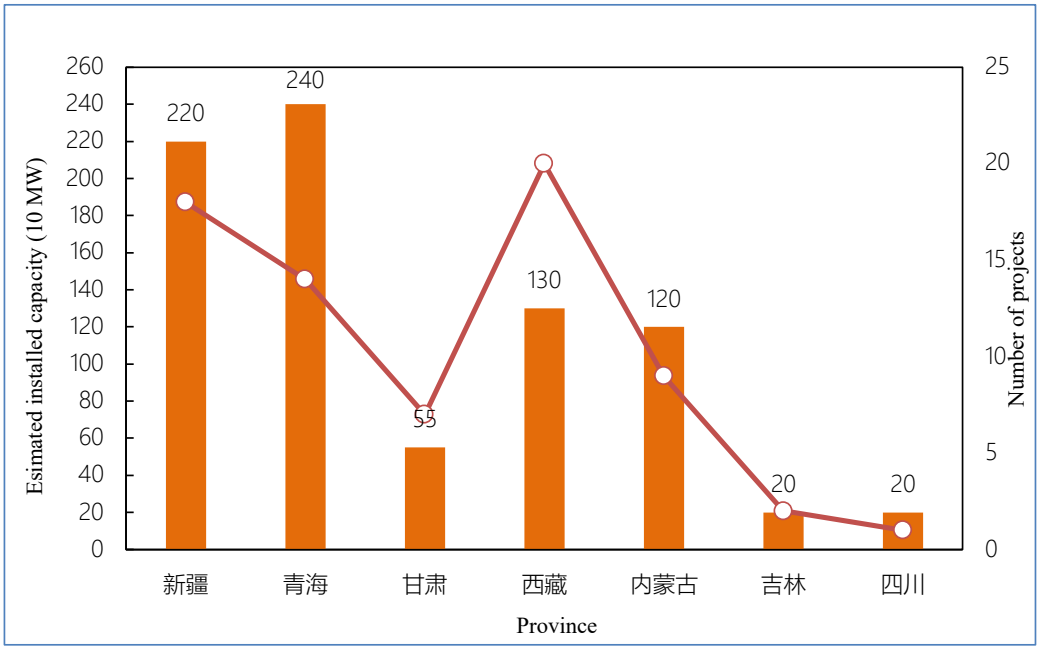


Fig. 2.6 Ongoing and Planned CSP Projects in China and Estimated Installed Capacity (Prepared by: CSTA)

Chapter III Operation of CSP Demonstration Projects in China

This Chapter presents the information about the operation of CSP demonstration projects in China in 2024 by courtesy of plant owners contributing information contained herein.

3.1 CGN Delingha 50 MW Parabolic Trough CSP Plant

Basic information about the operation of CGN Delingha 50 MW Parabolic Trough CSP Plant in 2024	
Capacity	50 MW
Area of the solar collector field	6200,000 m^2
Floor area	2.46 km^2
Solar concentrator dimensions	5.67*12 m
Receiver tube model	φ 76*4,060*3 mm
Number of loops in the solar collector field	190
Solar collector field HTF/working temperature	Thermal oil/393℃
TES medium/weight	Binary molten salt/about 35,000 T
TES duration	9 hours
TGU capacity/parameters	Medium-temperature high-pressure TGU, 50 MW/(main TGU operating normally at 381℃ ; 370℃ /stored-energy power generation mode)
Grid connection time	June 2018
Project investment	CNY 1.7 billion
Electricity generation in 2023	110.4 GWh
Electricity generation in 2024	141.2 GWh In 2024, the grid-tied CGN Delingha 50 MW Parabolic Trough CSP Plant generated 141000 MWh of electricity, setting a new record for electricity generation. Since 2024, CGN Solar Delingha Co., Ltd. has continuously strengthened the innovation and application of CSP technologies, carried out technical research for improving solar collection efficiency and equipment reliability, constantly optimized plant operation strategies, strived to improve power generation efficiency, carried out the optimization and rennovation of the mechanical draft tower packing (which increased the vacuum degree by 3%), further optimized the solar collector field cleaning strategy, increased the cleaning frequency by 30%, and maintained the collector cleanliness at levels above 90%, carried out intelligent drone monitoring of the solar collector field, significantly improved the efficiency of collector troubleshooting and management, and achieved a collector utilization rate of more than 99%. In 2024, the plant's daily on-grid electricity generation exceeded 1,140 MWh, its monthly on-grid electricity generation reached 18,920 MWh, and its annual equivalent utilization hours reached 2,824. The project titled "Improving the solar collection efficiency of parabolic trough CSP plants" was conferred the first-class achievement award of the China Association for Water and Electricity Quality Management.

1、 Acknowledgement (sort alphabetically by the pinyin): Dunhuang Shouhang Energy Saving New Energy Co., Ltd., Lanzhou Dacheng Technology Co., Ltd., Zhejiang Zhongguang New Energy Technology Co., Ltd., PowerChina Hami Solar Power Co., Ltd., PowerChina Renewable Energy Co., Ltd., CGN Solar Delingha Co., Ltd., CSSC New Energy Co., Ltd., Qinghai Company of China Green Development Group Luneng New Energy (Group) Co., Ltd.

3.2 Shouhang Hi-Tech Dunhuang 100 MW Solar Tower Plant

Basic information about the operation of Shouhang Hi-Tech Dunhuang 100 MW Solar Tower Plant in 2024	
Capacity	100 MW
Heliostat field total aperture area	1,380,000 m^2
Floor area	7.8 km^2
Heliostat dimensions	Aperture area: 115. 7 m^2, composed of 35 concave mirrors arranged in 5 longitudinal rows and 7 horizontal rows
Number of heliostats	12,000
Central receiver height	263 m
Receiver dimensions	φ 19.2*40 mm
Heliostat field dimensions	Heliostats arranged in 78 circumferential rows around the central receiver, with the farthest point 1,500 m away from the center of the central receiver
HTF/working temperature	Binary molten salt /565℃
TES medium/weight	Binary molten salt/25,000 T
TES duration	10 hours
TGU capacity/parameters	Design operating pressure: 12.6 Mpa, main TGU operating temperature: 550℃ , reheater operating temperature: 550℃ , discharge pressure: 8 Kpa
Grid connection time	Connected to the grid on December 28, 2018, full-load operation achieved in June 2019
Project investment	CNY 2,812 million
Electricity generation in 2019	86,471.7 MWh
Electricity generation in 2020	137 GWh
Electricity generation in 2021	200 GWh
Electricity generation in 2022	200 GWh Due to defects in steam turbines purchased from abroad, the maximum safe operating load of the plant did not exceed 63%, affecting power generation.
Electricity generation in 2023	235 GWh (January-November 2023) In 2023, the maximum safe operating load of the plant did not exceed 63%, resulting in the abandonment of a large amount of solar energy and directly reducing electricity generation by 65,790 MWh. Replacement of steam turbines' high-pressure cylinders began in December 2023.
Electricity generation in 2024	236.080 GWh The plant's electricity generation in 2024 is 1,080 MWh more than that in 2023. The plant resumed operation on January 25, 2024 after high-pressure cylinder and system replacement and started operating at full load on January 28, 2024. Subsequently, various unit tests and grid-related tests were carried out for 4 months and completed on May 28, 2025. The plant's daily electricity generation reached 227.14 GWh on August 17, 2024, setting a new record for daily electricity generation in its operation history.

3.3 Qinghai SUPCON Delingha 50 MW Solar Tower Plant

Basic information about the operation of Qinghai SUPCON Delingha 50 MW Solar Tower Plant in 2024	
Capacity	50 MW
Heliostat field total aperture area	542,700 m^2
Floor area	2.47 km^2
Heliostat dimensions	20 m^2
Number of heliostats	27,135
Central receiver height	200 m
Receiver dimensions	φ 12.14*15.03 m
Heliostat field dimensions	Rectangular in shape, 1,500 m wide (south-north), 1,721 m long (east-west), with heliostats arranged in a circumferential pattern
HTF/working temperature	Binary molten salt/565℃
TES medium/weight	Binary molten salt/10,116 T
TES duration	7 hours
TGU capacity/parameters	Design operating pressure: 13.7 Mpa, main TGU operating temperature: 540℃ , reheater operating temperature: 540℃ , discharge pressure: 8 Kpa
Grid connection time	December 30, 2018
Project investment	CNY 1,088 million
Electricity generation in 2019	59.7 GWh. The plant started generating electricity in April 2019.
Electricity generation in 2020	106.6 GWh
Electricity generation in 2021	105 GWh
Electricity generation in 2022	149.6 GWh
Electricity generation in 2023	152.4 GWh
Electricity generation in 2024	140.2 GWh

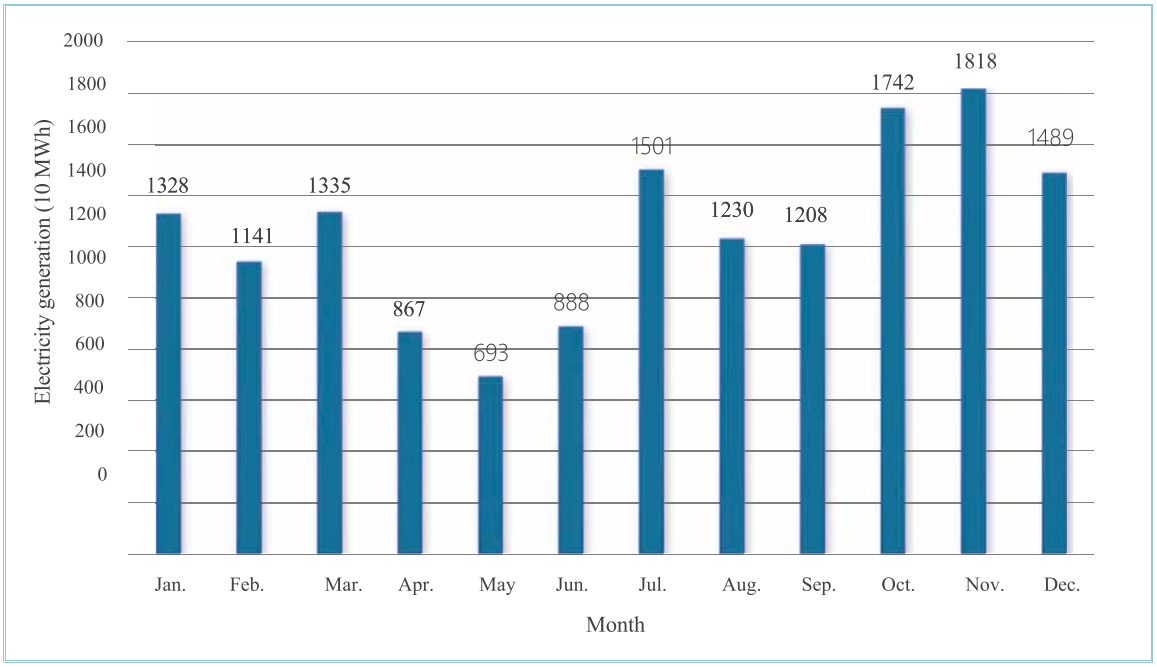


Fig. 3.3-1 Monthly electricity generation of Qinghai SUPCON Delingha 50 MW Solar Tower Plant in 2023 (Prepared by Cosin Solar/CSTA)

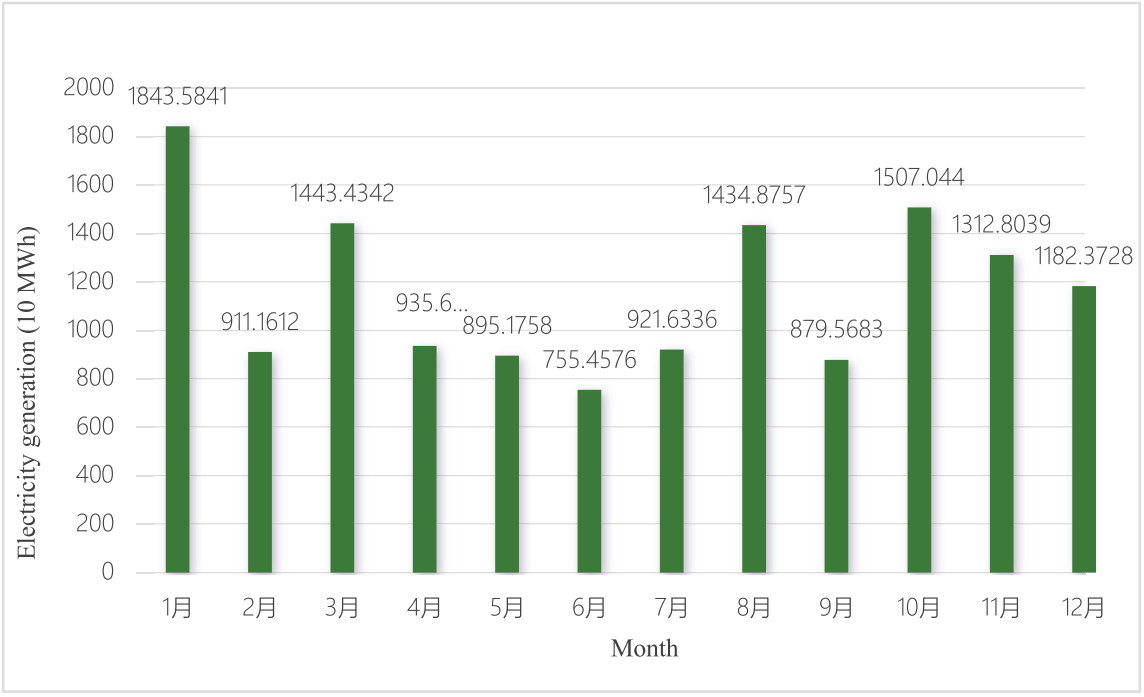


Fig. 3.3-2 Monthly electricity generation of Qinghai SUPCON Delingha 50 MW Solar Tower Plant in 2024 (Prepared by Zhejiang Zhongguang/CSTA)

3.4 Lanzhou Dacheng Dunhuang 50 MW Linear Fresnel CSP Plant

Basic information about the operation of Lanzhou Dacheng Dunhuang 50 MW Linear Fresnel CSP Plant in 2024	
Capacity	50 MW
Area of the solar collector field	1,210,000 m^2
Floor area	2.65 km^2
Solar concentrator dimensions	1,320*760 m
Receiver tube model	φ 76*4,060*3 mm
Length of loops in the solar collector field	1,100 m
Number of loops in the solar collector field	80
Solar collector field HTF/ working temperature	Molten salt/290℃ -550℃
TES medium/weight	Binary molten salt/about 23,000 T
TES duration	15 hours
TGU capacity/parameters	50 MW, main TGU operating temperature and pressure: 538℃ , 12.2 Mpa, steam flow rate: 150 t/h
Grid connection time	December 2019
Project investment	CNY 16.88 million
Electricity generation in 2024	The main tasks completed in 2024 include technological renovation and equipment upgrading. The scope of upgrading includes the optimization/adjustment of operation and maintenance plan, the upgrading of collector field equipment, and capacity expansion of cleaning equipment. As of the end of 2024, the Phase I renovation has been completed, significantly improving the continuity and reliability of plant operation. The maximum daily electricity generation is 895.24 MWh.

3.5 PowerChina Gonghe 50 MW Solar Tower Plant

The PowerChina Gonghe 50 MW Solar Tower Plant is the first CSP plant independently financed, designed, constructed, operated and maintained by PowerChina. The plant is located in the Ecological Solar Power Generation Park of Gonghe County, Hainan Prefecture, Qinghai Province, which has an average elevation of 2,880 m. The plant is connected to the self-costructed 110 kV step-up substation through the TGU-transfomer-circuit unit route and connected to the 339 kV step-up transformer substation of the power grid via the primary 100 kV overhead line. The construction of the plant was commenced on May 6, 2018. The plant was connected to the grid on September 19, 2019 and accepted as a CSP demonstration plant on April 22, 2021, becoming the fourth grid-connected CSP demonstration plant in China.

Basic Information about the operation of PowerChina Gonghe 50 MW Solar Tower Plant in 2024	
Capacity	50 MW
Heliostat field total aperture area	600,300 m^2
Floor area	2.13 km^2
Heliostat dimensions	Single heliostat reflecting area: 20 m2
Number of heliostats	30,016
Central receiver height	228 m
Receiver dimensions	Reception height: 14.2 m, receiver diameter: 12.9 m
Solar collector field HTF/working temperature	Binary molten salt/565℃
TES medium/weight	Binary molten salt/10,886 T
TES duration	6 hours
TGU capacity/parameters	1×50 MW steam turbine generator (model: N50- 13.21/540/540) designed and manufactured by Harbin Turbine Company Limited
Grid connection time	September 19, 2019
Project investment	CNY 1,206.0943 million (including power transmission)
Electricity generation in 2020	10431.7 MWh
Electricity generation in 2021	37626.7 MWh
Electricity generation in 2022	21946.5 MWh
Electricity generation in 2023	68192.3 MWh
Electricity generation in 2024	85712.5 MWh

3.6 EnergyChina Hami 50 MW Solar Tower Plant

The EnergyChina Hami 50 MW Solar Tower Plant is the first CSP plant independently financed, designed, constructed, operated and maintained by China Energy Engineering Corporation Limited (EnergyChina). It is located in the Naomao Lake Solar Power Park in Yiwu County, Hami City, Xinjiang. The steam turbine used at the plant is the first high-temperature, ultra-high-pressure, double-cylinder, double-shaft, intermediate reheating, axial exhaust, 8-stage condensing direct air-cooled steam turbine of Dongfang Electric Corporation (DEC), with a power rating of 50 MW, which is connected to Xinjiang's power grid via the primary 110 kV overhead line using the generator-transformer-line unit wiring method. The construction of the plant was commenced on October 19, 2017.

Basic Information about the operation of EnergyChina Hami 50 MW Solar Tower Plant in 2024	
Capacity	50 MW
Heliostat field total aperture area	700,000 m^2
Floor area	4.4 km^2
Heliostat dimensions	Aperture area: 48.5 m^2, with 11 mirrors arranged in a guana-like pattern
Number of heliostats	14,500
Central receiver height	220 m
Receiver dimensions	φ 14.15*15.69 m
Heliostat field dimensions	Heliostats arranged in 88 circumferential rows around the central receiver, with the farthest point 1,253.14 m away from the center of the central receiver
Solar collector field HTF/working temperature	Binary molten salt/565℃
TES medium/weight	Binary molten salt/17,000 T
TES duration	13 hours
TGU capacity/parameters	Design operating pressure: 14 Mpa, main TGU operating temperature: 550℃, reheater operating temperature: 550℃, discharge pressure: 8.5 Kpa
Grid connection time	Connected to the grid on December 30, 2019, full-load operation achieved in September 2022
Project investment	CNY 1,650 million
Electricity generation in 2021	9.34 GWh
Electricity generation in 2022	36.14 GWh. The plant started generating power on April 30, 2022.
Electricity generation in 2023	57.04 GWh. Electricity generation in this year was affected by evaporator leakage and hot MS pump fault/repair.
Electricity generation in 2024	132.55 GWh. After evaporator replacement, substitution and upgrading of cold and hot MS pumps, and SGS renovation were completed, the plant operated more stably, and electricity generation increased significantly.

3.7 CSNP Urat 100 MW Parabolic Trough CSP Plant

Basic Information about the operation of CSNP Urat 100 MW Parabolic Trough CSP Plant in 2024	
Capacity	100 MW
Area of the solar collector field	1,150,000 m^2
Floor area	4.867 km^2

Basic Information about the operation of CSNP Urat 100 MW Parabolic Trough CSP Plant in 2024	
Solar concentrator dimensions	5.7712 m
Receiver tube model	7,040,602.2 mm
Number of loops in the solar collector field	352
Solar collector field HTF/ working temperature	Thermal oil/393℃
TES medium/weight	Binary molten salt/about 70,234 T
TES duration	10 hours
TGU capacity/parameters	Medium-temperature high-pressure TGU, 100 MW/(main TGU operating normally at 383℃ ; 371℃ /stored-energy power generation mode)
Grid connection time	July 2021
Project investment	CNY 3.0 billion
Electricity generation in 2023	326 GWh (pure CSP)
Electricity generation in 2024	In 2024, Urad Middle Banner was affected by rainy weather, especially from June to September, with 54 rainy days, which had a severe impact on the local direct normal irradiance (DNI). Consequently, the cumulative DNI in 2024 is only 1,896 GWh (DNI = 1,647 kWh/m2), which is 16.77% less than the typical annual DNI of 2,278 GWh (DNI = 1,979.2 kWh/m2). In 2024, due to the high-quality construction and strong operation and maintenance capabilities of the CSNP Urat 100 MW Parabolic Trough CSP Plant, the plant's equipment utilization rate reached 99.99%, the pure CSP power generation reached 278 GWh, only 13.39% less than the typical annual electricity generation of 321 GWh, and the annual light-to-electricity conversion efficiency reached 14.67%, 4.12% higher than the design value of 14.09%. These results fully demonstrate CSNP's capabilities in parabolic trough CSP system integration and the advancement and reliability of domestically manufactured core equipment for parabolic trough CSP plants. The CSNP Urat 100 MW Parabolic Trough CSP Plant designed, constructed, commissioned, operated and maintained by CSNP ranks first in terms of single-unit capacity and TES period among the first batch of national CSP demonstration projects. The plant is located in Bayannur, Inner Mongolia. The construction of the plant was officially commenced in June 2018, and the plant started operating (generating electricity) at full load in December 2020. In July 2021, the molten salt TES system was put into full operation, and the plant achieved 24-hour continuous and stable high-load operation. The plant's light-to-electricity conversion efficiency and heat-to-electricity conversion efficiency are higher than the design values. The electricity generation of the plant for the year in which it was put into operation meets the target/design electricity output for that year During the construction of the plant, CSNP successfully obtained more than 100 patents, set five world records, built a well-trained talent team for the R&D, design, management and operation of CSP plants, developed process design, system integration, core equipment supply, operation and commissioning capabilities. Strict and refined quality control has ensured that the intercept factor of the parabolic trough collectors used at the plant is higher than 98% (while the current international level is 97%). The plant is designed with a service life of 35 years, and it has been constructed according to the optimized design and has taken a leading position internationally. The successful completion of this project has facilitated the development and application of key CSP products inside and outside the organization of CSNP and promoted the localization of parabolic trough CSP systems. Since the time of startup, the cumulative electricity generation of the plant has exceeded 1,149.5 GWh, the annual pure CSP power generation is about 340 GWh (equivalent full-load operating hours: 3,400 hours), the maximum monthly electricity generation is 52.3 GWh, and the maximum daily electricity generation is 2.216 GWh.

3.8 Luneng Golmud Multi-energy Complementary Project 50 MW Solar Tower Plant

The Luneng Golmud Multi-energy Complementary Project 50 MW Solar Tower Plant is part of the Luneng Haixi Multi-energy Complementary System Integration and Optimization National Demonstration Project—the world's first multi-energy complementary project that integrates wind power, PV, CSP, TES, and load regulation (which is a technological innovation project consisting of a 200 MW PV power plant, a 400 MW wind farm, and a 50 MW TES system in addition to the solar tower plant). The plant is located at an elevation of 2,800 m in the Golmud East Export Photovoltaic Park, Golmud City, Qinghai Province. The height of the concrete solar tower is 147.4 m, the height of the central solar receiver is 40.7m, and the power rating of the central solar receiver is 280 MW. The TES period is 12 hours. The TGU consists of an impulse turbine and a generator. One end of the generator is connected to the high-pressure cylinder of the impulse turbine, and the other end is connected to the low-pressure cylinder of the impulse turbine. The high-pressure cylinder rotates at a speed of 10,031 rpm and is connected to the generator through a reduction gearbox. The low-pressure cylinder rotates at a speed of 3,000 rpm and exhausts steam axially. The generator uses a brushless excitation system and a direct air-cooled exhaust system. The construction of the plant was commenced on May 8, 2018, and the plant was connected to the grid on September 19, 2019.

Basic Information about the operation of Luneng Golmud Multi-energy Complementary Project 50 MW Solar Tower Plant in 2024	
Capacity	50 MW
Heliostat field total aperture area	610,000 m^2
Floor area	5,500 mu
Heliostat dimensions	Aperture area: 138.672 m^2, with 64 mirrors arranged in 8 longitudinal rows and 8 horizontal rows
Number of heliostats	4,400
Central receiver height	147.4 m
Receiver dimensions	Diameter: 50.8 mm, thickness: 1.5 mm, height: 40.7 m
Heliostat field dimensions	Heliostats arranged in 48 circumferential rows around the central receiver, with the farthest point 1,500 m away from the center of the central receiver
Solar collector field HTF/working temperature	Binary molten salt/565℃

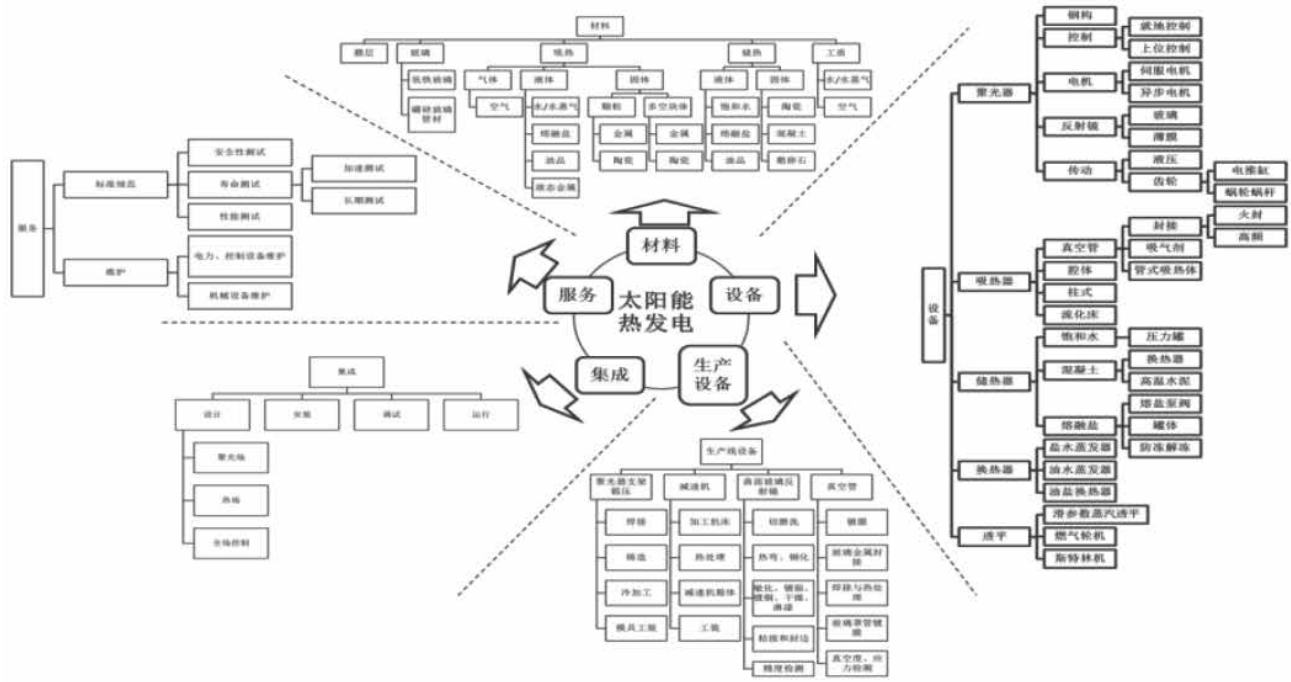
Basic Information about the operation of Luneng Golmud Multi-energy Complementary Project 50 MW Solar Tower Plant in 2024	
TES medium/weight	Binary molten salt/15,200 T
TES duration	12 hours
TGU capacity/parameters	Design operating pressure: 14 Mpa, main TGU operating temperature: 540 ℃ , reheater operating temperature: 540℃ , discharge pressure: 8 Kpa
Grid connection time	Connected to the grid on September 19, 2019, full-load operation achieved in August 2021
Project investment	
Electricity generation in 2019	373.3 MWh
Electricity generation in 2020	7,115.8 MWh
Electricity generation in 2021	69,498.6 MWh
Electricity generation in 2022	86,089.5 MWh
Electricity generation in 2023	91,027.6 MWh
Electricity generation in 2024	Owing to works such as the cleaning of receiver tube panels, oven box sealing, heliostat calibration and coordinates optimization, on-line oil filtering for heliostats and the optimization/adjustment of operating parameters, the plant's monthly electricity generation reached 13,452.08 MWh in October 2024, breaking the record of 11,524.275 MWh set in August 2024. The plant's annual electricity generation in 2024 is 95,067 MWh, exceeding the annual electricity generation of 91,020 MWh in 2023.

Chapter IV Development of China's CSP Industry

This section outlines the components of the CSP industry chain and provides data about the development of China's CSP industry in 2024.

4.1 China's CSP Capacity

The CSP industry can be divided into five major sectors: materials, equipment, production equipment, integration, and testing, as shown in Fig. 4.1-1. With the completion and operation of CSP plants, operation and maintenance technology has become an important part of the industry chain, and it is becoming more and more important. This is also a very different part between 2024 and 2023.



Prepared by: CSTA

Fig. 4.1-1 China's CSP Industry Chain

The material sector mainly includes: ultra-white glass sheets, mirror back paints, mirror weather-resistant paints, receiver absorption coatings, nickel-based alloy tubes, stainless steel tubes, MSs (binary salt of potassium nitrate and sodium nitrate), multicomponent salts, high-temperature MSs at 800 ℃, thermal oil (mainly biphenyl-diphenyl ether), silicone oil, concrete heat storage materials, various ordinary steel products, and various temperature insulation materials, etc. In recent years, ceramic heat-absorbing particle materials, ceramic heat storage materials, quartz glass tubes, carbon dioxide, aluminum silicate fiber refractory insulation materials and other fourth-generation materials for CSP industry have also been applied in the industry chain.

The equipment sector mainly includes:

1) Solar concentrators, including concentrator bodies, low-power control motors, electric push rods, high-precision

reducers, motors, hydraulic driving equipment and motor push rods;

2) Solar receivers, including central receivers, parabolic trough vacuum tubes, particle receivers, air receivers and receiver valves (MS, thermal oils, steam and solid particles);

3) TES containers: storage tank bodies, storage tank valves, electric heaters and controllers in storage tanks, MS or thermal oil level gauges, overflow tank containers of HTF & TES islands;

4) Pump valves: MS pumps, MS valves, thermal oil pumps, thermal oil valves, steam valves, water valves and high-temperature particle valves;

5) Heat exchange equipment: 600℃ particle elevators, thermal oil/MS heat exchangers, MS/steam generators, MS/particle heat exchangers, ceramic particle/supercritical CO2 heat exchangers and flowmeters;

6) Control equipment: plant control equipment, concentrator tracking control equipment, heliostat field correction equipment, pipeline HTF flow control equipment, receiver tube panel automated salt controllers, fully automated solar concentration and reception control equipment, and heliostat field and receiver coupling control technologies (heliostat field energy scheduling, receiver energy flow distribution adjustment, whole-field decentralized control system);

7) Tracking error measuring instruments: heliostat calibration equipment, target point imaging error measurement devices, machine vision error detectors, level inclinometers, laser calibration equipment, moonlight calibration equipment, and artificial light sources for concentrator calibration;

8) Power machinery and equipment: specific steam turbines for CSP, air turbines, Stirling engines, ORC turbines, supercritical CO2 compressors, supercritical CO2 turbines, generators, high-speed motors, and air cooling systems;

9) Auxiliary machines: pipeline anti-condensation heat tracing system (electric heating wires, magnesium oxide insulations, metal armored composite heating elements), electric heaters, electrical equipment, concentrator cleaning vehicles, water production equipment, grid-connected equipment, normal direct solar irradiance measurement instruments, meteorological stations, cloud forecasting systems (all-sky imagers, 30-min DNI forecast), and salt melting equipment, etc.

The production equipment sector mainly includes: ultra-white glass production lines, mirror coating production lines, glass bending and tempering production lines, tracking drive device production lines, parabolic trough receiver tube production lines, parabolic trough concentrator production lines, metal backboard stamping equipment, sub-mirror bonding curing and testing equipment, heliostat structure assembly and surface adjustment testing instruments, metal backboard stamping automatic production lines, sub-mirror bonding curing and testing production lines, heliostat structure assembly and surface adjustment testing production lines, heliostat final assembly production lines, MS production lines, TES tank production lines, heat exchanger production lines, and heliostat controller production lines, etc.

The integration sector mainly includes: design institutes, design consultation units, owner engineer units, equipment and system installation companies, system commissioning, system operation and maintenance companies, main steam pipeline design rules, heliostat field layout design softwares, linear collector field layout design softwares,

thermal and hydraulic programs of receivers, thermal load calculation programs of receivers, receiver efficiency calculation programs, and accident safety calculation programs, etc.

The testing sector mainly includes: performance and lifespan testing of liquid and solid heat-absorbing materials, optical efficiency and lifespan testing of concentrator fields, thermal performance testing of receivers, receiver lifespan testing, absorption ratio and emission ratio testing of heat absorbing coatings, lifespan testing of heat absorbing coatings, thermal performance testing of solar collection systems, thermal performance testing of heat exchangers, mechanical performance testing of receivers, thermal efficiency testing of solar collection systems, TGU heat-work conversion efficiency testing, electric output testing of CSP systems, system power generation efficiency testing, pipeline weld non-destructive testing, infrared monitoring of heat surface energy flow density of receivers, and formulation of various standards, etc.

4.2 Development history of China's technology industry

Since the "11th Five-Year Plan" period, in 2007, the Ministry of Science and Technology launched the key project "CSP Technology and System Demonstration (Project No. 2006AA050100)" under the National High-tech R&D Program (863 Program) in the advanced energy technology field, marking the beginning of the research and demonstration of CSP full-system integrated technology in China. This project aims to study the critical technologies of solar tower plants, establish experimental systems and platforms, and explore the technical approaches of high-efficiency, large-scale and low-cost commercial plants. Supported by the Ministry of Science and Technology, Beijing Municipal Science & Technology Commission and Chinese Academy of Sciences, this project is located in Badaling Town, Yanqing District, Beijing. The power generation facility covers an area of about 100 mu with an installed capacity of 1.5 MWe. In August 2012, the first MW-scale experimental solar tower plant in Asia, which was independently developed, designed and built by China, successfully started generating power through the concerted efforts of 11 units led by IEECAS, after six years of unremitting efforts [15]. The project has achieved many technical breakthroughs in core equipment, coordinated control, and system integration, etc., comprehensively mastered the design technologies of high-precision concentrators, concentrator fields, direct superheated receivers, TES and power generation units and systems, as well as the overall, concentrator field, maintenance, instrument control and electrical design technologies, and achieved a number of independent innovations represented by the process of directly generating superheated steam by coupling CSP fields, established the R&D system and standard specification system of CSP technologies, and compiled the first national standard of CSP technologies [16], laying the foundation for the development of CSP technologies in China. The project team members and equipment suppliers trained by the project have laid the foundation for CSP technologies in China, for example, China Electric Power Planning & Engineering Institute (plant design), Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group (plant design), and Dongfang Boiler Co., Ltd. of Dongfang Electric Corporation (receiver supply). The teams trained by the project, for example, IEECAS, Institute of Engineering Thermophysics, Chinese Academy of Sciences, Xi'an Jiaotong

University and Beijing University of Technology, have all become the backbone of research of CSP technologies in China. The picture below shows a panoramic view of the plant.

Fig. 4.2-1 Badaling Experimental Solar Tower Plant (Photo by IEECAS, July 30, 2024)

On October 30, 2012, the 1.5 MWth Linear Fresnel CSP Combined Cycle Hybrid Plant at 400°C jointly developed and built by Huaneng Clean Energy Research Institute and Huaneng Hainan Company was put into operation in Sanya, Hainan. The superheated steam generated by the project was connected to the steam supplement inlets of the TGUs of Huaneng Nanshan Plant and supplied to the steam turbines for power generation [17]. As the first MW-scale Fresnel CSP project in China, this plant is of great significance. The plant is designed with the line concentrating direct steam CSP technologies, automatic high-precision solar tracking systems and control softwares independently developed by the company, and all equipment is made in China.

Fig. 4.2-2 Panoramic View of CSP Collector Field in Huaneng Nanshan Plant (Photo by Huaneng Clean Energy Research Institute)

Fig. 4.2-3 Partial View of CSP Collector Field in Huaneng Nanshan Plant (Photo by Huaneng Clean Energy Research Institute)

On January 23, 2012, Hainan e-Cube 1 MW "Module Heliostat Matrix" CSP System (MH-CSP for short) Demonstration Project was basically completed and successfully commissioned for parallel power generation in Sanya [18]. The project is located in Sanya Nanshan Creative Industry Park, invested and constructed by e-Cube Energy Technology (Shanghai) Co., Ltd., with a total investment of CNY 35 million and an area of 95 mu. 5 solar collection matrices and 2,100 concentrating solar collection modules were planned and built in the plant area. "Module Heliostat Matrix" concentrating collectors are new solar thermal energy generators, which are of two-dimensional discrete reflective concentrator structures to realize quasi-two-dimensional solar tracking. The concentrating collectors replace the conventional boilers, heat the thermal oils, transports them to the heat exchangers to generate superheated steam at 350℃ , and then generate electricity through condensing steam turbine units.

Fig. 4.2-4 Hainan MH-CSP (Source: Network)

In July 2013, Phase I 10 MW Project of Qinghai SUPCON Delingha Solar Tower Plant supported by the National High-tech R&D Program (5 MW each for the east and west towers) was connected to Qinghai Power Grid for power generation [19]. With the direct steam generation (DSG) technology employed, this project team developed intelligent heliostats with a reflection area of 2 m2 each, developed high-precision intelligent tracking technologies of heliostats and the large-scale heliostat field control systems, realized the overall solar concentration and collection of large-scale heliostat clusters, studied the dynamic modeling and optimization design of solar tower plant energy under different geographical and climatic environments, designed high-energy flow density receivers, steam buffers, and energy circuits and equipment for power generation based on water working media, realizing the photoelectric energy conversion technologies of large-scale CSP technology routes.

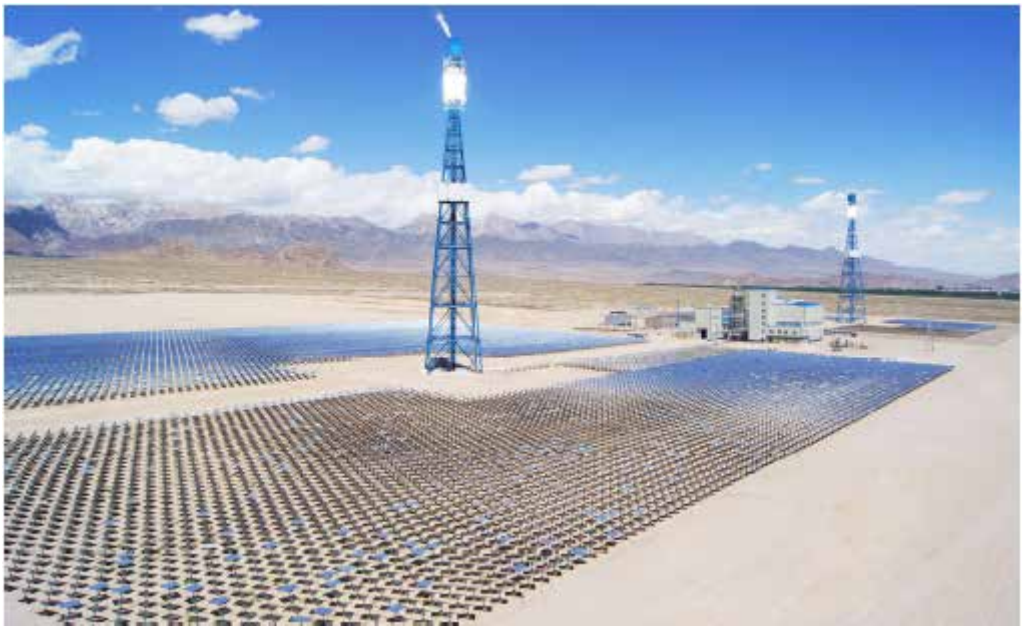


Fig. 4.2-5 Phase I 10 MW Project of Qinghai SUPCON Delingha Solar Tower Plant (Source: Cosin Solar Technology Co., Ltd.)

Supported by the National 863 Program "10 MW Solar Tower Plant Technology Research and Demonstration Project Based on Small-area Heliostat" (Project No.: 2013AA050200) in the advanced energy technology field, HTFs such as water/steam were changed to MSs in the SUPCON Solar Power Delingha 10 MW Solar Tower Plant. In August 2016, the completion of the operation of MS solar absorption, TES and heat exchange systems, made this project become the first commercial solar tower plant with large-scale TES systems in China and the third in the world, and the annual utilization time increased by over 30%. In early September 2014, the National Development and Reform Commission approved the feed-in tariff rate (including tax) of the plant at CNY 1.2/kWh [20], which was also the first time that CSP projects had received national approval for the feed-in tariff rate, marking a solid step towards commercial operation of CSP technologies independently developed in China. The project realized full-load power generation on August 21, 2016 [21]. The project fully demonstrates the technical level of solar tower system integration with independent intellectual property in China, as well as the core equipment development capability to adapt to

the high-cold and high-altitude area. On January 15, 2018, the High-tech Department of the Ministry of Science and Technology organized experts to accept this project in Hangzhou; the acceptance expert group thought that the project had completed the research contents specified in the project approval notice, reached the assessment indexes, and met the project acceptance requirements, and unanimously agreed that this project passed the technical acceptance. [22]

In June 2017, the completion of "Parabolic Trough CSP Technology Research and Demonstration Project (Project No.: 2012AA050600)" deployed by the Ministry of Science and Technology during the "12th Five-Year Plan" period marked that China began to research and demonstrate the MW-scale parabolic trough CSP technologies [23]. The supporting unit of the project, IEECAS, cooperated with 13 technologically superior units in China to research the critical equipment, critical processes and testing technologies of parabolic trough CSP technologies, as well as the design, integration and operation technologies of parabolic trough CSP system, aiming at large-scale and low-cost CSP technologies. Based on the researches on the hot bending and tempering processes of curved glasses, the project team proposed new parameters of high-speed heating processes and the corresponding quenching processes and control parameters for high wind pressure and far air grilles as for the performance characteristics of domestic glass sheets, which broke through the ex-factory process parameters of foreign mirrors for parabolic trough CSP plants, and established a parabolic trough curved mirror production line with an annual output of 1 million m^2 based on this process. Through in-depth research, the accelerated aging method of heat absorbing coatings of high temperature vacuum receiver tubes was established, and the formula for predicting the service life of heat absorbing coatings was put forward. The project established a vacuum life prediction model of the receiver tube based on many factors such as material outgassing, permeation, hydrogen absorption, leakage, etc. The error between the predicted data and the one-year vacuum change data was 3.9%, reaching the international advanced level. Based on the basic theories of heat transfer and engineering thermodynamics, a dynamic capacity matching design method of solar absorption, TES and steam generation system was put forward on the basis of research on the variation law of solar irradiation with time and combining the intermittent and fluctuation of solar irradiation. Based on this method, the design, construction and commissioning of the thermal system of the first 1 MW parabolic trough CSP plant in China were completed, and the first parabolic trough CSP system simulator in China was developed. The outdoor test platform and dynamic test method for the solar collection performances of parabolic trough concentrators was established. The formula of this test method has been included in the standard for solar parabolic trough components - *Solar Thermal Electric Plants Part 3-2: Systems and Components. General Requirements and Test Methods for Parabolic-trough Collectors* issued by International Electrotechnical Commission (IEC) [24]. The implementation of the project has played an industrial leading role for the first batch of CSP demonstration projects in China, which has brought the R&D and equipment localization of parabolic trough CSP projects with high efficiency and low cost in China to a new level, and is of great significance for further enhancing the competitiveness of CSP products in China.

In October 2013, Lanzhou Dacheng Technology Co., Ltd. commenced the construction of 1 MW Linear Fresnel CHP Project in Tibet [25]. In October 2015, Lanzhou Dacheng Technology Co., Ltd. built 1 MW Linear Fresnel Solar

CHP Plant on roofs of the production workshops [26].

Fig. 4.2-6 China's First MW-scale Parabolic Trough CSP System (Yanqing, Beijing, IEECAS)

Fig. 4.2-7 1 MW Linear Fresnel Solar Collection System Built on Roofs of the Production Workshops by Lanzhou Dacheng

In 2014, IEECAS, together with a number of domestic universities, completed the only 973 Program "Basic Research on Efficient Large-scale CSP Projects" in the CSP field. This project was officially launched in January 2010, and lasted for four years and eight months. The project team consists of eight units, including IEECAS, Institute of Engineering Thermophysics, Chinese Academy of Sciences, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Xi'an Jiaotong University, Hohai University, Sun Yat-sen University, Beijing University of Technology and Wuhan University of Technology. Focusing on several critical scientific issues related to efficient and large-scale CSP projects, with improving conversion efficiency as the core, the project team conducted researches and achieved multiple important innovative results in six aspects (including establishing the theories of

collaborative design of solar thermal transmission, the basic theories of radiation - heat conduction - convection coupling heat transfer mechanisms and efficient enhancement under extreme conditions, multi-scale characterization and heat transfer enhancement methods for high-temperature heat transfer and high-temperature TES processes, microstructure design/green preparation principles of new high-temperature heat transfer and TES materials and their environmental effects, multi-level modeling and control strategies for the integration of non-steady "light - heat- work" energy systems, and environmental adaptability of large-scale CSP projects), solving the main challenges currently restricting the development of CSP technologies. On September 28, 2014, the project conclusion and acceptance meeting was held at IEECAS. Through inquiry and appraisal, the expert group believed that all six research projects had completed the scheduled objectives of the task assignment at a high level and passed the acceptance smoothly [27].

In terms of commercialization projects, in September 2016, NEA released the *Notice on Building CSP Demonstration Projects*, and the first batch of 20 demonstration projects with a total installed capacity of 1,349 MW were determined after expert review [10].

(1) Background and purpose of document release

Background: In order to promote the development of China's CSP industry and solve a series of critical technical problems for solar concentration and reception, TES and conversion of heat to work, NEA decided to build CSP demonstration projects.

Objective: To lead the development of CSP industry, improve the technical level and industrial scale, and promote the utilization of clean energy through the construction of demonstration projects.

(2) Main contents of the document

Number and scale of projects: The first batch of 20 CSP demonstration projects with a total installed capacity of 1,349 MW;

Project distribution: Qinghai Province, Gansu Province, Hebei Province, Inner Mongolia Autonomous Region and Xinjiang Autonomous Region;

Policies for feed-in tariff rate: The benchmark feed-in tariff rate of CSP demonstration projects (including TES functions for more than 4 hours) issued by the National Development and Reform Commission is CNY 1.15/kWh (including tax).

(3) Implementation of the document

Seven plants out of the first batch of national demonstration projects were completed, with a total on-grid capacity of 450 MW. Three of them were completed in 2018, three in 2019 and one in January 2020. As of January 2020, there were a total of eight 500 MW CSP Demonstration Plants in China, including 50 MW Luneng Haixi Plant, Multi-energy Complementary Demonstration Project approved by NEA.

The above data shows that CSP demonstration projects in 2016 are one of the important measures to promote the development of CSP industry in China. The construction of demonstration projects has not only improved the technological level and industrial scale of CSP plants, but also made positive contributions to determining the positioning of CSP plants in the power system.

According to the *2021 Notice on Matters Related to the Construction of Wind and PV Power Generation Projects* (NEA New Energy Document No. [2021] 25) released by NEA in May 2021, for projects that still tend to be connected to the grids outside the assurance-oriented grid-connected scope, the grid enterprises can connect them to the grids after implementing the grid-connected conditions through market-oriented methods such as self-construction, joint construction and sharing or purchasing services. Grid-connected conditions mainly include newly-added flexible adjustment capabilities such as pumped storage, TES CSP, peak shaving of thermal power, new TES and adjustable load [28]. As one of the supporting options for implementing grid-connected conditions, TES CSP systems and fluctuating power sources such as PV and wind power complement each other, which can not only give full play to TES and peak shaving capacities of CSP systems, reflecting the role of solar thermal energy as the power source for peak shaving to support the development of new energy, but also take advantage of the rapid decline in wind power and PV costs in recent years, fully releasing the low-cost advantages of PV and wind power, filling the power supply gap of PV power generation at the peak of electricity consumption, and effectively improving the energy utilization efficiency and economic benefits.

In 2016, IEECAS completed the "R&D Project of Critical Components and Systems of MW-scale Solar Tower Plant with MS Solar Absorption - TES" deployed by Beijing Municipal Science & Technology Commission, and established a 1 MW_{th} MS solar absorption and evaporation system. In September 2021, it completed the "Research Project of the Fourth Generation High-temperature Solid Particle Receiver for CSP" deployed by Beijing Municipal Science & Technology Commission, and established a MWth-scale quartz pipe high-temperature particle receiver.

IEECAS together with 18 domestic units were approved in 2019 to undertake the project "research on key issues in supercritical CO_2 CSP systems" of the national key R&D plan during the "13th Five-Year Plan" period, the first solar-driven 200 kW supercritical CO_2 CSP system in the world on May 28, 2024 [29].

In 2021, the State Council released the *Action Plan for Achieving Peak Carbon Dioxide Emissions by 2030*, which clearly stated the active development of CSP systems, and the promotion of the establishment of wind power, PV and CSP comprehensive renewable energy power generation base with complementary adjustment of CSP, PV power generation and wind power generation [30].

On May 30, 2022, the General Office of the State Council forwarded the *Implementation Plan on Promoting the High-quality Development of New Energy in the New Era* (General Office of the State Council Document No. [2022] 39) released by the National Development and Reform Commission and NEA, which proposed to innovate the development and utilization mode of new energy and accelerate the construction of large-scale wind power and PV bases focusing on desert and Gobi areas [31].

On April 7, 2023, the General Department of NEA released the *Notice of the General Department of NEA on Promoting the Large-scale Development of CSP Plants* (NEA General Department New Energy Notice No. [2023] 28) [11]. The main contents of the notice are to fully understand the significance of the large-scale development of CSP plants, and point out that CSP technology has the dual functions of peak shaving and TES, and can regulate and support renewable energy with renewable sources, provide higher long-term peak shaving capability and higher moment of

inertia for power systems, and serve as both peak shaving and basic power supply in some areas. In addition, CSP technology offers an effective way to safely and reliably replace conventional energy sources with renewable ones. It is planned to build a 1,000 MW CSP plant during the "14th Five-Year Plan" period. In addition, the notice may also contain a series of specific policy measures and implementation requirements, aiming at promoting the further upgrading and commercial application of CSP technologies and accelerating the planning and construction of new energy systems. The announcement of this notice indicates that China attaches importance to and supports the CSP technologies, and also indicates that the CSP industry will usher in new development opportunities.

4.3 China's CSP industry chain

After over 10 years of development, numerous CSP plants, especially the first batch of CSP demonstration projects approved by NEA, have been completed, significantly improving China's CSP industry support capabilities. CSTA inquires the enterprises related to the CSP industry chain in China according to five factors, such as enterprise name, business scope, enterprise profile, brand products and enterprise renewal. The search results only show domestic limited liability companies and joint stock limited companies, excluding self-employed entrepreneurs and other organizational types. As a result, there are about 441,102 enterprises related to the CSP industry chain in China, including 16,834 enterprises with patent information related to CSP technologies, 14,155 state-owned enterprises, 421,593 private enterprises, 3,000 foreign-invested enterprises, and 235,237 small and micro enterprises.

In terms of enterprise registration time, there are 23,153 enterprises registered for more than 10 years, 67,653 enterprises registered for 3-5 years, 129,401 enterprises registered within 1 year, and 39,510 enterprises registered with CSP businesses in the last three months.

The picture below shows the distribution of enterprises related to the CSP industry chain in different provinces.

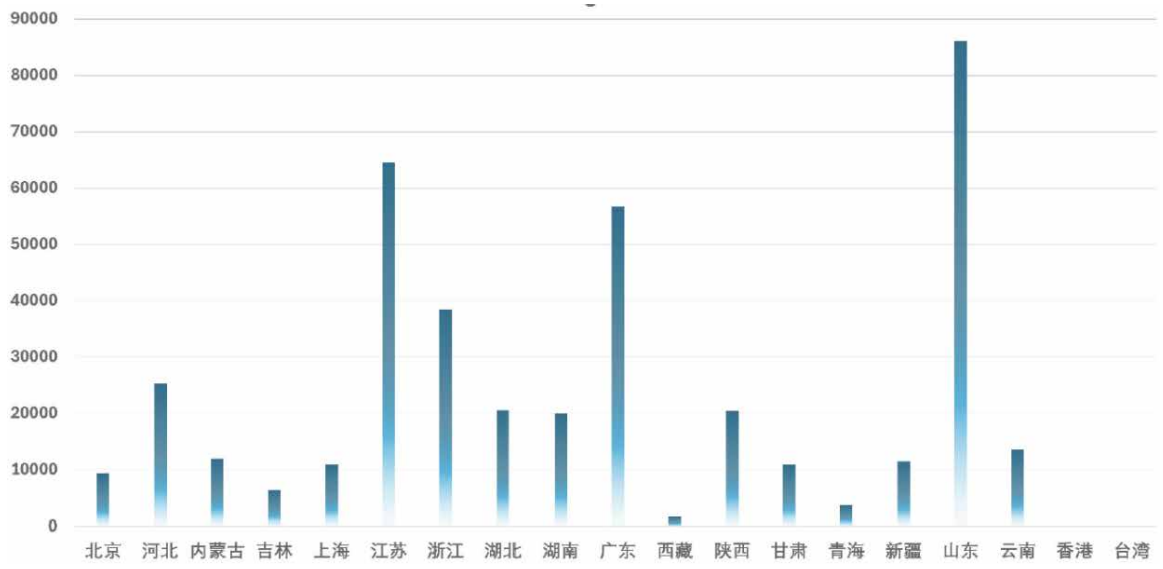


Fig. 4.3-1 Distribution of CSP Enterprises in Major Provinces (Prepared by CSTA)

There are 69 A-share listed companies, 117 NEEQ companies and 7 Hong Kong share listed companies in the industry chain.

There are 8,741 high-tech enterprises, 293 gazelle enterprises, 4,419 private science and technology enterprises, 1,293 enterprise technology centers and 1,084 technologically advanced enterprises.

There are 12,075 enterprises with a registered capital of over CNY 100 million and 33,568 large enterprises.

There are 24,592 manufacturing enterprises in the industry chain, including 650 metal pressure vessel manufacturers, 731 manufacturers for flat glasses for solar energy, 731 glass mirror manufacturers, 176 ferrous metallurgy enterprises, 282 mechanical and electrical equipment maintenance enterprises and 3,392 computer communication and electronic equipment manufacturers.

There are 12,400 natural science research and engineering technology research units, 10,893 testing and metrological accreditation units, 348 quality inspection units and 7 meteorological service enterprises.

There are 71,983 technology extension service enterprises and 50,002 technology intermediaries.

Products and services of solar tower plants, parabolic trough CSP plants, and linear Fresnel CSP plants cover ultra-white glass sheets, mirrors, concentrators, control systems, solar tracking mechanisms, hydraulic drives, speed reducers, receivers and tubing materials, rotary joints, supports, mirror coatings, thermal oils, thermal oil valves, thermal oil pumps, hot-dip galvanizing, solar radiation measurement, mirror production lines, and mirror testing. There are about 135 suppliers of products, equipment and services related to the TES systems of various CSP plants, including MSs, MS storage tanks, insulation materials, MS pumps, MS valves, salt melting, heating furnaces, electric heaters, and electric heat tracing.

The production and supply capacity of critical CSP materials and components in China basically meets the annual production capacity of over 4 GW. On the basis of the 2023 Blue Book stating that "the manufacturing capacity of critical product components in China can support the construction of at least 3 GW CSP projects per year", the additional production capacity publicly announced by the media in 2024 is that: the CSP glass production lines of Fujian Ruibo Glass Co., Ltd. have been put into operation, with a daily output of up to 600 tons [32]; Shandong Haihua Liwei New Materials Co., Ltd. has launched its annual production capacity of 100,000 tons of potassium nitrate, 20,000 tons of magnesium nitrate, and 200,000 tons of solar MS products [33]. More suppliers of equipment and materials have established flexible production lines. Once new orders are placed, they can quickly organize production and fulfill the contract as scheduled. For example, the high-temperature resistant MS 347H stainless steels for CSP independently developed by JISCO achieved a total supply capacity of over 200 tons in April 2023; as of the end of 2024, such stainless steels had been supplied to a number of CSP projects successfully, with cumulative sales exceeding 7,000 tons. The *Notice of the General Department of NEA on Promoting the Large-scale Development of CSP Plants* [11] states that: CSP plants can digest and upgrade traditional industries such as special glasses, steels, cements and MSs, and can also promote the development of new industries such as new materials, precision equipment and intelligent control. The large-scale development and utilization of CSP plants will become a new growth point of new energy industry in China.

CSTA has compiled incomplete statistics with respect to production and supply capacity for some critical CSP materials and components (as detailed in Table 4.2-1).

Table 4.4-2 Production Capacity of Some Chinese Companies for Critical CSP Materials and Components

Product type	Enterprise name (listed in alphabetical order)	Production capacity
Ultra-white glass for CSP	Dalian Yaopi Glass Co., Ltd.	700 t/d, annual production capacity of 2 GW, and glass thickness of 2 mm - 4 mm
	Henan Ancai Hi-tech Co., Ltd.	600 t/d, annual production capacity of 2.5 GW, and glass thickness of 3 mm - 15 mm
	Gansu Kaisheng Daming Solar Energy Technology Co., Ltd.	600 t/d
	Fujian Ruibo Glass Co., Ltd.	600 t/d
Mirror	Shandong Yuying Optical Instrument Co., Ltd.	Fresnel lenses with transmission, reflection and positive and negative focal lengths can be provided in optical form; PMMA, HDPE, PC, PVC, PS, tempered glass and silicone Fresnel lens can be provided according to materials; Fresnel lens with a diameter of 3 - 2,200 mm can be provided according to the size.
	Zhaoqing Dexin Vacuum Equipment Co., Ltd.	A new production line of solar concentration plane mirrors is built.
Reflective mirrors	Beijing TeraSolar Photothermal Technologies Co., Ltd	Mirrors for linear Fresnel CSP plants: 5 million m^2/year, and solar concentration and collection heliostat fields for linear Fresnel CSP plants: 3 million m^2/year
	Chengdu Chande New Energy Storage Technology Co., Ltd.	Mirrors for parabolic trough CSP plants: 3.5 million m^2/year, and flat mirrors for solar tower plants: 6 million m^2/year
	Gansu Kaisheng Daming Solar Energy Technology Co., Ltd.	Mirrors for parabolic trough CSP plants: 3.6 million m^2/year, flat mirrors: 10 million m^2/year, and bonding capacity of mirrors: 5 million m^2/year
	Lanzhou Dacheng Technology Co., Ltd.	Production capacity of the complete set of mirrors for linear Fresnel CSP plants: 3 million m^2/year, production capacity of secondary double parabolic mirrors: 500,000/year, and supply and construction capacity of MS linear Fresnel collector field equipment: 300 MW/year
	Inner Mongolia Baichuan Solar Technology Co., Ltd.	Mirrors for parabolic trough CSP plants: 3.5 million m^2/year, and flat mirrors: 6.5 million m^2/year
	Shouhang High-Tech Energy Technology Co., Ltd.	Mirrors for parabolic trough CSP plants: 2 million m^2/year, and flat mirrors: 5.6 million m^2/year
	Wuhan Sunnpo Solar Technology Co., Ltd.	800 MW/year (mirrors for parabolic trough CSP plants, solar tower plants, linear Fresnel CSP plants, parabolic dish CSP plants, secondary mirrors and concentrated PV mirrors)

Product type	Enterprise name (listed in alphabetical order)	Production capacity
Vacuum receiver tubes	Beijing TRX Solar Technology Co., Ltd.	80,000/year
	Royal Tech CSP Limited	320,000/year (70 standard tubes)
	Lanzhou Dacheng Technology Co., Ltd.	60,000/year (MS vacuum receiver tubes)
	Shandong Huiyin New Energy Technology Co., Ltd.	200,000/year
	Hebei Daorong New Energy Technology Co., Ltd.	200,000 medium-high temperature vacuum receiver tubes
	Inner Mongolia Xuchen Energy Co., Ltd.	200,000
	Shandong SIMED New Energy Technology Co., Ltd.	100,000
	Shaanxi Baoguang Vacuum Electric Device Co., Ltd.	Annual production capacity of 4 m vacuum receiver tubes for CSP: 30,000, and annual production capacity of 2 m receiver tubes for CSP utilization engineering: 60,000
High-temperature nickel-based alloy tubes	Changzhou Shenneng Metal Product Co., Ltd.	1500t/year
Nitrates	Hubei Yuntu Molten Salt Technology Co., Ltd.	Sodium nitrate and sodium nitrite: 150,000 tons/year
	Jiangxi Jinlida Potassium Industry Co., Ltd.	Potassium nitrate: 100,000 t/year (unable to be produced at full capacity due to nitramine control)
	Golden Potassium Technology Co., Ltd.	Potassium nitrate: 150,000 t/year
	Qinghai Salt Lake Wojin Thermal Storage Technology Co., Ltd.	MS-grade potassium nitrate and sodium nitrate: 400,000 t/year
	Shanxi Wojin New Materials Co., Ltd.	MS-grade potassium nitrate, sodium nitrate, calcium nitrate, and various high-, medium- and low-temperature MS: 140,000 tons/year
	Jiaocheng County Bingsheng Chemical Co., Ltd.	MS-grade potassium nitrate, sodium nitrate, and various high-, medium- and low-temperature MS: 40,000 tons/year
	Sinkiang Nitrate Minerals Co., Ltd.	Sodium nitrate: 70,000 t/year
	Sociedad Quimica Y Minera De Chile S.A.(SQM) (Shanghai) (originally known as SQM (Shanghai) Chemical Co., Ltd.)	Total capacity of potassium nitrate and sodium nitrate: 300,000 t/year
	Shandong Huayang Dr Chemical Industry Co., Ltd.	270,000 tons of nitric acid plants, 100,000 tons of potassium nitrate and water-soluble fertilizer plants
	Shandong Enesoon New Material Technology Co., Ltd.	Capacity of 300,000 tons of binary, ternary and multicomponent MSs and salt melting capacity of 30 t/h
	Shandong Aobo Energy Storage Technology Co., Ltd.	Annual supply capacity of 120,000 tons of compound MSs such as MS-grade potassium nitrate, sodium nitrate and sodium nitrite
	Shandong Haihua Liwei New Materials Co., Ltd.	Annual production capacity of 100,000 tons of potassium nitrate, 20,000 tons of magnesium nitrate and 200,000 tons of solar MS products

Product type	Enterprise name (listed in alphabetical order)	Production capacity
Thermal oil	Jiangsu Zhongneng Chemical Technology Co., Ltd.	30000 t/year
	Hebei Jindong Technology Group Co., Ltd.	36,800 t/year (in which, biphenyl-diphenyl ether: 25,000 t/year)
MS pumps	Jiangsu Feiyue Pump Co., Ltd.	Over a thousand MS pumps per year for various industrial services
	Jinan Huawei Pump Co., Ltd.	100 long-axis MS pumps/year
	Lanzhou Lanpump Co., Ltd.	Production capacity of MS pumps at 700℃
	PowerChina Shanghai Energy Equipment Co., Ltd. PowerChina Renewable Energy Co., Ltd.	MS pump engineering prototypes for 100 MW Solar Tower Plant
MS valves	Shanghai Yahe Valve Completion Co., Ltd.	7000 sets/year
	Beijing Jiajie New Energy Saving Technology Co., Ltd.	3000 sets/year
	Zhejiang High and Medium Pressure Valve Co., Ltd.	Annual production capacity of valves: about 8,000 tons
	Chengdu Huaxi Fluid Control Technology Co., Ltd.	Total annual output: about 1,000 tons, which can meet the supply of packaged whole set of 10 CSP + 10 TES projects
Thermal insulation materials	Hubei Shuoli New Material Technology Co., Ltd.	Thermal insulation materials for solar power towers (central receivers), thermal insulation systems at the inlet and outlet of parabolic trough collector loops, and new thermal insulation systems for storage tanks: totally 25,000 tons
	Luyang Energy-Saving Materials Co., Ltd.	500,000 t
Stainless steel pipes	Changzhou Shenneng Metal Product Co., Ltd.	10,000 t
	Jiangsu Xinchang Special Steel Pipe Co., Ltd.	HT molten salt, HTF and electric heating pipes: 35,000 tons/year
	Sinosteel Stainless Steel Pipe Technology (Shanxi) Co., Ltd.	HT molten salt and HTF pipes: 10,000 tons/year
	Shanghai Feiting Pipe Manufacture Co., Ltd.	12,000 tons of various material fittings and 7,200 tons of flanges
Speed reducers	Hengfengtai Precision Machinery Co., Ltd.	200,000 sets/year
MS electric heaters	Hangzhou Runpaq Energy Equipment Co., Ltd.	2,000 MW/year
	Zhejiang Green Storage Technology Co., Ltd.	2,000 MW
	Xi'an Huijin Technology Co., Ltd.	1 GW
MS flowmeters	Shanghai Topfm Technology Development Co., Ltd.	500 sets/year
Prepared by CSTA		

Chapter V Overview of CSP R&D Projects in China

5.1 National Science and Technology Projects

In 2024, one national key R&D project was completed. There are 16 CSP-related national key R&D projects under implementation (as shown in Table 5.1-1, arranged according to their start time). The main research areas of these projects and the results achieved in 2024 are presented below. We owe special thanks to all project managers for sharing project progress information for the year.

Table 5.1-1 CSP-related National Key R&D Projects in 2024

No.	Project	Project Name	Lead entity	Director/ Chief Scientist	Participant	Conclusion time and effects
1	Resarch on key issues in supercritical CO_2 CSP systems (basic research)	National key R&D project "Renewable Energy and Hydrogen Energy Technology"	IEECAS	Prof. Wang Zhifeng	Tsinghua University, Peking University, Nanjing University of Aeronautics and Astronautics, Xi'an Jiaotong University, Zhejiang University, Beijing University of Technology, Wuhan University of Technology, Tianjin University, Sun Yat-sen University, Institute of Engineering Thermophysics, Chinese Academy of Sciences, Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Dongfang Boiler Co., Ltd. of Dongfang Electric Corporation, Shouhang High-Tech Energy Technology Co., Ltd., Xi'an Thermal Power Research Institute Co., Ltd., Chongqing Jiangjin Shipbuilding Industry Co., Ltd., and Shandong Electric Power Construction Corporation III (SEPCOIII)	On August 13, 2024, it passed the project performance evaluation organized by the National Natural Science Foundation of China.
2	Design of high-performance bionic TES materials and processes	National key R&D project "Key Scientific Problems of Transformative Technologies"	Nanjing University of Aeronautics and Astronautics	Prof. Liu Xianglei	University of Science and Technology Beijing, Nanjing Jinhe Energy Materials Co., Ltd., Jilin University, Harbin Institute of Technology, and Shanghai Jiaotong University	In progress

No.	Project	Project Name	Lead entity	Director/ Chief Scientist	Participant	Conclusion time and effects
3	Broadband metasurface solar concentrators and solar collection systems	National key R&D project "Key Scientific Problems of Transformative Technologies"	Wuhan University of Technology	Prof. Guan Jianguo	IEECAS, Fudan University, Xiamen University, University of Science and Technology of China, and Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences	In progress
4	Theory and method for high-flux solar-to-chemical energy conversion and storage	National key R&D project "Engineering Science and Comprehensive Crossing"	Xi'an Jiaotong University	Prof. Wei Jinjia	Zhejiang University, IEECAS, Technical Institute of Physics and Chemistry, CAS, Fuzhou University, and Beijing Institute of Petrochemical Technology	In progress
5	Development and application of HT molten salt resistant special alloys for CSP systems	National key R&D project "Advanced Structures and Composites"	Institute of Metal Research, Chinese Academy of Sciences (IMRCAS)	Prof. Sun Xiaofeng	Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Ningbo Institute of Materials Technology & Engineering, CAS, Gansu CSP Co., Ltd., Songshan Lake Materials Laboratory, Royal Tech CSP Limited, Zhenshi Group Eastern Special Steel Co., Ltd., Baoshan Iron & Steel Co., Ltd., Fushun Special Steel Shares Co., Ltd., and Zhejiang Jiuli Hi-Tech Metals Co., Ltd.	In progress
6	Wide-temperature-range HT molten salt TES technology	National key R&D project "TES and Smart Grids"	Beijing University of Technology	Prof. Wu Yuting	Institute of Engineering Thermophysics, Chinese Academy of Sciences, Xi'an Jiaotong University, South China University of Technology, Cosin Solar Technology Co., Ltd., Xi'an Thermal Power Research Institute Co., Ltd., Cosin Solar Technology Research Institute Co., Ltd., Bluestar (Beijing) Chemical Machinery Co., Ltd., North China Electric Power University, and Hebei University of Technology	In progress

No.	Project	Project Name	Lead entity	Director/ Chief Scientist	Participant	Conclusion time and effects
7	Research on key technologies for stable power output of CSP-PV hybrid plants with reflective secondary concentrators	National key R&D project "Intergovernmental International Scientific and Technological Innovation Cooperation"	Xinchen Solar (Shanghai) New Energy Co., Ltd. (Chines Side) Now it is renamed as Zhongqing Solar Thermal (Shanghai) New Energy Co., Ltd.	Prof. Xie Wentao	Shanghai Jiaotong University, Alia Energy Consulting SL	In progress
8	Mechanics research and service life prediction for HT molten salt storage tanks in CSP systems	National key R&D project "Intergovernmental International Scientific and Technological Innovation Cooperation"	IEECAS	Mrs. Zang Chuncheng	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, CGN Solar Energy Development Co., Ltd., Harbin Turbine Company Limited, and National Renewable Energy Laboratory (NREL)	In progress
9	Research on wind load fluctuation characteristics and wind-induced vibration characteristics of heliostat structures of solar tower plant	National key R&D project "Intergovernmental International Scientific and Technological Innovation Cooperation"	Chang'an University	Guohua Xing	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, CPECC International Engineering Co., Ltd., and Empresarios Agrupados Internacional, S.A.	In progress
10	Research and industrial verification of coal and solar thermal coupling power generation technologies	National key R&D planning projects	North China Electric Power University	Yongping Yang	Xi'an Jiaotong University, Tsinghua University, IEECAS, and CSTA	In progress

No.	Project	Project Name	Lead entity	Director/ Chief Scientist	Participant	Conclusion time and effects
11	Research on the Thermal Energy Storage Tank	IEA-SolarPACES funding member team collaboration project	IEECAS	Chuncheng Zang	NREL, CIEMAT, DLR, CSP Energies, Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, and Cosin Solar Technology Co., Ltd.	In progress
12	R&D and application of high absorptivity coatings for tower high-temperature MS receivers	Major demonstration project for science and technology innovation "competitions are opened to select the best candidates" in Inner Mongolia Autonomous Region	Inner Mongolia Electric Power Survey & Design Institute Co., Ltd.	Xiao Gang	Zhejiang University, CGN Solar Energy Development Co., Ltd., Inner Mongolia University of Technology, Xizi Clean Energy Equipment Manufacturing Co., Ltd., and Inner Mongolia Power (Group) Co., Ltd.	In progress
13	Research project on key technologies of tripod turnover and solar concentration and collection systems of CSP solar towers	Construction technology project plan for 2024 of Department of Housing and Urban-Rural Development of Gansu Province	Gansu Province Installation & Construction Group Co., Ltd.,	Fuguo Shi		In progress
14	Coupling theories and methods of solar seawater desalination and in-situ photocatalytic steam hydrogen production	National key R&D planning projects	**Nanjing University**			Starting
15	Design theories and methods of low-carbon energy system for heavy oil thermal recovery with multi-energy coupling	National key R&D planning projects	Institute of Engineering Thermophysics, Chinese Academy of Sciences			Starting

No.	Project	Project Name	Lead entity	Director/ Chief Scientist	Participant	Conclusion time and effects
16	Design theories and regulation methods of renewable distributed energy system coupled with solar energy and biomass energy	National key R&D project "Young Scientist Program"	Chongqing University			Starting
17	Theories and methods of multi-energy coupled thermochemical conversion and integrated design of electricity/ heat/steam cogeneration system for heavy oil thermal recovery		University of Chinese Academy of Sciences			Starting
Prepared by CSTA						

5.1.1 Resarch on key issues in supercritical CO_2 CSP systems (basic research)

On August 13, 2024, it passed the project performance evaluation organized by the National Natural Science Foundation of China. As for three critical scientific problems, namely, design theories and methods for high temperature receivers, the impact of TES and release mode on system performance, and the interaction between CO_2 cycles and conversion of heat to work in steam turbines, the following important outputs are obtained.

For scientific problem I,

1. The mechanisms of space-time synergistic absorption, transformation and heat transfer of concentrated solar radiation in flexible discontinuous particle flow have been established;

2. Three types of concentrators and four types of receivers including 700°C/1 MWth particle receivers have been

developed.

3. Two high-density energy measurement methods have been proposed.

For scientific problem II,

1. The inhibition mechanisms of MS on metal corrosion have been explored.

2. The matching of heat transfer characteristics between high-temperature solid endothermic particles and sCO_2 under the conditions of variable heat flux, variable temperature and strong variable physical properties has been broken through;

3. Three types of TES and heat exchange devices including 550℃ /1 MWth have been developed.

For scientific problem III,

1. The constitutive matching relationship of main parameters of high-efficiency CSP systems with high solar energy flow, high temperature, high expansion ratio and high specific work has been constructed;

2. The whole system model of light-heat-electricity energy conversion with sCO_2 flow as the core has been established;

3. 550℃ /0.2 MW sCO_2 TGUs have been developed;

4. Empirical systems of "light-heat-electricity" have been established and put into operation.

Fig. 5.1-2 Supercritical CO_2 CSP System in Yanqing, Beijing

On November 29, 2024, the first edition of People's Daily published an article titled Building a System and Mechanism to Support All-round Innovation, which indicated that we should deepen the reform of science and technology system and fully stimulate innovation and creativity. This year, China successfully developed the first supercritical CO_2 CSP plant, which is at the forefront of the world. The CSP plant involves basic theoretical research, technical equipment development and system integration, and embodies the wisdom of 18 units, including IEECAS,

Tsinghua University and SEPCOIII Electric Power Construction Co., Ltd. [34].

5.1.2 Design of high-performance bionic TES materials and processes

TES technologies can effectively solve the problems caused by the mismatch between renewable energy/thermal energy supply and demand in terms of time, space and intensity, maximize energy utilization in the entire system while minimizing energy utilization costs, and play a strategically important role in building a "clean, low-carbon, safe, and efficient" modern energy system and promoting the supply-side reform of China's energy industry and the transformation of energy production and utilization modes. Existing TES technologies have a variety of problems, such as low thermal conductivity (less than 5 W/m·K), low TES density (less than 200 kJ/kg), low TES efficiency, and low system reliability. These problems have become bottlenecks restricting the development of CSP, heating, waste heat recovery, and other related technologies. Therefore, it is imperative to develop TES technologies with high efficiency and high reliability.

This project aims to break through traditional thinking patterns and conduct research on heat storage, transfer and release processes based on multiple disciplines including heat transfer, materials science, and bionics. An integrated volume method for solar energy conversion and storage has been proposed; the mechanisms of transmission of multi-scale photons and phonons in bionic porous materials have been investigated; a method for preparing bionic porous composites under controlled conditions and improving the reliability of such composites has been established; bionic optimization has been carried out at multiple levels (material-unit-system) to overcome the restrictions of conventional methods; revolutionary TES materials characterized by high TES density, quick response, and high reliability have been developed; and a dynamic control strategy for long-life high-reliability, and high-efficiency TES systems has been established.

In 2024, the project made a series of important progresses and original research achievements: (1) An integrated volume method for solar energy conversion and storage was proposed, with a solar energy absorption efficiency of 96.2%; (2) based on the mechanisms of transmission of multi-scale photons and phonons in bionic porous materials, the thermal conductivity of the designed bionic porous materials and composite structures reached 26.6 W/(m·K); (3) three kinds of TES composites were designed, with TES densities of 690 kJ/kg, 918 kJ/kg and 1,167 kJ/kg at a temperature difference of 200℃ ; (4) a method for preparing bionic porous composites under controlled conditions and improving the reliability of such composites was proposed. As a result, the cycle life of designed TES composites is over 5,200 times, and the performance attenuation is only 6.7%; (5) a dynamic control strategy for long-life high-reliability, and high-efficiency TES systems was established. As a result, the designed TES systems have a cycle life of 5,300 times. The related achievements have won one first prize of Jiangsu Science and Technology Award.

5.1.3 Broadband metasurface solar concentrators and solar collection systems

CSP technology has the advantages of low TES cost and easy adjustment of basic power load of power grid, and is an ideal renewable energy power generation technology. Existing solar concentrators require the use of high-

precision paraboloids and complex solar trackers, resulting in high operation and maintenance costs, which restricts the rapid development of the CSP industry. This project aims to develop planar metasurface solar concentrators, change the original space-controlled solar concentration mode of existing parabolic concentrators to phase-controlled solar concentration to effectively concentrate broadband solar radiation at a wide angle, eliminate the need of solar tracking, and reduce the operating costs of solar concentrators.

The important achievements made are as follows:

(1) The focusing performance has been optimized by guiding the reflection perfect focusing into the transmission perfect focusing with symmetric materials, and the transmission concentration efficiency can reach 90%; a double-layer structure consisting of a gold cylinder and a titanium dioxide cylinder has been designed to control the angular dispersion, achieving the elimination of angular chromatic aberration and focusing of 800 nm incident light at 0°-30°; the quadratic phase distribution formula has been constructed, achieving the wide-angle wide-field focusing imaging focusing of incident light with wavelength of 1,310-1,550 nm at 0°-45°; a software for numerical modeling and performance analysis and calculation of large-scale planar metasurface mirrors has been developed based on the equivalent macroscopic parameter model of geometrical optics.

(2) The nano-transfer printing technologies of metasurface concentrators and nanoimprinting stripping etching technologies of double-layer adhesives have been developed, solving the problem of difficult stripping of nanoimprinting adhesives in the dissolution stripping process, with the transfer accuracy of hard mask of ≤ 0.05 um; a roll-to-roll nanoimprinting system integrating uniform gluing, imprinting, curing and demoulding has been developed, with the imprinting area of 400 mm × 600 mm; the etching equipment and process has been updated, achieving the uniformity of etching depth distribution less than 3%.

(3) The thermal stress distribution of the receiver tubes has been comprehensively simulated by "light-heat-force", and the scheme design of the double-coated vacuum receiver tubes has been completed; based on the theory of transformation optics, the optical cavity of electromagnetic black hole has been designed and realized, which obviously inhibits the radiation loss of light. Based on the theory of "negative energy flow zone", new progressive adaptive eccentric double-coated solar collection loops with the best eccentric double-coated receiver tubes have been applied in different positions, which can increase the electric output by up to 12.74% in areas with large radiation heat loss and anti-condensation heat loss. A two-tank MS experimental system capable of providing 290℃ -400℃ MSs and receiving 290 ℃ -570 ℃ MSs, has been developed, and can meet the experimental requirements of planar metasurface solar collection system.

5.1.4 Theory and method for high-flux solar-to-chemical energy conversion and storage

This project aims to overcome the bottlenecks of conventional solar TES systems such as low TES density and low heat release temperature and study high-efficiency solar-to-chemical energy conversion and storage technologies with high TES density, high heat release temperature, and long life cycle. A series of innovations and key technologies

(as detailed below) have been achieved in numerous areas such as the mechanism of multi-field coupled energy storage, composition and production of energy carriers, solar thermochemical reaction unit and operation control, TES system integration and evaluation.

In 2024, this project aims to overcome the bottlenecks of conventional solar TES systems such as low TES density and low heat release temperature and study high-efficiency solar-to-chemical energy conversion and storage technologies with high TES density, high heat release temperature, and long life cycle. A series of innovations and key technologies (as detailed below) have been achieved in numerous areas such as the mechanism of multi-field coupled energy storage, composition and production of energy carriers, solar thermochemical reaction unit and operation control, TES system integration and evaluation.

(1) The theory of thermochemical conversion synergistically enhanced by multi-scale coupling of multiple fields including light, heat, force, flow, chemical and sound fields under non-steady high-flux light-concentrating conditions has been established, and the related mathematical model has been built. The errors in modeling and experimental results are less than 8.67%.

(2) An experimental platform for testing long heat absorption and release cycles of calcium-based energy carriers has been built based on a 2.2 kW solar concentrator simulator, a method for fabricating and producing high-performance chemical energy carriers has been established, and a variety of high-performance chemical energy carriers have been successfully developed. For these energy carriers, the reaction temperature is 800°C, the initial energy storage density is 1311 kJ/kg, and the performance degradation after 2000 cycles is 29.2%.

(3) A direct moving bed endothermic reaction unit with a conversion rate of 85.7% and its experimental test system have been built, a bubbling fluidized bed exothermic reaction unit and its experimental test system have been built, with the average bed temperature of 783°C, peak temperature of 848.9°C, a conversion rate of 90.12% and system efficiency of 77.9%; and a scheme for real-time control of the endothermic and exothermic reaction units and a scheme for adjusting/controlling the structure of energy carriers have been developed.

(4) An outdoor high-flux solar concentration and tracking unit with thermal power of 27 kW and peak heat flux density of 1.9 MW/m^2 has been built; the implementation plan for an integrated high-efficiency solar thermochemical TES system (an integrated demonstration system) that combines solar concentration and collection with chemical TES has been completed; and a platform for onsite dynamic performance testing of the high-efficiency solar thermochemical TES system has been built, for which the measurable temperature is 1,100℃ , the measurable energy flux density is 3 MW/m^2, and the frame rate is 10,000 frames per second.

The advancements and achievements listed above provide strong support for the construction of subsequent demonstration systems of the project.

5.1.5 Development and application of HT molten salt resistant special alloys for CSP systems

This project aims to meet the needs of low-cost efficient power generation and sustainable development of the CSP industry by studying key scientific topics such as composition optimization and microstructure control for HT alloys/stainless steels, corrosion control for special alloys in HT molten salt environments, the design of heat resistant coatings, and the coupling mechanism of multiple photophysical effects, developing special alloys, HT molten salts, heat absorbing coatings, and other critical materials required for heat collection, storage and exchange units/components of next-generation CSP systems, making technological breakthroughs in batch production of materials, and finally achieving the integration of critical materials into CSP systems and the application of demonstration CSP systems.

The main research achievements of this project are detailed below. The high-homogeneity ingot smelting-plate/tube adding-welding whole process technologies and low-cost bimetallic composite technologies of GH3539 alloy and new type in-situ precipitation oxide strengthened stainless steel resistant to 800 ℃ MS corrosion have been successfully developed; based on thermodynamic calculation and experimental verification, two kinds of high stability and low corrosion MSs have been prepared by MS formula control combined with corrosion inhibition and purification technology. By combining three strategies of alloying metal nanoparticles, modifying amorphous parent phase network, and introducing diffusion barrier layers, a long tube outer wall coating technology with component structure regulation, multieffect coupling, and interface strengthening has been developed to break the bottleneck of existing absorption coatings that cannot balance optical performance and thermal stability. The 600℃ high-temperature MS receiver tubes have been demonstrated and applied successfully in the Aksai parabolic trough solar collection testing platforms by integration of the above achievements.

5.1.6 Wide-temperature-range HT molten salt TES technology

This project aims to meet the needs of electric/heat pump TES power generation, energy storage and peak shaving plants, deep peak shaving systems of thermal power plants, new-generation CSP systems, and multi-energy complementary energy systems for large-capacity and long-term TES storage under high temperature conditions, make breakthroughs in key technologies for the optimal design of wide-temperature-range HT molten salt TES systems, molten salt mixtures with low melting point, high decomposition temperature, low cost and low corrosivity, large-capacity HT molten salt storage tanks and their foundations, HTHP high-differential-pressure molten salt heat exchangers, HV molten salt heaters, and system integration and control, and complete the verification and demonstration of the 10 MWh HT molten salt TES system.

In 2024, the project team developed quaternary nitrate and carbonate MS mixtures with a melting point of 142℃ and a decomposition temperature of 711 ℃ , and obtained the influence rules of the size, concentration and types of nanoparticles on the thermal properties of ternary nitrate and carbonate MS nanofluids, and tested the thermal stability of ternary nitrate and carbonate MS nanofluids; developed new electric heating elements with high temperature resistance (normal temperature to 660℃) and high voltage resistance (6 kV AC), obtained the optimized design schemes of shell-

and-tube MS electric heaters with segmental baffles and multi-shell pass spiral coil MS-water/steam heat exchangers, and screened out the structural schemes and storage tank design schemes of 660℃ high-capacity high-temperature MS storage tanks and their foundations suitable for 10 MWh and 100 MWh respectively; innovatively proposed the electric storage systems of Brayton cycle heat pumps (two-stage adiabatic compression, adiabatic + isothermal compression), deep peak shaving systems coupled with fire and storage (segmented TES and steam compression after TES) and CSP systems (segmented TES) based on new high-temperature MSs, which reveals the energy coupling, transmission and loss mechanism of each system and verifies that the use of new high-temperature MS instead of solar salt can significantly improve the efficiency and economy of the new energy system coupled with MS TES; proposed the technical scheme of frequency modulation assisted by MS system and modular power adjustment scheme, and initially built the demonstration project of frequency modulation and peak shaving safety heating based on MS TES in Huaneng Haimen Plant. The 10 MWh MS TES verification platform has been commissioned at 565℃ using solar salt.

5.1.7 Research on key technologies for stable power output of CSP-PV hybrid plants with reflective secondary concentrators

This project aims to develop a novel solar concentration technique with reflective secondary concentrators, key components for integrated heat absorption/collection, storage and exchange, and a high-parameter, high-flexibility supercritical CO_2 power generation technology; establish a capacity allocation and scheduling method for CSP-PV hybrid plants; achieve low-cost stable operation and grid connection of CSP plants.

In 2024, the project team completed the independent design, development and experimental testing of new heliostat components, heliostat field closed-loop control systems, solar absorption/TES/heat exchange integrated components, etc., carried out the theoretical analysis of the optimal matching between the operation characteristics of supercritical CO_2 power cycle and the TES/release characteristics under various system configurations, and jointly studied the PV output and the coupling characteristics of CSP output and grid-connected dispatching characteristics of the CSP-PV hybrid plants. The project team completed the exchange visits and mid-term assessment in China and Spain, and jointly applied for 5 patents and published 6 papers, including 3 SCI papers. In the future, the project team will continue to deepen the technology cooperation and academic exchanges between China and Spain in areas such as heliostat fields, solar absorption, TES and heat exchange properties of solid particles, improvement of the efficiency of supercritical CO_2 power cycles, and optimization methods and control strategies for capacity allocation of CSP-PV hybrid plants, to realize the low-cost stable output of solar power and the grid connection of clean power.

5.1.8 Mechanics research and service life prediction for HT molten salt storage tanks in CSP systems

This project aims to solve the problems caused by corrosion and thermal fatigue in HT molten salt storage tanks under complex operating conditions, such as leakage, failure, and reduction in service life; carry out mechanics research and service life prediction for HT molten salt storage tanks; experimentally verify and optimize the service life prediction model; develop a structural design software suite capable of predicting service life based on the engineering

practices of commercial CSP plants; overcome technical difficulties in predicting the service life of large-capacity molten salt storage tanks; and provide technical guidance for assessing the service life of molten salt storage tanks at CSP plants, optimizing the structural design of molten salt storage tanks, and ensuring the safe operation of molten salt storage tanks.

In 2024, the project team experimentally verified and optimized the service life prediction model, developed a structural simulation design software suite capable of predicting service life based on the engineering practices of commercial CSP plants, overcame technical difficulties in predicting the service life of large-capacity MS storage tanks, and provided technical guidance for assessing the service life of MS storage tanks at CSP plants, optimizing the structural design of MS storage tanks, and ensuring the safe operation of MS storage tanks. The main achievements of the project are detailed below.

(1) Based on the temperature test data of HT molten salt storage tanks at commercial solar tower plants and parabolic trough CSP plants, the distribution characteristics and patterns of temperature fields in molt salts and storage tanks have been studied to provide supporting data from boundary load analysis for investigating the mechanical properties of molt salt storage tanks.

(2) A numerical model for making structural and temperature field calculations of MS storage tanks has been built, and the stress distribution response of key parts of MS storage tanks under the static and dynamic change conditions of thermal energy charge and release has been analyzed, which provides a theoretical reference for the strain test research of storage tanks, and the stress test of MS storage tanks during the operation of 50 MW parabolic trough CSP plants has been completed.

(3) Based on the structural characteristics and operating conditions of molten salt storage tanks, the theoretical basis for predicting the service life of molten salt storage tanks has been investigated, and the theories of fatigue strength of the nominal stress and structural strain methods have been studied.

(4) The mechanical properties of MS storage tank materials and welds have been tested.

(5) The prototypes of MS storage tanks have been processed, the platform for accelerated fatigue life testing of MS storage tanks is being built, and the fatigue testing plan of storage tanks has been determined.

(6) Based on the structures and operating conditions of MS storage tanks in the 50 MW solar tower plant, the numerical simulation of the thermal-mechanical properties of MS storage tanks has been completed in cooperation with NREL.

On the basis of this research, China and the United States have once again cooperated, and successfully applied for the research project of MS storage tanks funded by IEA SolarPACES in collaboration with DLR, CIEMAT and CSP Energies.

5.1.9 Progress in the first year of the national key R&D project "Research on Key Issues of Cement Clinkers and Ceramics Prepared by Solar High-power Flexible Concentration" of "Renewable Energy Technology"

In response to the problem of high carbon emissions from fossil fuels in the high-temperature preparation process of cement clinkers and ceramics in the building materials industry, the project team proposed to directly burn cement/ceramic materials by concentrating solar radiation multiple times to form high-density energy flow. Through precise control of energy flow, the energy and temperature parameters required for the cement clinkers and ceramic firing process can be met, and the technology of direct preparation of cement clinkers and ceramics with high-power solar concentration can be achieved. The phased achievements made include:

(1) In the aspect of solar concentration system, this project established a design model for a secondary reflection concentrator, proposed a configuration scheme for rotating ellipsoidal and hyperbolic heliostat fields, analyzed the influence rules of composition, geometric structure parameters, and curved surface shape of the solar concentration system on the energy flow density distribution of the reactor focal plane, and preliminarily completed the design scheme for the solar concentration system.

(2) In the aspect of physical and chemical reactions of silicates under concentrator-driven mode, the project team built a platform for testing physical and chemical reactions of silicates by concentrating solar simulators, studied the absorption performance of cements and ceramic materials and their different temperature stages on solar spectra, and investigated the influence rules of high-energy high-density photons on the properties and microstructures of ceramic rock slabs and Portland cements.

(3) In the aspect of reactor design, the project team analyzed the relationship between concentrated energy flow density, material temperature, and material residence time, revealing the influence rules of discontinuous sintering on the quality and performance of Portland cement clinkers; analyzed the operation mode of cement clinkers and ceramic reactors under varying solar concentrating conditions, and preliminarily completed the design of cement clinker reactors and ceramic reactors.

(4) In the aspect of solar-powered cement clinker/ceramic kilns, the project team studied the process parameters of the solar-powered cement/ceramic kiln systems, preliminarily completed the mass heat balance calculations of the entire process of preheating, decomposition, sintering, and cooling in the preparation of cement clinkers/ceramics, and preliminarily determined the overall integrated design scheme of the solar-powered cement clinker and ceramic kilns.

The research achievements of the project are helpful to upgrade the high-energy consumption and high-carbon emission industries, help the development of green and low-carbon circular development of building materials industry system, and hopefully provide a new technical path for the green and low-carbon development technology direction of building materials industry at home and abroad.

5.10 Research on wind load fluctuation characteristics and wind-induced vibration characteristics of heliostat structures of solar tower plant

With the deepening of energy transition in various countries in the world, China, Spain and other countries are investing heavily in constructing solar tower plants. Heliostat field is an important constituent part of solar tower plant, and its investment accounts for about half that of the plant. However, solar tower plants are often built on open and

flat sites with weak obstruction effect, and heliostat structure shows obvious blunt body effect in fluid, which easily causes local damage and deformation of the mirror surface and support structure under the wind load effect, causing uneven heat flux of receiver and light overflow, thereby seriously reducing the power generation efficiency of the plants. Therefore, in order to ensure stable and efficient operation of the plants, heliostat should meet the requirements of high mirror reflectivity, profile error controlled in certain range, high overall mechanical strength, normal working under the action of force 6 wind and resistance to force 10 wind, which are the key of sustainable operation of solar tower plant at present.

The Project aims to systematically study the wind load distribution rules of tower heliostat structure under multiple conditions and the causes, define the key influencing factors, reveal the interference effect of heliostats, expound the characteristics of wind pressure fluctuation on mirror surface, analyze the dynamic response of heliostat structure in combination with the wind pressure time history information, propose the method of calculating equivalent wind load, achieve intelligent analysis of heliostat field optimization and wind-resistant design for solar tower plant, and form the domestic and international application demonstration cases of sustained and efficient service of heliostat field, hence providing scientific basis and technical support for wind-resistant design and long-term stable operation of solar tower plant.

In 2024, the Project focused on studying the scientific problems of the characteristics of wind pressure distribution on the heliostat surface and the causes, the interference effect of radial arrangement of heliostats and the impact of wind-induced vibration on the concentration efficiency of heliostats. It built the numerical wind tunnel by wind tunnel test and secondary development of User Defined Function (UDF), to analyze the influence rules of elevation angle and wind direction angle on the wind pressure distribution on the heliostat surface, reveal the action mechanism of each factor on wind load, study the aerodynamic characteristics of heliostat structure and its influence on the bottom of column, define the most unfavorable design conditions, and establish the structural shape factor value of wind load in wind resistance design. On such a basis, it discussed the interference effect of radial arrangement of heliostats and defined the interference rules of heliostat field under radial arrangement in combination with the streaming characteristics of flow field. It established the concentration efficiency model of wind-induced vibration of heliostat based on random sampling ray tracing, and analyzed the influences of wind-induced vibration on the concentration efficiency, wind load and fluctuation characteristics of mirror displacement.

5.11 Research and industrial verification of coal and solar thermal coupling power generation technologies

In 2024, the Project carried out in-depth study on key technologies including the coupling integration technology of coal and photothermal coupling power generation system, the design of new MS TES heat exchanger and high-temperature MS storage tank, energy regulation of heliostat field and key parameters monitoring of MS solar receiver, energy saving in transient process of hybrid power generation system and flexible and efficient coordinated regulation, to get a series of innovation achievements and key technologies, detailed as follows:

(1) Based on 660 MW ultra-supercritical coal-fired unit, it proposed a kind of solar power-coal hybrid power generation system with integrated TES which takes high efficiency and peak shaving flexibility into account, and its operation strategy, to improve the flexibility of coal-fired units through relatively small TES system, expand the operating interval of unit and improve the consumption of renewable energy. The results indicated that, the standard coal consumption of solar power-coal hybrid power generation system coupling 30 MW CSP under low load is 12 kg/kWh. When the new system runs under 30% boiler maximum continuous rating (BMCR) condition with the main steam extracted and load reduced, the peak regulation capacity is 18.22 MW and the peak shaving depth is 2.8%.

(2) The project team researched and developed a kind of ternary mixed MS with melting point of 98.11°C, primary crystal point of 110.20°C and decomposition temperature of 582.1°C. According to relevant national standards, the recommended liquid operating temperature range of optimized mixed MS is 150-550°C, and the thermophysical properties of mixed MS are obtained in experiment. High and low temperature thermal shock test, high temperature constant temperature test and high temperature constant temperature weight loss test proved that, optimized mixed MS can satisfy the expected goals of power generation by solar concentration and solar collection, as well as full heat recovery from steam extraction in thermal power plant.

(3) The engineering design plans of typical solar power-coal hybrid power generation system were proposed. One is the deep peak shaving scheme of energy flow decoupling of boiler and furnace based on 660 MW coal-fired unit integrated with 30 MW CSP, and through calculation, its standard coal consumption per kWh is reduced by > 3 g/kWh, and its energy (power generation) reuse rate is 77.38%; the other is the engineering design scheme of solar power-coal hybrid power generation system based on 660 MW coal-fired unit integrated with 30 MW CSP, with the standard coal consumption per kWh reduced by > 3 g/kWh, and the internal rate of capital return reaching 5.98%.

(4) A kind of energy saving technology in transient process regulated by energy-to-working medium ratio with consideration to heat storage change rate was proposed, with variable load rate of 15 MW/ min and transient energy saving potential of 0.61 g/kWh. A kind of control strategy integrating the heat storage characteristics of boiler-solar collector system was proposed, which improved the variable load rate of unit, with limit variable load rate reaching 4% Pe/min.

(5) The method of calculating the theoretical peak shaving limit of solar-assisted coal-fired system was developed and the wide-load flexible steam turbine scheme was proposed, including the flexible operation design scheme of main and auxiliary turbines, which revealed the system performance change rules of solar-assisted coal-fired tower power generation system under different operation modes and coupling modes.

The advancements and achievements listed above provide strong support for the construction of subsequent demonstration systems of the project.

5.2 CSP standards

5.2.1 National standards

According to the rough statistics of CSTA, as of 2024, there are 7 published national standards related to CSP, 5 CSP-related national standards under approval, and 4 CSP-related national standards under preparation or revision; as of the end of 2024, China has published 41 standards related to CSP (including thermal energy utilization).

Table 5.2-1 CSP-related Chinese National Standards Published or Under Approval in 2024

No.	Standard	Prepared by	Managed by	Issued on
1	Technical Requirements for Thermal Energy Storage/ Heat Transfer Media of Solar Thermal Power Plants- Part 1: Molten Salt (GB/T44800-2024)	Cosin Solar Technology Research Institute Co., Ltd., Beijing University of Technology, Cosin Solar Technology Co., Ltd., CGN Wind Energy Limited, North China Electric Power University	National CSP Standardization Technical Committee	October 26, 2024
2	Technical Requirements for Heliostats at Solar Tower Plants (GB/T44140-2024)	Cosin Solar Technology Co., Ltd., CGN Wind Energy Limited, Zhejiang Cosin Solar CSP Technology Research Institute Co., Ltd., Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, North China Electric Power University, and China Energy Construction Group Shaanxi Electric Power Design Institute Co., Ltd.	National CSP Standardization Technical Committee	June 29, 2024
3	Technical Requirements for Heat Collection Systems of Solar Power Tower Plants (GB/T44422-2024)	Cosin Solar Technology Co., Ltd., Zhejiang Cosin Solar CSP Technology Research Institute Co., Ltd., Ltd., Xi'an Thermal Power Research Institute Co., Ltd., CGN Wind Energy Limited, Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, North China Electric Power University, and China Energy Construction Group Shaanxi Electric Power Design Institute Co., Ltd.	National CSP Standardization Technical Committee	July 24, 2024
4	Code for Operation of Solar Tower Plants (GB/T44079-2024)	CEEC (China Energy Engineering Corporation Limited) Technology Development Co., Ltd., Beijing Nengmai Technology Co., Ltd., Qingdao Huafeng Weiye Electric Power Technology Engineering Co., Ltd., Engineering Research Institute of China Energy Engineering Group Co., Ltd., Zhejiang University, SunCan Co.,Ltd., China Huadian Engineering Co. Ltd., BJ Energy International Holdings Co., Ltd., and Beijing North-Star Technology Development Co., Ltd.	National CSP Standardization Technical Committee	May 28, 2024

No.	Standard	Prepared by	Managed by	Issued on
5	Technical Requirements for Thermal Energy Storage/ Heat Transfer Media of Solar Thermal Power Plants- Part 1: Molten Salt	Cosin Solar Technology Research Institute Co., Ltd., Beijing University of Technology, Cosin Solar Technology Co., Ltd., CGN Wind Energy Limited, North China Electric Power University	National CSP Standardization Technical Committee	October 20, 2024
6	Technical Requirements for Grid Connection, Scheduling and Operation of Solar Thermal Power Plants (GB/T44788-2024)	China Electric Power Research Institute, State Grid Corporation of China Limited, State Grid Qinghai Electric Power Company, State Grid Gansu Electric Power Co., Ltd., and State Grid Xinjiang Electric Power Co., Ltd.	National CSP Standardization Technical Committee	October 26, 2024
7	Technical Standard for Fresnel CSP Plants (GB/T51467-2024)	China Electricity Council, Beijing TeraSolar Photothermal Technologies Co., Ltd., with participating units including China Energy Engineering Group Northwest China Electric Power Test Research Institute Co., Ltd., North China Power Engineering Co., Ltd. of China Power Engineering Consulting Group, Inner Mongolia Electric Power Survey & Design Institute Co., Ltd., Hebei Electric Power Engineering Co., Ltd., China Gezhouba Group Electric Power Co., Ltd., Shandong Huiyin New Energy Technology Co., Ltd., Royal Tech CSP Limited and Shandong Electric Power Construction Corporation III (SEPCOIII)	Ministry of Housing and Urban-Rural Development	December 26, 2024
Prepared by CSTA				

Table 5.2-2 CSP-related National Standards under Preparation or Revision in 2024

No.	Standard	Prepared by	Managed by	Project progress
1	Technical Requirements for Molten Salt Thermal Energy Storage Systems of Solar Thermal Power Plants (20230049-T-524)	Cosin Solar Technology Co., Ltd., Zhejiang Green Storage Technology Co., Ltd., CGN Wind Energy Limited, Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, Beijing University of Technology, and Shandong Electric Power Engineering Consulting Institute Corp., Ltd.	National CSP Standardization Technical Committee	Under approval

No.	Standard	Prepared by	Managed by	Project progress
2	Technical Specifications for Master Control Systems of Solar Tower Plants (20221275-T-524)	CEEC (China Energy Engineering Corporation Limited) Technology Development Co., Ltd., Engineering Research Institute of China Energy Engineering Group Co., Ltd., Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, Zhejiang University, and China Power Construction Engineering Consultants Company	National CSP Standardization Technical Committee	Under approval
3	Specifications for Solar Energy Resource Assessment of Solar Power Plants (20204028-T-416)	Public Meteorological Service Center, China Meteorological Administration, Beijing Goldwind Technology Co., Ltd., China Huadian Engineering Co. Ltd., TBEA Sunoasis Co., Ltd., Anhui Meteorological Public Service Center, Huadian Zhong Guang New Energy Technology Co., Ltd., and Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group	National Climate and Climate Change Standardization Technical Committee	Under approval
4	Characteristics of Direct and Indirect Active Sensible Heat Storage Systems of Solar Thermal Power Plants (20214675-Z-524)	Cosin Solar Technology Co., Ltd., CGN Wind Energy Limited, China Datang Corporation Technology Innovation Co., Ltd., Zhejiang Cosin Solar CSP Technology Research Institute Co., Ltd., Huaneng Clean Energy Research Institute, China State Shipbuilding Corporation Haizhuang Windpower Co., Ltd., Royal Tech CSP Limited and North China Electric Power University	National CSP Standardization Technical Committee	Under approval
5	CSP Plants — Part 3-2: Systems and Components - General Requirements and Test Methods for Large-size Parabolic Trough Collectors (20230050-T-524)	Royal Tech CSP Limited, China Datang Corporation Science and Technology General Research Institute Ltd., China Datang Corporation Technology Innovation Co., Ltd., and CGN Wind Energy Limited	National CSP Standardization Technical Committee	Under approval

No.	Standard	Prepared by	Managed by	Project progress
6	Test Method for Determining the Heat Loss Coefficient of Parabolic Trough Receiver Tubes (Plan No.: 20231000-T-469)	IEECAS, Royal Tech CSP Limited, Grimat Engineering Institute Co., Ltd., Beijing TRX Solar Technology Co., Ltd., Shandong Huiyin New Energy Technology Co., Ltd., Lanzhou Dacheng Technology Co., Ltd., Beijing Sunda Solar Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., CGN New Energy Holdings.Co., Ltd., China State Shipbuilding Corporation New Energy Co., Ltd., etc.	National CSP Standardization Technical Committee	Under opinions solicitation
7	Technical Specifications for Field Control Systems of Solar Tower Plants (Plan No.: 20241801-T-524)	Cosin Solar Technology Co., Ltd., Zhejiang Cosin Solar CSP Technology Research Institute Co., Ltd.	National CSP Standardization Technical Committee	Drafting
8	Risk-based Inspection Rules for Complete Set of Units - Part 4: Parabolic Trough CSP Plants (Plan No.: 20240112-T-469)	China Special Equipment Inspection & Research Institute	China Standardization Committee on Boilers and Pressure Vessels	Drafting
9	Code for CSP Projects	/	Ministry of Housing and Urban-Rural Development of the People's Republic of China	Opinions solicitation completed
Prepared by CSTA				

5.2.2 Industrial standards

On June 28, NEA released the Notice on Soliciting Public Opinions on the Proposed Industry Standard Preparation and Revision Plans Project and Translation Plans Project in Foreign Language for the Energy Field in 2024, of which the Proposed Industry Standard Preparation Plans Project for the Energy Field in 2024 covers 24 standards related to CSP [35]. According to the rough statistics of CSTA, as of 2024, there are 30 national standards related to CSP industry already published or under preparation or revision.

Table 5.2-3 CSP-related Industry Standards for the Energy Sector Prepared in 2024

No.	Standard	Prepared by	Scope of application and main content
1	Estimate Quota of CSP Project	China Renewable Energy Engineering Institute (Renewable Energy Quota Station), PowerChina Northwest Engineering Corporation Limited, Electric Power Planning & Engineering Institute Co., Ltd., Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, PowerChina Zhongnan Engineering Corporation Limited, and Cosin Solar Technology Co., Ltd.	This document is applicable to budget estimate (estimation) preparation of construction, renovation and expansion projects of parabolic trough CSP plants, solar tower plants and linear Fresnel CSP plants, and can be used as a reference for engineering budget estimates (estimations) employing other CSP forms.
2	Design of Heat Storage System for CSP Plant	CPECC Northeast Electric Power Design Institute Co., Ltd.	This document is applicable to the design of hot water TES system and solid TES system for newly built, expanded and renovated CSP plants.
3	Technical Conditions and Test Methods for Flexible Connection Modules of Parabolic Trough CSP Plants	CGN New Energy Investment (Shenzhen) Co., Ltd., National Energy Solar Center, CGN Delingha New Energy Co., Ltd., Jiangsu Haofeng Pipeline Equipment Co., Ltd., and Grimat Engineering Institute Co., Ltd.	This document is mainly applicable to flexible connection modules of parabolic trough CSP plants, and its main technical contents include the type of rotary joints, technical parameters and test methods, identification, packaging, transportation and storage.
4	Technical Regulations for Installation and Commissioning of Collectors for Parabolic Trough CSP Plants	CGN New Energy Investment (Shenzhen) Co., Ltd., National Energy Solar Center, CGN Delingha New Energy Co., Ltd., China Datang Corporation Renewable Power Science and Technology Research Institute Co., Ltd., Royal Tech CSP Limited, and Beijing Shouhang IHW Resources Saving Technology Co., Ltd.	This document is mainly used to formulate the technical regulations for installation and commissioning of the collectors for parabolic trough CSP plants, and applicable to the collectors of parabolic trough CSP plant, including the basic requirements on the collector foundation, technical installation requirements for hoisting, positioning and fixation of collector column, technical installation requirements for hoisting, positioning and fixation of collector modules, technical requirements for installation of receiver tubes, and technical requirements for testing and trial operation of collectors after installation. This standard is inapplicable to the technical regulations for parts manufacturing and assembly of parabolic trough collector.

No.	Standard	Prepared by	Scope of application and main content
5	Code for Implementation of Work Safety Standardization in CSP Plants	China Energy Engineering Investment Corporation Limited	This document specifies the principles and general requirements for the establishment, maintenance and evaluation of work safety standardization management system of CSP plants, as well as the core technical requirements of eight system elements: target responsibility, institutionalized management, education and training, site management, graded safety risk control and potential hazard investigation and management, emergency management, incident (accident) management and continuous improvement. It is applicable to the construction of work safety standardization of CSP plants.
6	Specification for Acceptance of Heat Collection Systems of Linear Fresnel CSP Plants	China Longyuan Power Group Corporation Limited	This document specifies the construction quality inspection, acceptance and engineering construction quality management and control of the solar collection systems of Fresnel CSP plants.
7	Rotary Transmission for Solar Tower Plant Tracking JB/T 14689-2024	Hangzhou Sino-Deutsche Power Transmission Equipment Co., Ltd., Jiangsu Zhonggong Research Institute of Advanced Equipment Co., Ltd., Zhengzhou Machinery Research Institute Co., Ltd., Chongqing University, Jiangsu Province Product Quality Supervision and Inspection Center, National Gear Product Quality Inspection and Testing Center, ZRIME Gearing Technology Co., Ltd., ESSOR PRECISION MACHINERY INC., Shanghai SGR Heavy Industry Machinery Co., Ltd., and Cosin Solar Technology Co., Ltd.	This document specifies the model, basic parameters, overall dimensions and technical requirements of rotary transmission for solar tower plant tracking, describes the corresponding testing method and stipulates the inspection rules, signs, packaging, transportation and storage conditions.
8	Code for Design of Molten Salt Pipeline	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, PowerChina Northwest Engineering Corporation Limited, Electric Power Planning & Engineering Institute Co., Ltd., and China Renewable Energy Engineering Institute Co., Ltd.	Scope of application: This standard is applicable to the design of MS pipelines for CSP plants adopting binary MS ($60\%NaNO_3+40\%KNO_3$) as HTF or TES medium, TES and peak shaving units, and compressed-air energy storage plants. The design of other pipelines adopting nitro MS as the medium can implement with reference to this document. Main technical contents: basic provisions, selection and calculation of piping components, pipeline layout, hydraulic calculation, pipeline stress analysis and calculation, support and hanger design, etc.

No.	Standard	Prepared by	Scope of application and main content
9	Code for Design of Thermal Switching Quantity and Analog Quantity Control System for CSP Plants	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group,	This document is applicable to the design of thermal switching quantity and analog quantity control system for newly built, expanded and renovated CSP plants. This document specifies the Code for Design of Thermal Switching Quantity and Analog Quantity Control System for CSP Plants.
10	Specification for Acceptance of Solar Collection Systems of Linear Fresnel CSP Plants	Longyuan (Beijing) New Energy Engineering Design and Research Institute Co., Ltd., China Datang Corporation Technology Innovation Co., Ltd., China Datang Corporation Science and Technology General Research Institute Ltd., Shanghai Survey, Design and Research Institute Co., Ltd., PowerChina Hebei Electric Power Engineering Co., Ltd., Gansu Longyuan New Energy Co., Ltd., and China Longyuan Power Group Corporation Limited.	This document is applicable to newly built, expanded and renovated Fresnel CSP plants. This document specifies the main technical requirements for construction engineering acceptance of linear Fresnel CSP plants.
11	Guidelines for Post-evaluation of CSP Plant Projects	Shanghai Survey, Design and Research Institute Co., Ltd.	This document is applicable to newly built, expanded and renovated on-grid CSP plants. This document specifies the principles, scope and contents of post-evaluation of CSP plant projects.
12	Guidelines for Construction Organization Design of CSP Projects	Shanghai Survey, Design and Research Institute Co., Ltd.	This document is applicable to newly built CSP projects. This document specifies the general provisions, construction organization and staffing, comprehensive construction progress, construction general layout, temporary facilities and site for construction, construction force supply, main method statement and special construction measures, quality management, occupational health and safety management and environmental management, civilized construction, application of computer network, etc.

No.	Standard	Prepared by	Scope of application and main content
13	Specification for Acceptance of Solar Collection Systems of Parabolic Trough CSP Plants	CGN Solar Energy Development Co., Ltd., SEPCOIII Electric Power Construction Co., Ltd., and China Datang Corporation Technology Innovation Co., Ltd.	This document is applicable to the construction quality acceptance of newly built, expanded and renovated parabolic trough solar collection system. This document specifies the construction progress management of solar collection system of parabolic trough CSP plants, overall comprehensive evaluation of construction quality, integrity of construction process, on-site spot check and quality grading. According to the evaluation and inspection results, it can perform quality control over concentrator and collector units, receiver tubes, reflective mirror and its supporting structures and other key components.
14	Specifications for Supervision of Collector Units of Parabolic Trough CSP Plants	CGN Solar Energy Development Co., Ltd.	This document is applicable to the supervision of collectors for CSP plants, involving the production and assembly quality control of concentrator and collector units, receiver tubes, reflective mirror and its supporting structures and other key components. This document specifies the definition of the responsibilities of all supervision parties, specifications for supervision process, quality control points of key components and supervision requirements for finished products. Specific technical requirements cover material selection, production and processing, assembly, welding, cladding, reflective mirror shape and dynamic balancing testing of receiver tubes, to ensure effective supervision of design, manufacturing, assembly and testing links of collectors, so as to meet the operating and performance requirements.
15	Standard for Quality Evaluation of CSP Plant Projects	PowerChina Hebei Electric Power Engineering Co., Ltd., PowerChina Northwest Engineering Corporation Limited, and China Datang Corporation Technology Innovation Co., Ltd.	This document is applicable to the construction quality evaluation of newly built, expanded and renovated CSP projects. This document specifies the construction quality inspection and evaluation.

No.	Standard	Prepared by	Scope of application and main content
16	Code for Supervision of CSP Projects	Guangdong Chuangcheng Construction Supervision Consulting Co., Ltd., Zhejiang Electric Power Construction Supervision Co., Ltd., Fujian Minneng Consulting Co., Ltd., China Datang Corporation Technology Innovation Co., Ltd., China Datang Corporation Science and Technology General Research Institute Ltd., Hu'nan Electric Power Construction Supervision Consultation Co., Ltd., SinoDaan Co., Ltd., Zhongnan Electric Power Project Management Consulting (Hubei) Co., Ltd., Xinjiang Electric Power Engineering Supervision Co., Ltd., Inner Mongolia Electric Power Survey & Design Institute Co., Ltd., China Energy Engineering Group Xinjiang Electric Power Design Institute Co., Ltd., and JAKS HAI DUONG Power Company Limited.	This document is applicable to the supervision of solar tower plant, parabolic trough CSP plant, linear Fresnel CSP plant and parabolic dish CSP projects. This document specifies the personnel and supervision allocation of project supervision organization, the quality control in construction preparation stage, construction stage, commissioning stage, project trial operation, startup, acceptance, handover and warranty stages, supervision of work safety management, control of project progress and project cost, contract management, supervision of environmental protection and soil and water conservation, digital supervision, etc.
17	Determination of Chlorides in MS for Energy Storage - X-ray Fluorescence Spectrometry	Xi'an Thermal Power Research Institute Co., Ltd., North China Electric Power Research Institute Co., Ltd., China Datang Corporation Science and Technology General Research Institute Ltd. North China Electric Power Test and Research Institute, Guoneng Nanjing Electric Power Test and Research Co., Ltd., and State Grid Shandong Electric Power Company Electric Power Research Institute	This document specifies the general requirements on determination of chloride content in MS for energy storage by X-ray fluorescence spectrometry, including method summary, analysis steps, etc.
18	Method for Evaluation of Developable Quantity of CSP Projects	China Renewable Energy Engineering Institute, PowerChina Chengdu Engineering Corporation Limited, PowerChina Northwest Engineering Corporation Limited, PowerChina Beijing Engineering Corporation Limited, PowerChina Huadong Engineering Corporation Limited, etc.	Scope of application: It is applicable to the calculation and evaluation of developable quantity of onshore and offshore centralized PV power generation projects and onshore CSP projects. Main technical contents: data requirements, calculation boundary, calculation method, and main parameter selection for theoretical developable quantity, developable quantity of resources, and technical developable quantity.

No.	Standard	Prepared by	Scope of application and main content
19	Regulations on Calculation of Design Quantities of CSP Projects	China Renewable Energy Engineering Institute, PowerChina Northwest Engineering Corporation Limited, PowerChina Zhongnan Engineering Corporation Limited, etc.	Scope of application: It is applicable to the calculation of design quantities and preparation of the BOQ in feasibility study and preliminary design stages of CSP projects. Main technical contents: It specifies the requirements for calculation of divided quantities and preparation of BOQ in feasibility study and preliminary design stages of CSP projects. Specifically, it includes the regulations for calculation of quantities and preparation of BOQ for divisional and subdivisional works such as the solar concentration and collection system, TES system, and steam generation system, as well as related annexes.
20	Code of Valuation with BOQ for CSP Projects	China Renewable Energy Engineering Institute, PowerChina Northwest Engineering Corporation Limited, PowerChina Zhongnan Engineering Corporation Limited, etc.	Scope of application: It is applicable to the preparation of BOQ, valuation and cost management in the contracting and construction stages of CSP projects. Main technical contents: It specifies the requirements for preparing BOQ and valuation documents, as well as the principles of cost management for CSP projects. Specifically, it includes the preparation of BOQ, valuation with BOQ, composition and format of BOQ, composition and format of valuation with BOQ, and annexes for CSP projects.
21	Code for Electrical Design of CSP Projects	PowerChina Northwest Engineering Corporation Limited, etc.	Scope of application: It is applicable to the electrical design of solar tower plant, parabolic trough CSP plant, linear Fresnel CSP plant and parabolic dish CSP plant projects for TGU. Main technical contents: power system, TGU and main transformers, main electrical connection, AC auxiliary power system, DC power supply system and AC UPS, HV distribution equipment, electrical monitoring and control, component relay protection and automatic safety device, lighting system, overvoltage protection and grounding, intra-station communication, cable selection and laying, electrical equipment layout, and other facilities.

No.	Standard	Prepared by	Scope of application and main content
22	Code for Design of MS Storage Tanks for CSP Projects	PowerChina Northwest Engineering Corporation Limited, China Renewable Energy Engineering Institute Co., Ltd., Hualu Engineering & Technology Co., Ltd., Shouhang High-Tech Energy Technology Co., Ltd., etc.	Scope of application: It is applicable to the design of vertical cylindrical steel welded MS storage tanks under atmospheric or near-atmospheric pressure in CSP projects. Main technical contents: basic provisions, materials, tank bottom design, tank wall design, fixed roof, tank accessories, seismic action and seismic checking, wind-resistant stability and anchorage design, prefabrication, assembly, welding and inspection, tank foundation, tank insulation, etc.
23	Code for Design of Electric MS Heater Systems for CSP Projects	PowerChina Northwest Engineering Corporation Limited, China Renewable Energy Engineering Institute Co., Ltd., PowerChina Northwest Engineering Corporation Limited, Cosin Solar Technology Co., Ltd., PowerChina Renewable Energy Co., Ltd., etc.	Scope of application: It is applicable to the design of electric MS heater systems for newly built, expanded, and renovated CSP projects. Main technical contents: process system, selection and configuration of main equipment, pipelines and accessories, equipment and pipeline layout, auxiliary systems, and technical requirements for electrical system, instrumentation, and control system.
24	Regulations on the Content Depth of Construction Drawing Design Documents of CSP Projects Part 1 General	PowerChina Northwest Engineering Corporation Limited, PowerChina Zhongnan Engineering Corporation Limited, PowerChina Hebei Electric Power Engineering Co., Ltd., China Renewable Energy Engineering Institute Co., Ltd., PowerChina Renewable Energy Co., Ltd., etc.	Scope of application: It is applicable to the design of construction drawings for newly built, expanded, and renovated CSP projects. Main technical contents: main design content of construction drawing design documents for various parts of CSP projects, including general provisions, construction drawing design documents, and main contents of each part.

No.	Standard	Prepared by	Scope of application and main content
25	Regulations on the Content Depth of Construction Drawing Design Documents of CSP Projects Part 2 General layout and transportation	PowerChina Northwest Engineering Corporation Limited, PowerChina Zhongnan Engineering Corporation Limited, PowerChina Hebei Electric Power Engineering Co., Ltd., China Renewable Energy Engineering Institute Co., Ltd., PowerChina Renewable Energy Co., Ltd., etc.	Scope of application: It is applicable to the construction drawing design of general layout and transportation for newly built, renovated, and expanded CSP projects. Main technical contents: construction drawing design documents, general description and volume catalog of construction drawings, description of sign system design, overall planning of the plant, general layout of the plant area, vertical layout of the plant area, comprehensive piping layout of plant area, road layout and detail of the plant area, trench layout and detail of the plant area, details of plant walls, fences and gates, and green planning of plant area.
26	Regulations on the Content Depth of Construction Drawing Design Documents of CSP Projects Part 3 Solar concentration and collection	PowerChina Northwest Engineering Corporation Limited, PowerChina Zhongnan Engineering Corporation Limited, PowerChina Hebei Electric Power Engineering Co., Ltd., China Renewable Energy Engineering Institute Co., Ltd., PowerChina Renewable Energy Co., Ltd., etc.	Scope of application: It is applicable to the design of construction drawings of solar concentration and collection system for newly built, expanded, and renovated CSP projects. Main technical contents: construction drawing design documents, general description and volume catalog of construction drawings, description of sign system design, detailed list of equipment and materials, general layout of solar concentration and collection system, system diagram, system design description, equipment installation drawing, pipeline installation drawing, thermal insulation paint, etc.
27	Regulations on the Content Depth of Construction Drawing Design Documents of CSP Projects Part 4 HTF & TES	PowerChina Northwest Engineering Corporation Limited, PowerChina Zhongnan Engineering Corporation Limited, PowerChina Hebei Electric Power Engineering Co., Ltd., China Renewable Energy Engineering Institute Co., Ltd., PowerChina Renewable Energy Co., Ltd., etc.	Scope of application: It is applicable to the design of construction drawings of heat storage and exchange system for newly built, expanded, and renovated CSP projects. Main technical contents: construction drawing design documents, general description and volume catalog of construction drawings, description of sign system design, detailed list of equipment and materials, general layout of SGS, system diagram, system design description, equipment installation drawing, pipeline installation drawing, thermal insulation paint, etc.

No.	Standard	Prepared by	Scope of application and main content
28	Regulations on the Preparation of As-built Drawing Documents for CSP Projects	PowerChina Northwest Engineering Corporation Limited, China Renewable Energy Engineering Institute Co., Ltd., PowerChina Hebei Electric Power Engineering Co., Ltd., PowerChina Renewable Energy Co., Ltd., etc.	Scope of application: It is applicable to the preparation of as-built drawings for newly built, expanded, and renovated CSP projects. Main technical contents: requirements for preparation of as-built drawings, scope and depth of as-built drawings, review of as-built drawings, publication, delivery, and archiving of as-built drawings, etc.
29	Technical Specification for Soil and Water Conservation of CSP Projects	PowerChina Northwest Engineering Corporation Limited, etc.	Scope of application: It is applicable to the design of soil and water conservation of CSP projects. Main technical contents: basic provisions, level and design standards of soil and water conservation works, evaluation of soil and water conservation, scope of responsibility and zoning of soil erosion prevention and control, prediction of soil erosion, objectives and measures for soil and water conservation and control, monitoring of soil and water conservation, and design requirements for soil and water conservation.
30	Code for Design of Labor Safety and Occupational Health of CSP Projects	PowerChina Northwest Engineering Corporation Limited, etc.	Scope of application: It is applicable to the design of labor safety and occupational health of newly built, renovated, and expanded solar tower plant, parabolic trough CSP plant, parabolic dish CSP plant and linear Fresnel CSP plant projects which are grid-connected. Main technical contents: site selection and general layout, safety design in production, control of harmful factors in workplaces, safety of special equipment, safety and health during construction, safety information, safety colors and signs, safety and health management agencies, auxiliary rooms and emergency equipment and facilities, and investment budget for labor safety and occupational health.
Prepared by CSTA			

5.2.3 Alliance standards

By the end of 2024, CSTA has released 21 alliance standards. Among them, the *Test Method for Determining the Heat Loss Coefficient of Parabolic Trough Receiver Tubes* has been upgraded to a national standard, and the collection of comments has been completed [36].

Table 5.2-4 Released Alliance Standards

No.	Standard	Prepared by	Scope of application	Issued on
1	Test Method for Quality of Heliostats	IEECAS, Himin Solar Energy Group Co., Ltd., Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, and China National Institute of Standardization	This standard is applicable to the quality test of heliostats and their core components.	August 21, 2014
2	Measurement Method for Tracking Accuracy of Solar Heliostats	IEECAS, Himin Solar Energy Group Co., Ltd., Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, and China National Institute of Standardization	This standard is applicable to heliostats of different sizes and drive methods that can reflect and concentrate the direct normal radiation of the sun to fixed positions.	August 21, 2014
3	Method for Performance Test of Non-tracking Solar Medium-temperature Collectors	Shandong Linuo New Material Co., Ltd., Shanghai Jiaotong University, Beijing Tsinghua Sunshine Energy Development Co., Ltd., Linuo Ritter, IEECAS, China National Institute of Standardization, Dongguan Camda Electromechanical Engineering Co., Ltd., Sunrain Group Co., Ltd., Guangdong Fivestar SOLAR ENERGY Co., Ltd., Hubei Guizu Vacuum Science & Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., Jiangsu Product Quality Supervision and Inspection Institute, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Nanjing Tech University, and Yunnan Normal University	This standard is applicable to non-tracking solar medium-temperature collectors using solar radiation for heating, including the following forms: non-concentrating all-glass evacuated tube solar collectors with liquid HTF, glass-metal vacuum tube solar collectors, and heat pipe vacuum tube solar collectors.	January 12, 2015

No.	Standard	Prepared by	Scope of application	Issued on
4	Measurement Method for Surface Performance of Solar Concentrators	Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, China National Institute of Standardization, IEECAS, Beijing Tsinghua Sunshine Energy Development Co., Ltd., Dongguan Camda Electromechanical Engineering Co., Ltd., Guangdong Fivestar SOLAR ENERGY Co., Ltd., Hubei Guizu Vacuum Science & Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., Jiangsu Product Quality Supervision and Inspection Institute, Sunrain Group Co., Ltd., Nanjing Tech University, Shandong Linuo New Material Co., Ltd., Shanghai Jiaotong University, Xi'an Jiaotong University, and Yunnan Normal University	This standard is applicable to the measurement of surface performance of solar concentrators.	January 12, 2015
5	Method for Performance and Quality Testing and Evaluation of Solar Air Conditioners	Shanghai Jiaotong University, and Shandong Lucy New Energy Technology Co., Ltd.	This standard is applicable to absorption solar air conditioning units driven by hot water, steam, or thermal oil generated by solar collectors. Absorption solar air conditioning units driven by hot water, steam, or thermal oil may also refer to this standard.	January 12, 2015
6	Terminology for Medium-temperature Solar Heat Utilization	IEECAS, China National Institute of Standardization, Shanghai Jiaotong University, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Beijing Tsinghua Sunshine Energy Development Co., Ltd., Dongguan Camda Electromechanical Engineering Co., Ltd., Guangdong Fivestar SOLAR ENERGY Co., Ltd., Hubei Guizu Vacuum Science & Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., Jiangsu Product Quality Supervision and Inspection Institute, Beijing Micoe Solar Technology Group Co., Ltd., Nanjing Tech University, Shandong Linuo New Material Co., Ltd. and Yunnan Normal University	This standard is applicable to the processes of concentration, photothermal conversion, TES, industrial application and operation in medium-temperature solar heat utilization.	January 12, 2015

No.	Standard	Prepared by	Scope of application	Issued on
7	Method for Performance Test of Heat Storage Materials for Medium-temperature Solar Heat Utilization	IEECAS, China National Institute of Standardization, Shanghai Jiaotong University, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Beijing Tsinghua Sunshine Energy Development Co., Ltd., Dongguan Camda Electromechanical Engineering Co., Ltd., Guangdong Fivestar SOLAR ENERGY Co., Ltd., Hubei Guizu Vacuum Science & Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., Jiangsu Product Quality Supervision and Inspection Institute, Beijing Micoe Solar Technology Group Co., Ltd., Shandong Linuo New Material Co., Ltd. and Yunnan Normal University.	This standard is applicable to heat storage materials for medium-temperature solar heat utilization (100°C-400°C).	November 15, 2015
8	Method for Performance Test of Solar Medium-temperature Collectors	Solar Energy Research Institute of Yunnan Normal University, Yunnan Solar Photothermal engineering Technology Center, IEECAS, China National Institute of Standardization, Guangdong Fivestar SOLAR ENERGY Co., Ltd., Shanghai Jiaotong University, Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Beijing Tsinghua Sunshine Energy Development Co., Ltd., Dongguan Camda Electromechanical Engineering Co., Ltd., Hubei Guizu Vacuum Science & Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., Jiangsu Product Quality Supervision and Inspection Institute, Beijing Micoe Solar Technology Group Co., Ltd., Nanjing Tech University, and Shandong Linuo New Material Co., Ltd.	This standard is applicable to flat solar medium-temperature air collectors heated by solar radiation and with transparent cover, which use air as the HTF and own a single inlet and a single outlet.	December 29, 2015

No.	Standard	Prepared by	Scope of application	Issued on
9	Dynamic Test Method for Thermal Performance of Parabolic Trough Solar Collectors	IEECAS, SunCan Co.,Ltd., China Power Engineering Consulting Group Co., Ltd., Beijing Nonferrous Metal Research Institute, Beijing Solar Energy Research Institute Co., Ltd., Rayspower Energy Group Co., Ltd., Jiangsu Sunhome New Energy Co., Ltd., Wuhan Sunnpo Solar Technology Co., Ltd., Changzhou Longteng CSP Equipment Co., Ltd., Camda New ENERGY Equipment Co., Ltd., Sundhy (Chengdu) SOLAR POWER Co., Ltd., Shanxi Lihu Glass (GROUP) Co., Ltd., Asahi Glass Special Glass (Dalian) Co., Ltd., Beijing TRX Solar Technology Co., Ltd., SPIC Central Research Institute, Beijing Tsinghua Sunshine Energy Development Co., Ltd., Beijing CSP Engineering Technology Research Center, and Key Laboratory of Solar Energy Utilization and PV System, Chinese Academy of Sciences.	This standard is applicable to solar collectors which employ single-axis tracking parabolic trough concentrators, use thermal oil, water, MS, and others with no phase change liquid medium in the heat absorption process as the HTF, and own a geometric concentrating ratio of greater than 7, including collector arrays composed of multiple parabolic trough concentrators.	March 25, 2016
10	Test Method for Determining the Heat Loss Coefficient of Parabolic Trough Receiver Tubes	IEECAS, Beijing Solar Energy Research Institute Co., Ltd., Royal Tech CSP Limited, Grimat Engineering Institute Co., Ltd., Beijing TRX Solar Technology Co., Ltd., Lanzhou Dacheng Technology Co., Ltd., Shandong Huiyin New Energy Technology Co., Ltd., Himin Solar Energy Group Co., Ltd., Rayspower Energy Group Co., Ltd., Camda New ENERGY Equipment Co., Ltd., and China Power Engineering Consulting (Group) Corporation	This standard is applicable to parabolic trough solar receiver tubes used in CSP systems, and other solar receiver tubes with glass-metal inner tube structures can refer to this standard.	June 23, 2016
11	Organic Heat Carrier for CSP Plants - Mixture of Diphenyl and Diphenyl Ether	Jiangsu Zhongneng Chemical Technology Co., Ltd., China Boiler and Boiler Water Treatment Association, IEECAS, CGN Solar Energy Development Co., Ltd., Shandong TIANYI Chemical Corporation, Beijing TRX Solar Technology Co., Ltd., Suzhou Therminol Thermal Oil Co., Ltd., Rayspower Energy Group Co., Ltd., Huaneng Clean Energy Research Institute, Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, Shenzhen Enesoon Science & Technology Co., Ltd., Huadian New Energy Technology Development Co., Ltd., and Bo Yu Chengdu New Energy Co., Ltd.	This standard is applicable to organic heat carrier products prepared from diphenyl and diphenyl ether for CSP plants. This product is suitable for closed heat transfer system.	April 25, 2017

No.	Standard	Prepared by	Scope of application	Issued on
12	Test Method for Thermal Performance of Heat Storage Water Vapor Solar Steam	Guangdong Fivestar SOLAR ENERGY Co., Ltd., IEECAS, and Shanghai Jiaotong University	This standard is applicable to three thermal performance tests, including collection performance test, heat storage tank flash test, and heat loss coefficient test of heat storage tank.	May 11, 2018
13	Method for Quality and Performance Inspection of Heliostat Supports	IEECAS, Zhejiang Supcon Solar Technology Co., Ltd., Qingdao Xingyue Iron Tower Co., Ltd., and Bo Yu Chengdu New Energy Co., Ltd.	This standard is applicable to the quality and performance inspection of metal heliostat supports.	October 14, 2019
14	Glass Tubes for Medium-temperature Vacuum Receiver Tubes	Linuo Ritter, IEECAS, Beijing TRX Solar Technology Co., Ltd., Beijing University of Technology, Shandong Dongfang Weimin New Thermal Technology Co., Ltd., Royal Tech CSP Limited, and CEEC Equipment Industry Co., Ltd.	This standard is applicable to glass tubes for medium-temperature vacuum receiver tubes using thermal oil and others as the HTF, and inapplicable to glass tubes for high-temperature vacuum receiver tubes using MS as the HTF.	October 14, 2019
15	Method for Thermal Performance Test of Tower Solar Liquid Medium Receiver Units	Zhejiang University, Engineering Research Institute of China Energy Engineering Group Co., Ltd., IEECAS, Xi'an Jiaotong University, Beijing University of Technology, Tianjin University, Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group., Inner Mongolia Electric Power Survey & Design Institute Co., Ltd., Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Zhejiang Zhongguang New Energy Technology Co., Ltd., Zhejiang Supcon Solar Technology Co., Ltd., Hangzhou Boiler Group Co., Ltd., Beijing Shouhang IHW Resources Saving Technology Co., Ltd., China Energy Engineering Group Zhejiang Electric Power Design Institute Co., Ltd., Quzhou Special Equipment Inspection Center, Material Research Institute of China Special Equipment Inspection & Research Institute, and Shandong Electric Power Engineering Consulting Institute Corp., Ltd.	This standard is applicable to tower solar receiver units using liquid HTF, specifies the method for thermal performance test of receiver units, and is suitable for the testing and evaluation of tower solar liquid medium receiver units.	January 06, 2020

No.	Standard	Prepared by	Scope of application	Issued on
16	Method for Optical Efficiency Testing of Parabolic Trough Receiver Tubes	Grimat Engineering Institute Co., Ltd., IEECAS, Linuo Ritter, and Royal Tech CSP Limited	This standard is applicable to receiver tubes used in CSP systems, and other receiver tubes with glass-metal structures can refer to this standard. This standard is inapplicable to all-glass vacuum receiver tubes.	August 21, 2020
17	Technical Specification for Nitrate MS Used in CSP Systems	Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Sun Yat-Sen University, Beijing University of Technology, IEECAS, Zhejiang University, China Special Equipment Inspection & Research Institute, Qinghai Institute of Salt Lakes, Chinese Academy of Sciences, Jiaocheng County Bingsheng Chemical Co., Ltd., and Beijing University of Civil Engineering and Architecture	This standard is applicable to the technical specifications, quality testing, and evaluation of nitrate MS used in CSP systems.	March 11, 2021
18	Measurement Method for Thermochemical Energy Storage Temperature and Energy Storage Density of Solid Metal Oxides	Zhejiang University, Engineering Research Institute of China Energy Engineering Group Co., Ltd., Xi'an Jiaotong University, IEECAS, and Shanghai Institute of Applied Physics, Chinese Academy of Sciences	This standard is applicable to the measurement of thermochemical energy storage temperature and energy storage density of solid metal oxides under 100-1500°C.	April 21, 2021
19	Method for Corrosion Testing and Evaluation of MS Used in CSP Plants	Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Sun Yat-Sen University, Beijing University of Technology, ChinaSalt Jintan Co., Ltd., Shanxi Wojin New Materials Co., Ltd., IEECAS, Zhejiang University, China Special Equipment Inspection & Research Institute, and Qinghai Institute of Salt Lakes, Chinese Academy of Sciences	This standard is applicable to the corrosion testing and evaluation of MS on metal materials in CSP plants.	May 25, 2021

No.	Standard	Prepared by	Scope of application	Issued on
20	Design Specification for Long-term Sensible Heat Storage Systems	Tsinghua University, IEECAS, Solareast Solar Energy Co., Ltd., Inner Mongolia Fulong Heating Engineering Technology Co., Ltd., Beijing Zhonghuan Hechuang Environmental Protection Energy Technology Co., Ltd., Shouhang High-Tech Energy Technology Co., Ltd., and Grimat Engineering Institute Co., Ltd.	This standard specifies the term, definitions and general provisions of long-term sensible TES system, as well as the design requirements for long-term water tank TES system, long-term buried pipe TES system, and long-term pool TES system.	January 11, 2023
21	Test Method for Concentrated Energy Flux Density in Heliostat Fields	IEECAS, and Lanzhou University of Technology	This standard specifies the test method for the concentrated energy flux density on the aperture area of the solar receivers in heliostat fields. This document is applicable to the test for the concentrated energy flux density on the aperture area of the solar receivers in heliostat fields.	May 28, 2024

5.3 Award-winning projects in 2024

In 2024, awards were conferred to some technological achievements of CSP projects (as listed in Table 5.3).

Table 5.3 Award-winning Technological Achievements of CSP Projects (Ranked Randomly)

No.	Project	Completed by	Award
1	Key Technologies for Safe and Efficient Solar Photo-thermal Conversion and Storage in Tower CSP Plants and Their Application	PowerChina Northwest Engineering Corporation Limited Xi'an Jiaotong University SunCan Co.,Ltd.	The First Prize of Science and Technology Progress Award of Shaanxi Province
2	R&D and industrialization of green production technology for high-performance heat transfer media/ materials	Hebei Jindong Technology Group Co., Ltd.	The Second Prize of Hebei Provincial Science and Technology Progress Award in 2023
3	Hami 50MW MS Solar Tower Plant	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group,	The Third Prize for Excellent Engineering Survey of the "Four Excellences" Award by China Electric Power Planning & Engineering Association

No.	Project	Completed by	Award
4	Research on the Development and Consumption Schemes of New Energy Outbound Transmission Base in the South Xinjiang Desert	Electric Power Planning & Engineering Institute Co., Ltd.	The First Prize of Excellent Engineering Consulting Achievements in the Power Industry by China Electric Power Planning & Engineering Association
5	Feasibility Study Report on the 6,100 MW New Energy Project of Huadian Xinjiang at the Northern Foot of Tianshan Mountain	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group,	
6	Feasibility Study Report on the CGN "Zero-carbon Lithium Extraction" Source-Grid-Load-Storage Demonstration Project in Lhaguo Tso	Electric Power Planning & Engineering Institute Co., Ltd.	
7	Feasibility Study on the New Energy Base Project in the Central and Northern Ordos Region in Kubuqi Desert, Inner Mongolia	Electric Power Planning & Engineering Institute Co., Ltd. Shanghai Survey, Design and Research Institute Co., Ltd.	
8	Research on the Optimization and Joint Operation Scheme of CSP System at Gobi Base in Hainan Prefecture, Qinghai Province	Electric Power Planning & Engineering Institute Co., Ltd.	The Second Prize of Excellent Engineering Consulting Achievements in the Power Industry by China Electric Power Planning & Engineering Association
9	Feasibility Study Report on 100 MW CSP Works at Haixi Base in Phase II (Lot II) of Qinghai-Henan DC Project	PowerChina Northwest Engineering Corporation Limited	
10	Research on the Optimization of Power Source Structure and Mechanism Construction for Source-load Interaction in Qinghai Power Grid under the New Power System	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, Economic and Technological Research Institute of State Grid Qinghai Electric Power Company	
11	Feasibility study reports for CEEC Hami "Solar (Thermal) Energy Storage" Multi-energy Complementary Integrated Green Electricity Demonstration Project	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group,	The Third Prize of Excellent Engineering Consulting Achievements in the Power Industry by China Electric Power Planning & Engineering Association
12	Report on Transmission Planning for 12,000 MW New Energy Base Project in the Central and Northern Ordos in Kubuqi Desert, Inner Mongolia	Inner Mongolia Electric Power Survey & Design Institute Co., Ltd. Inner Mongolia EHV Power Supply Company	
13	Key Technologies for Collaborative Planning and Intelligent Regulation of Wind Power, PV, CSP and TES Multi-Energy Complementation System and Their Application	Hohai University Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group, Qinghai Golmud Luneng New Energy Co., Ltd. Nanjing Branch of China Electric Power Research Institute, and Hong Kong Polytechnic University	The First Prize of Technology Innovation Award under China Renewable Energy Society's Science and Technology Award in 2024

No.	Project	Completed by	Award
14	Key Technologies for Multi-Source Collaborative Planning and Operation of Hydro-Wind-Solar Energy in Western China	PowerChina Guiyang Engineering Corporation Limited Hohai University Nanjing NARI Water Conservancy and Hydropower Technology Co., Ltd. Guizhou Qianyuan Power Co., Ltd., China Huadian Corporation Ltd. Huaneng Lancang River Hydropower Inc.	The Second Prize of Technology Innovation Award under China Renewable Energy Society's Science and Technology Award in 2024
15	Efficient Parabolic Trough Solar Thermal Coupling Off-peak Energy Storage for Residential Distributed Heating Systems	Inner Mongolia Baichuan Solar Technology Co., Ltd.	The First Prize in the 9th Innovation and Entrepreneurship Competition in Ejin Horo Banner
16	Improvement of Tank Stability During Hydraulic Jacking Construction of Storage Tanks	Gansu Province Installation & Construction Group Co., Ltd.,	The Third Prize in the 2024 Power Construction Quality Management Group Activity Competition
17	Improvement of the Appearance Quality of Cylinder Wall in Tripod Turnover Formwork Process of Solar Tower		The Third Prize in the 2024 Power Construction Quality Management Group Activity Competition
18	Improvement of the Appearance Quality of Cylinder Wall in Tripod Turnover Formwork of Solar Tower		Class III Achievement Award in QC Group Competition of Gansu Provincial Engineering Construction Quality Management Group
19	Guazhou 700 MW "Solar TES+" Project	China Gezhouba Group Electric Power Co., Ltd. Gansu Province Installation & Construction Group Co., Ltd., SunSum Technology Co., Ltd.	Excellent Demonstration Project of "Ten Characteristic Management" in Project Management by CEEC
20	Research and Application of Localized Independent Development of Heliostat Assembly Production Line for CSP Projects	Dongfang Boiler Co., Ltd. of Dongfang Electric Corporation	Special Prize of 2024 National Employee Technology Innovation Achievement Award in Machinery, Metallurgy, and Building Materials Industries
21	Improvement of Weld Pass Rate of Duplex and Super Duplex Steel Welded Pipes	Sinosteel Stainless Steel Pipe Technology (Shanxi) Co., Ltd.	The Second Prize in 2024 Quality Improvement Activity in Jinzhong City

Chapter VI Technical and Economic Aspects of CSP

6.1 Electricity prices and investment costs of CSP projects

The cost-effectiveness of power generation projects is closely related to electricity prices. According to the Notice of the National Development and Reform Commission on Matters Related to the 2021 New Energy Feed-in Tariff Rate Policy (NDRC Pricing Document [2021] No. 833), from 2021 onwards, the feed-in tariff rate for newly approved (registered) CSP projects shall be determined by competent provincial authorities (pricing authorities) and may be determined through competitive allocation if conditions allow. If the feed-in tariff rate for a CSP project is higher than the local benchmark price of coal-fired power plants, the part within the benchmark price will be settled by the responsible power grid enterprise[37]. As shown in Table 6.1-1, there are significant differences in feed-in tariff rates among provinces in Northwest China.

Table 6.1-1 Policies for Feed-in Tariff Rates of CSP Projects in Northwest China

Region	Electricity rate	Other descriptions
Xinjiang Autonomous Region	Unified benchmark feed-in tariff rate: CNY 0.262/kWh.	Benchmark feed-in tariff rate of coal-fired power generation: CNY 0.25/kWh.
Inner Mongolia Autonomous Region	Market-based pricing mechanism of "benchmark feed-in tariff rate + floating range".	The benchmark feed-in tariff rate is based on the current benchmark feed-in tariff rate of coal-fired power generation. The benchmark feed-in tariff rate of the power grid of West Inner Mongolia: CNY 0.2829/kWh; the benchmark feed-in tariff rate of the power grid of East Inner Mongolia: CNY 0.3035/kWh, with a floating range of not more than 10% at most and not lower than 15% at least in principle.
Gansu Province:	Benchmark feed-in tariff rate of coal-fired power generation: CNY 0.3078/kWh.	Time-of-use feed-in tariff rate shall be adopted for PV project.

Region	Electricity rate	Other descriptions
Qinghai	Qinghai New Energy Document No. [2023]57: For local consumption-oriented CSP projects included in the new energy development and construction plan of Qinghai Province for 2021 and 2022 and completed on schedule, the feed-in tariff rates should be determined based on the benchmark feed-in tariff rate for electricity from coal-fired power plants. From 2023 to 2025, all PV-CSP hybrid projects acquired through competitive allocation will participate in market-based transactions. The feed-in tariff rates for CSP projects should be in accordance with NDRC Price Document [2021] No. 1439. Qinghai Provincial Development and Reform Commission Pricing Document No. [2024] 778: For CSP projects that have been constructed separately according to basic construction procedures and included into the annual CSP demonstration (pilot) project development program of Qinghai Province as reviewed and approved by Qinghai Provincial Development and Reform Commission and Energy Bureau for the period from 2024 to the end of 2028, the feed-in tariff rate will be CNY 0.55/kWh (including tax) from the date on which the plant is put into commercial operation. These projects do not participate in power market transactions.	The Notice on Promoting Large-scale Development of CSP Projects During the "14th Five-year Plan" (Qinghai New Energy Document No. [2023] 57) states that no other regulation capability facilities will be configured for PV-CSP hybrid project. CSP projects shall be settled and metered separately. Participation in electrical auxiliary services in line with the operation rules of electrical auxiliary service market of Qinghai and the Northwest China or the "Two Detailed Rules" of Northwest China is encouraged to obtain corresponding income. In market transactions, electricity from CSP plants should be dispatched in a scientific way based on the principle of giving priority to green electricity while leveraging the capabilities of CSP plants in peak load supply, peak shaving, and other load regulation tasks. It is recommended that CSP plants be equipped with natural gas furnaces and high-power electric heaters for molten salt heating. When self-generated electricity is used to heat the molten salt through high-power electric heaters, electricity grid and capacity fees shall not be charged.
Prepared by CSTA		

Under the new situation involving the removal of subsidies, the focus of national CSP development strategy on desert and Gobi areas, and the accelerated construction of large wind and PV energy generation bases, CSP plants are constructed in the form of wind-PV-CSP hybrid projects. For the system configuration of CSP plants, consideration should be given to reducing initial investment while meeting the requirements in respect of installed capacity, energy storage duration, and system/equipment safety. Compared with the first batch of CSP demonstration projects in China, most of the existing CSP + renewable power plants are equipped with large-capacity electric heaters to absorb the abandoned PV and wind energy; the function of CSP plants in the power grid has changed from "serving as independent power sources for generating electricity as much as possible" to "energy storage and peak shaving", and their energy storage duration has been optimized and adjusted to about eight (8) hours based on project needs. The scale of concentration system is reduced compared with the first batch, resulting in lower equivalent annual utilization hours. By comparing the costs (feasibility study) of a 100 MW solar tower plant in Yumen (which is among the first batch of CSP demonstration projects in China) and the 100 MW CSP plant of the Turpan CSP + new energy project, Northwest

Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group.[38] has found that the solar field area has been reduced from 1,400,000 m^2 to about 656,000 m^2; the prices of major equipment such as the solar field, steam turbine, steam generator, power generator, and molten salt storage tanks have decreased significantly; the unit price of molten salt used at the 100 MW CSP plant of the Turpan CSP + new energy project has increased by about 100% compared to the first batch of CSP demonstration projects. In general, the unit cost of a 100 MW solar tower plant has been reduced by about 45.6% from CNY 29,770 /kW to CNY 16,209 /kW.

It is to be noted that the cost of a CSP plant with molten salt TES is closely related to the solar irradiance and meteorological conditions in the region/province where the plant is located, as well as the policies and requirements of the region/province with respect to the energy storage period, the ratio of solar thermal energy to new energy, and feed-in tariff rate for CSP projects. Due to the change in the functional position of CSP plants, the annual operating (power generation) hours and equipment utilization rate of CSP plants have decreased, resulting in an increase in the amortized cost of equipment and a slight decrease in plant cost per kWh.

CSTA has compiled statistics (Table 6.1-2) on the award of EPC contracts for some CSP plants under construction according to the bid and contract award information published on various bidding websites. The highest EPC contract value is approximately CNY 1.698 billion, and the lowest is CNY 1.199 billion. However, it should be noted that, although these CSP projects have the same installed capacity, they are different from one another in aspects such as project site (including solar irradiance and meteorological conditions), scope of work, scope of service, technical route, solar field area (1.30 million m^2 at maximum, 0.44 million m^2 at minimum), TES period (ranging from 8 hours to 12 hours), and financial management model.Therefore, the EPC prices of different CSP projects are not comparable.

Table 6.1-2 Award of EPC Contracts for Some CSP Plants under Construction (Arranged in Random Order)

No.	Project	Solar concentration technique	General contractor of CSP project
1	CHN Energy Longyuan Power 100 MW CSP + 480 MW Wind Power + 120 MW PV Project	Linear Fresnel	PC contractor: Gansu Province Installation & Construction Group Co., Ltd.,
2	CNNP Rich Energy Jinta 1,600 MW Clean Energy Security Project	Parabolic trough plant	EPC for Steam Supply Station and Heliostat Field Project: Consortium of Nuclear Industry Engineering Research & Design Limited
3	100 MW CSP Plant in Bid Section 1 of the CHN Energy Qingyu DC Power Outbound Transmission Project	Tower plant	PowerChina Northwest Engineering Corporation Limited PowerChina Hubei Engineering Co., Ltd.
4	100 MW CSP Plant in Bid Section 3 of the Three Gorges (CTG) Qingyu DC Power Outbound Transmission Project Phase II	Tower plant	PowerChina Northwest Engineering Corporation Limited Cosin Solar Technology Co., Ltd. China Energy Engineering Group (CEEC) Zhejiang Thermal Power Construction Co., Ltd.

No.	Project	Solar concentration technique	General contractor of CSP project
5	Qinghai Golmud 1,100 MW Solar Power Plant in Three Gorges New Energy Haixi Solar PV Park	Tower plant	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group (leader) Shouhang High-Tech Energy Technology Co., Ltd. PowerChina Sichuan Engineering Corporation Limited (SCECC), Shanghai Survey, Design and Research Institute Co., Ltd.
6	CGN Delingha 2,000 MW PV, CSP and TES Hybrid Project (200 MW CSP)	Tower plant	PowerChina Northwest Engineering Corporation Limited PowerChina Hubei Electric Power Construction Co., Ltd. Northwest Water Conservancy & Hydropower Engineering Co., Ltd.
7	PowerChina Gonghe 1,000 MW PV + CSP Project	Tower plant	PowerChina Northwest Engineering Corporation Limited PowerChina Hubei Electric Power Construction Co., Ltd. Northwest Water Conservancy & Hydropower Engineering Co., Ltd.
8	No. 1-1 (100 MW CSP) Plant of the CGN Jixi Base DC 1,400 MW DC Power Outbound Transmission Project in Lugu County, Baicheng City, Jilin	Tower plant	PowerChina Jilin Electric Power Engineering Co., Ltd. (Consortium: Shandong Electric Power Engineering Consulting Institute Corp., Ltd.)
9	No. 2-1 (100 MW CSP) Plant of the CGN Jixi Base DC 1,400 MW DC Power Outbound Transmission Project in Lugu County, Baicheng City, Jilin	Tower plant	PowerChina Zhongnan Engineering Corporation Limited
10	Luneng Fukang Multi-energy Complementary (and New Energy Market-oriented Grid-connected) Project	Tower plant	Consortium of CGDG-Cosin Engineering Technology Co., Ltd. and Inner Mongolia Electric Power Survey & Design Institute Co., Ltd.
11	CEEC Hami "Solar (Thermal) Energy Storage" Multi-energy Complementary Integrated Green Electricity Demonstration Project and 150 MW CSP Project	Tower plant	Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group,
12	Three Gorges New Energy Hami 1,000 MW Hybrid CSP + PV Demonstration Project	Linear Fresnel	EPC contractor: Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group
13	Northern Hami 900 MW PV + 100 MV CSP Project	Tower plant	Shouhang High-Tech Energy Technology Co., Ltd. North China Power Engineering Co., Ltd. of China Power Engineering Consulting Group, China Energy Engineering Group Northwest City Construction Co., Ltd.

No.	Project	Solar concentration technique	General contractor of CSP project
14	Datang Shichengzi 1,000 MW "CSP + PV" Hybrid Clean Energy Demonstration Project	Linear Fresnel	Consortium of Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group & Northwest Electric Power Construction Third Engineering Co., Ltd.
15	CSP + PV Hybrid Project in Wusitong, Toksun County, Turpan	Tower plant	PowerChina Zhongnan Engineering Corporation Limited (leader) SOCOL Corporation Limited, PowerChina Nuclear Engineering Company Limited PowerChina Hebei Electric Power Engineering Co., Ltd.
16	CSP + PV Hybrid Project of State Power Investment Group Henan Electric Power Co., Ltd.	Tower plant	Shandong Electric Power Engineering Consulting Institute Corp., Ltd.
17	CSP + PV Hybrid Project of China Energy Engineering Group (CEEC) Zhejiang Thermal Power Construction Co., Ltd.	Tower plant	Cosin Solar Technology Co., Ltd. China Energy Construction Group Zhejiang Electric Power Design Institute Co., Ltd. Zhejiang Huaye Power Engineering Corporation Limited
18	SDIC Ruoqiang 100 MW CSP + 900 MW PV Market-oriented Grid-connected Power Generation Project	Tower plant	North China Power Engineering Co., Ltd. of China Power Engineering Consulting Group, Shouhang High-Tech Energy Technology Co., Ltd.
19	PowerChina (Ruoqiang) New Energy 100 MW CSP (Energy Storage) + 900 MW PV Demonstration Project	Tower plant	SOCOL Corporation Limited, PowerChina Jiangxi Electric Power Engineering Co., Ltd., Shandong Electric Power Construction Corporation III (SEPCOIII)
20	Xinhua Hydropower Bozhou 100 MW TES CSP and 900 MW New Energy Project	Tower plant	PC (procurement and installation) contractor: Gansu Province Installation & Construction Group Co., Ltd., SunSum Technology Co., Ltd.
21	Xinhua Hydropower Jinghe New Energy "Solar TES New Energy" Integrated Base Project	Tower plant	PC contractor: PowerChina Sichuan Engineering Corporation Limited (SCECC), Shouhang High-Tech Energy Technology Co., Ltd.
22	"Zero Carbon" CSP Demonstration Project in Ali Snowy Plateau of CGN (EPC for Conventional Island, TES Island, and Heating System of 50 MW CSP and Heating Project)	Parabolic trough plant	PowerChina Zhongnan Engineering Corporation Limited
23	ZDI 100 MW CSP + 800 MW PV Hybrid Project in Tushuo, Anduo County, Tibet	Tower plant	Consortium of PowerChina Northwest Engineering Corporation Limited & PowerChina Sepco1 Electric Power Construction Co., Ltd.

No.	Project	Solar concentration technique	General contractor of CSP project
Integrated Project EPC			
24	Hi-tech Wealth (China Three Gorges Corporation) Guazhou "100 MW CSP + 200 MW PV + 400 MW Wind Power" Project		Consortium of China Gezhouba Group Electric Power Co., Ltd. (leader), Gansu Province Installation & Construction Group Co., Ltd., and SunSum Technology Co., Ltd. for the development and construction project of Three Gorges SunSum Technology Co., Ltd.
25	CSP + PV Hybrid Project of Haitai Solar Technology Co., Ltd.		China Energy Engineering Group Northwest Power Construction Engineering Co., Ltd.
Prepared by CSTA			

6.2 Technical and economic comparison between CSP with molten salt TES and PV + other novel energy storage systems

In 2022, CSTA conducted a generic technical research project titled Technical and Economic Comparison between CSP with MS TES and PV + Other Novel Energy Storage Systems (undertaken by Cosin Solar Technology Co., Ltd., completed in 2023). This section presents the main research results.

Energy storage techniques such as molten salt thermal energy storage (MS TES), pure electric heating MS TES, pumped hydro energy storage (PHES), compressed air energy storage (CAES), and electrochemical energy storage (EES) are suitable for large-scale, long-term, and long-life energy storage and peak shaving scenarios in power systems. Unlike CSP plants with MS TES, CSP plants with pure electric heating MS TES systems are not equipped with solar concentration and collection systems, at which electric heaters are used to heat the MS TES systems by absorbing abandoned solar PV and wind energy. The other systems/parts of these two types of CSP plants are completely identical. Based on the solar resources of Delingha City, Qinghai Province and without considering the geographical constraints at the project site, the economic aspects of CSP plants and solar PV projects with other energy storage systems were comparatively analyzed while ensuring the same overall on-grid power curve.

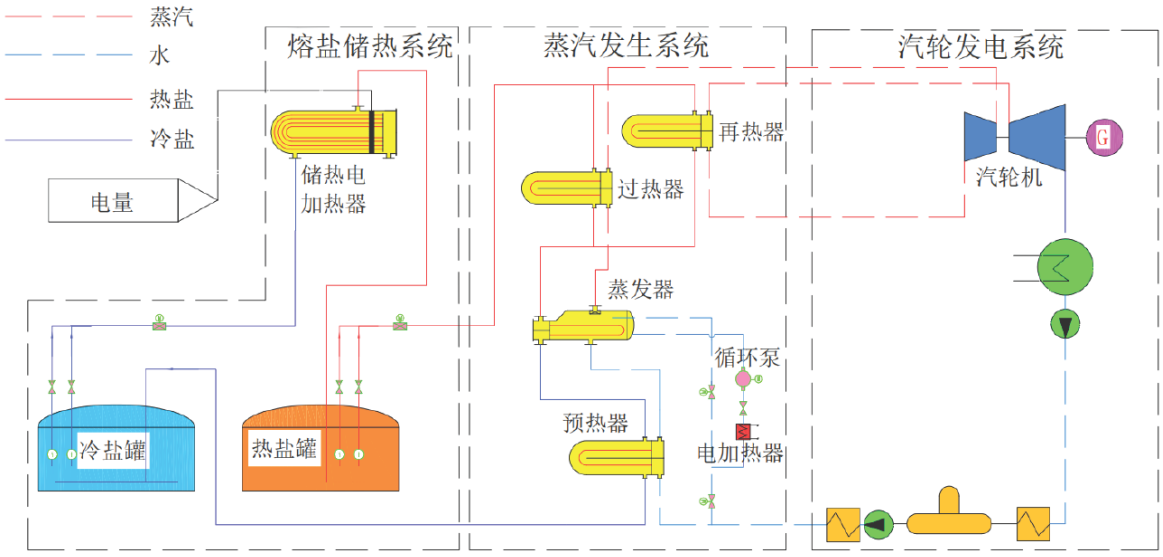


Fig. 6.2-1 Schematic Diagram of a Pure Electric Heating MS TES System

Under defined boundary conditions, as the energy storage period increases from 2 h to 12 h, the LCOE of MS TES decreases from CNY 1.6523/kWh to CNY 0.6926/kWh, the LCOE of PV + pure electric heating MS TES decreases from CNY 1.6631/kWh to CNY 0.7825/kWh, the LCOE of PV + EES decreases from CNY 0.9512/kWh to CNY 0.8052/kWh.

These calculation results show that, when the energy storage period is between 2 h and 7 h, the LCOE of PV + EES is the lowest; when the energy storage period is longer than 7 h, the LCOE of CSP + MS TES is the lowest. CSP + MS TES, PV + pure electric heating MS TES, and PV + PHES systems have similar LCOE. When the energy storage period increases from 2 h to 12 h, the LCOE of CSP + MS TES is the lowest, and the LCOE of PV + CAES (artificial storage) is higher than those of the other three types of energy storage systems. In general, CSP plants with MS TES are more cost-effective than solar PV power plants with other energy storage systems.

Table 6.2-2 LCOE (per kWh) of CSP + MS TES and PV + Different Energy Storage Systems (Unit: CNY/kWh)

Energy storage period (h)	Annual electric output (million kWh)	CSP + MS TES	PV + pure electric heating MS TES	PV + EES	PV + PHES	PV + CAES (efficiency: 70%)	PV + CAES (efficiency: 60%)
2	1.04	1.6523	1.6631	0.9512	1.6481	2.1735	2.2081
4	2.21	1.0238	1.1071	0.8323	1.0513	1.2730	1.3077
6	3.21	0.8764	0.9721	0.8296	0.9053	1.0402	1.0748
8	4.19	0.8052	0.8894	0.8296	0.8298	0.9191	0.9538
10	5.31	0.7388	0.8259	0.8134	0.7671	0.8283	0.8630
12	6.41	0.6926	0.7825	0.8052	0.7291	0.7711	0.8057
Prepared by CSTA							

Fig. 6.2-3: LCOE (per kWh) of CSP + MS TES and PV + different energy storage systems

The research suggests that China's CSP industry is currently in the stage of large-scale development and rapid technological progress, and with the reduction of costs and the improvement of power generation efficiency, the LCOE of CSP plants with MS TES will further decline. The LCOE of solar tower plants is estimated to decline to CNY 0.5287-0.5312/kWh (including expenses for operation and maintenance optimization) by 2026. Compared with other power sources, CSP plants have a lower-carbon life cycle and superior on-grid performance.With the deepening of the electricity market reform and the establishment and maturation of green power trading and emissions trading markets, the values of CSP plants in load regulation, support services, and green and low-carbon development will be reflected in project income, and the cost-effectiveness of CSP plants will be greatly improved.

6.3 Prediction of and main technical measures for CSP cost reduction during the 15th Five-year Plan period

The cost of a solar tower plant, including the initial investment for the plant and the support costs incurred throughout the entire lifecycle of the plant, is affected by many factors and mainly related to factors such as construction, operation and maintenance expenses, annual electric output, financial expenses, and taxes. The factors affecting LCOE are listed in the table below (classified according to the significance of their impacts).

Table 6.3-1 Factors Affecting LCOE

Direct factors	Indirect factors
Cost	Loan-to-value ratio (LVR)
Operation and maintenance expenses	Loan interest rate
Power generation	Auxiliary power consumption rate
Internal rate of return (IRR) *	Value-added tax (VAT), income tax
Operating period (year)	Installed capacity
Land costs	Energy storage period
Costs allocated to power generation companies for outbound transmission lines	Construction time
Direct normal irradiance (DNI)	Year-over-year investment ratio
	Repayment method (equal principal and equal interest payments)
	Loan period (year)
	Depreciation method and period (year)
	Wind speed
	Ambient temperature
* Note: It refers to the discount rate for capital when the net present value within the life cycle of the project is 0.	
Prepared by CSTA	

(1) Overall objectives

By 2030, driven by CSP technology innovation, CSP plants will see increased single-unit capacity and reduced unit cost. The Delingha site (annual total DNI of 2,009 kWh/m^2) is taken as an example. When the single-unit capacity reaches 600 MW and the installed cost per kW is ≤ CNY 11,000, the LCOE of CSP plant could drop to about CNY 0.39/kWh. When the solar supercritical Rankine cycle technology is adopted, the LCOE may reach CNY 0.38/kWh.

(2) Phased objectives and technical route

In view of the rapid technological progress, this report divides the "15th Five-year Plan" into two phases.

Phase 1 (2025–2027) objectives: carry out research on novel key technologies for large-capacity, low-cost, and intelligent solar tower plants. When the single-unit capacity increases from 100 MW to 500 MW (storage period ≥ 8 h), the installed cost per kW will reach CNY 12,500, plant operation will be automated, O&M cost will be lowered, and the LCOE will decrease to about CNY 0.51/kWh. Main paths for cost reduction:

(a) When the single-unit capacity of CSP plant increases from 100 MW to 300 MW (storage period ≥ 8 h), the turbine efficiency and electric output will be obviously improved, the installed investment per kW will be reduced and the LCOE will be lowered from CNY 0.82/kWh to about CNY 0.64/kWh.

(b) The O&M cost of plant mainly covers the expenses of repair, personnel work and welfare, insurance, materials, and others. As the equipment reliability and plant automation is improved, and the plant O&M level is continuously improved, the repair costs and staffing need will be reduced, thus significantly lowering the O&M expenses. The first batch of CSP demonstration plants have accumulated considerable operation and maintenance experience and established relatively mature cost management systems. Compared with the O&M cost obtained by the method in the *Guidelines for Economic Evaluation of CSP Projects*, the actual O&M cost is relatively low and the LCOE after O&M optimization can be reduced by CNY 0.07/kWh to about CNY 0.57/kWh.

(c) By optimizing the heliostat field control strategy, reducing the abandoned solar energy, enhancing the efficiency of solar concentration and collection system, and optimizing the peak shaving operation strategy of CSP plant, the income can be increased and the LCOE can be reduced to CNY 0.55/kWh;

(d) Adopt new drive mechanisms, optimize the heliostat design and reduce the steel consumption; optimize the structural design of MS tank, reduce the consumption of MS and tank material, and replace long-shaft pump with short-shaft pump, to realize localization of MS pump; adopt domestic receiver materials to lower the cost of relevant equipment; adopt system integration and modular, digitalized and intelligent construction measures to lower the cost of pipelines and construction and installation, to have the overall cost decrease by about 7% and the LCOE reduce to about CNY 0.51/kWh.

Let's take the 350 MW CSP project organized by Qinghai Province through competitive allocation in 2024 as an example. Its annual DNI is 2,009 kWh/m^2, heliostat field area is 3.6 million m^2, annual utilization duration is 2,700 hours, and the LCOE is about CNY 0.508/kWh.

Phase 2 (2027–2030) objectives: With continued scale expansion of solar thermal industry, further expansion of single-unit capacity, and gradual improvement of CSP standardization system, the cost per kW will be further reduced. And the key technologies of high-temperature MS and supercritical power generation will be upgraded. When the annual installed capacity of CSP plant reaches 5-10 GW, single-unit capacity reaches 600 MW, installed cost per kW

is ≤ CNY 11,000, plant operation is highly automated, and high-temperature novel MS and other technologies become mature, the LCOE will drop to about CNY 0.43/kWh. Main paths for cost reduction:

(a) When the single-unit capacity of CSP plant is further increased from 300 MW to 600 MW (storage period ≥ 8 h), the turbine efficiency will increase, the installed investment per kW will decrease, and the LCOE of CSP plant will reduce from CNY 0.51/kWh to about CNY 0.49/kWh;

(b) The scale of solar thermal industry continues to expand, the annual installed capacity of CSP plant reaches 5-10 GW, the CSP standardization system tends to be perfect, and large-scale competitive strength, standardized reproduction and processing, and centralized procurement are realized, to lower the overall cost by about 10% and reduce the LCOE to about CNY 0.45/kWh.

(c) Further improvement of the intelligent level of plant makes the operation highly intelligent, and only a small number of personnel are required on duty, further cutting the O&M cost of plant and reduce the LCOE to about CNY 0.44/kWh.

(d) Breakthroughs in high-temperature novel MS and other key technologies make high-temperature MS increase from 565°C to 620°C, with the temperature difference in the MS TES system rising from 275°C to 355°C. The thermoelectric efficiency of the system will increase with increasing values of system parameters; when the electric output of the system remains unchanged, the required amount of heat to be absorbed will decrease, and the costs of solar concentration and collection system, and TES and exchange systems will therefore be reduced; as the temperature difference in the MS TES system increases, the amount of thermal energy stored per unit mass will increase, the amount of MS used will decrease, and the cost of the TES and exchange systems will be further reduced. Mature application of high-temperature new MS will reduce the overall cost of plant by about 2%, lowering the LCOE to about CNY 0.43/kWh.

(e) The adoption of high-temperature MS or solid particles for heat absorption and storage in combination of supercritical Rankine cycle technology with steam of 610°C can boost the efficiency of TGU from 45% to 48%, and lower the LCOE to about CNY 0.39/kWh.

6.4 Prediction of and main technical measures for CSP cost reduction during the early 16th Five-year Plan period

With the technological progress in solar thermal industry, it is expected that by 2033, significant breakthroughs in 1,000 MW CSP technology, including the supercritical Rankine cycle technology and supercritical CO_2 Brayton cycle CSP technology, will reduce the LCOE of CSP plants, for example, Delingha site (annual DNI of 2,009 kWh/m^2) to about CNY 0.35-0.4/kWh.

Main paths for cost reduction:

(a) When the single-unit capacity of CSP plant is further increased from 600 MW to 1,000 MW (storage period ≥ 8 h), the turbine efficiency of large-capacity, high-temperature, and high-voltage power plant will increase, the installed investment per kW will decrease, and the LCOE of CSP plant will reduce from CNY 0.43/kWh to about CNY 0.41/kWh;

(b) With further scale expansion of CSP plant, the national annual installed capacity will reach above 10 GW, the effect of scale strategy will be obvious and the centralized procurement cost will be further reduced, resulting in a

reduction in the LCOE of CSP plant to CNY 0.40/kWh.

(c) Remarkable achievements in researches on cutting-edge technologies such as high-temperature MS, particle receivers, and supercritical CO_2 Brayton cycle power generation, and gradually maturing of related technologies will result in significant improvement of power generation efficiency and greatly reduce the cost of CSP technology. 100 MW supercritical CO_2 power plants could be established, to reduce the LCOE to CNY 0.35/kWh.

6.5 Cost reduction pathways for line-focusing CSP plants

The cost line of parabolic trough solar collectors and Fresnel solar collectors focus on solar collector. Owing to the standardized design and modular production, and the fact that the heliostat field consists of linear collectors connected in series and loops in parallel, linear concentrating CSP technology is more suitable to the deployment of large capacity and scale power plants. With the determination of market scale objectives and the maturation of supporting production chains, parabolic trough CSP technology has significant cost-reduction potential. Based on the current development of parabolic trough CSP technologies at home and abroad, there are three cost-reduction paths:

(1) Increasing the aperture width of parabolic trough collectors

Currently, the concentration ratio of parabolic trough collectors generally ranges from 80 to 90. For a fixed concentration ratio, increase of the solar collection temperature may lead to a decrease in thermal efficiency. However, at the same solar collection temperature, increasing the concentration ratio can improve the photothermal conversion efficiency of the collector. Improving efficiency is the most direct way to reduce system cost. Therefore, to further improve the efficiency of parabolic trough CSP plant and reduce cost, concentration ratio and solar collection temperature should be improved coordinately.

The aperture width of parabolic trough collector has evolved from the earliest 2.55 m LS-1 collector, 5 m LS-2 collector, 5.7 m LS-3 collector, 6.7 m Sener-2 collector, 7.5 m Ultimate Trough collector, and 8.2 m Spacetube to the 8.6 m collector recently developed by domestic manufacturers. Some manufacturers have even announced plans to develop collectors with apertures exceeding 10 m. By continuously increasing the aperture width, it is possible to further improve the concentration ratio of parabolic trough collectors while ensuring a certain level of concentration efficiency, thereby addressing the issue of decreased solar collection efficiency caused by replacement of thermal oil with MS of a higher operating temperature. On the other hand, as the aperture width of the parabolic trough collector increases, the number of collector system loops can be significantly reduced for the same lighting area. For example, while keeping the total lighting area unchanged, increasing the aperture size of PTCs from 5.7 m to 8.6 m can reduce the number of solar collector loops by about 40%, significantly reduce the number of collector foundations, local operating controllers (LOC), hydraulic drive systems, flexible connections, transmission pipelines and their inlet/outlet valves, and the quantity of insulation materials accordingly, thereby significantly lowering the cost of heliostat field.

(2) Increasing the single-unit capacity of parabolic trough CSP plants.

The single-unit installed capacity of parabolic trough CSP plants started to show an increase trend from the SEGS (Solar Electric Generating Station) I plant of about 13.8 MW in the U.S., gradually reaching 30 MW, 50 MW, 80 MW, 100 MW, 160 MW, and up to 200 MW in the Noor Energy 1/DEWA IV 3×200 MW trough segment project commissioned in 2023. With the expansion of single-unit capacity, the economies of scale have proven to effectively reduce the LCOE of parabolic trough CSP plant projects and promote the development of parabolic trough CSP

technology.

The single-unit installed scale of parabolic trough CSP plants of above 200 MW can increase the purchase volume of various equipment and components, facilitate continuous and stable mass/batch production in the supply chain, reduce the unit cost of equipment and components, dilute indirect costs such as design and overhead costs, and reduce the initial investment. In addition, the unit cost of plant operation and maintenance during the operation phase can be reduced through centralized management, operation and maintenance of large-scale projects. Meanwhile, parabolic trough CSP plants with a single-unit capacity of over 300 MW can be matched with the most advanced and mature large-capacity thermal power turbine units in China, achieving higher generation efficiency. Additionally, the increase in installed capacity will enhance the peak-shaving ability of projects, cut the O&M costs, and further drive the reduction in LCOE.

(3) Raising the solar collection system temperature and reducing cost by using MS as the HTF.

For parabolic trough CSP plants already in operation, biphenyl and diphenyl ether thermal oil is mainly used as the HTF. Due to the temperature resistance property of thermal oil, the maximum operating temperature is generally controlled at 393°C, making it difficult to further raise the temperature, which limits the further improvement of power generation efficiency of turbine-generator units (usually ≤ 40%). Compared with MS tower plants, thermal oil parabolic trough plants require an additional thermal oil and MS heat exchange system in addition to the thermal oil and water heat exchange system. This reduces the heat exchange efficiency. Besides, the low temperature of MS TES leads to large amount of MS, making it difficult to achieve decoupled operation of solar collection and power generation, and limiting its application in wind and solar energy bases.

Compared with thermal oil, the use of MS as the HTF and TES medium can increase the temperature at the solar collection outlet of the system, reduce the number of thermal oil and MS heat exchange systems, and improve the thermoelectric conversion efficiency of TGU. On the other hand, MS cost is about 1/4 that of thermal oil. The use of MS can eliminate the thermal oil system, reduce the amount of MS in TES system, achieve decoupled operation of solar collection and power generation, and will significantly lower the LCOE of the system when combined with parabolic trough collectors of high concentration ratio and large aperture.

However, it is important to note that although the use of MS as the HTF increases the temperature of solar collection system, its corrosiveness and high freezing point will raise the material requirements for the metal inner tube of parabolic trough receiver tubes and system pipes, increase the investment in electric tracing systems, and raise the self-consumption during night operation, leading to certain increase in the system cost. Therefore, new MS with low freezing points and wide temperature ranges, and highly reliable parabolic trough receiver tubes with low thermal loss and using MS, will be the key technologies that need to be addressed in current parabolic trough CSP plants.The resolution of these issues will further reduce the cost of parabolic trough CSP plants.

Chapter VII Whole Lifecycle Carbon Emissions of CSP Plants

7.1 International research results

CSP technology is an important technology of power generation by renewable energy. Domestic and foreign scholars have conducted life-cycle assessment studies to evaluate its environmental impact throughout its entire life cycle, from raw material acquisition, product manufacturing, to post-use disposal. Current studies findings show that CSP plants have great carbon emission reduction capacity and environmental benefits, with an average life cycle carbon emission of about 18 gCO_2eq/kWh[38].

According to a study by Viebahn et al. in 2008, the carbon emissions of the 20 MW Solar Tres tower plant in Spain were approximately 22 gCO_2eq/kWh; a study in 2011 showed that, with an average annual direct normal irradiation (DNI) of 2,000 kWh/m^2, the carbon emissions of Andasol-I 50 MW parabolic trough CSP plant in Spain were 33.4 gCO_2eq/kWh, while under the DNI of 2,500 kWh/m^2, its carbon emissions were 30.9 gCO_2eq/kWh. A study by Corona et al. found that the carbon emissions of the parabolic trough CSP plant in Ciudad Real of Spain were 26.6 gCO_2eq/kWh[39].

A life-cycle assessment study by Burkhardt et al. (2011) from the U.S. National Renewable Energy Laboratory on a 103 MW parabolic trough plant (wet cooling) in California showed that the life cycle carbon emissions were 26g CO_2eq/kWh, water consumption was 4.7 L/kWh, and energy demand was 0.4 MJeq/kWh. The energy payback time (EPBT) was approximately one year. The use of air-cooled units would lower the water consumption by about 77%, but increase greenhouse gas emissions and cumulative energy demand by about 8%. Additionally, the use of synthetic nitrate salts results in about 52% more greenhouse gas emissions compared with the use of mined nitrate[40].

LCA studies by Gemma Gasa et al. (2022) from Spain on a 110 MW tower plant with storage period of 17.5 hours and a 110 MW tower plant without TES system found that the environmental impact of the tower plant with TES system was 9.8 gCO_2eq /kWh, while the one without TES system had carbon emissions of 31 gCO_2eq/kWh [38].

7.2 Domestic research results[39]

Taking the 135 MWe solar tower plants in Northwestern China as research objects, Zhu Xiaolin et al. from Zhejiang Cosin Solar CSP Technology Research Institute Co., Ltd. calculated the carbon emissions over the whole lifecycle of such plants. The parameters and conditions set for the research are: whole life cycle of plants: 25 years; average annual direct solar irradiance: 2,015 kWh/m^2; mirror field area: 1.45 million m^2; average annual CSP efficiency: 14.9%; TES period by cold and thermal MS TES tanks: 11.2 h; cooling method: direct air cooling. For a single solar tower plant, the design annual electric output taking into account peak load regulation is 435 GWh, and the annual feed-in power by the plant taking into account auxiliary power consumption is 395 GWh. The life cycle of a solar tower plant can be divided into four phases, namely, plant equipment and material manufacturing

The research has found that the carbon emissions per kWh by a solar tower plant over its whole life cycle is 22.7 CO_2eq/kWh, which is a low level of carbon emissions per unit by similar power plants at home and abroad. In addition, it has also been found that the carbon emissions per kWh by a solar tower plant over its life cycle decline as the average annual DNI and TES period increase, and the rate of such decline gradually decreases.

Among the carbon emissions per kWh by the plant during the four phases over the whole life cycle, the carbon emissions per kWh during the equipment and material manufacturing phase are the highest, accounting for 87.40% of the total carbon emissions per kWh; the carbon emissions per kWh during the operation and maintenance phase next, accounting for 7.16% of the total carbon emissions per kWh; the carbon emissions per kWh during the abandonment phase are 0.75 g CO_2e/kWh, accounting for 3.33% of the total carbon emissions per kWh by the plant over its whole life cycle. the carbon emissions per kWh during the equipment and material manufacturing phase are the lowest. The carbon emissions per kWh in the four stages are presented in the table below.

Table 7.2-1 Whole Lifecycle (WLC) Carbon Emissions (per kWh) of 135 MWe Solar Tower Plants in Northwestern China

LCA phase	Carbon emissions per kWh (g CO_2e/kWh)	Proportion	Description
Equipment and material manufacturing phase	19.8	87.4%	For a single solar tower plant, the carbon emissions per kWh by the mirror field are the highest (7.87 gCO_2e/kWh), accounting for about 40.8% of the total WLC carbon emissions per kWh by the plant. The reason is that the fabrication of heliostats at a solar tower plant requires large quantities of steel and glass. The carbon emissions per kWh by the TES system are 4.04 gCO_2e/kWh, accounting for about 20.9% of the total WLC carbon emissions per kWh by the plant. Specifically, the carbon emissions per kWh by the hot and cold salt tanks account for 49.7% and 12.9% of the carbon emissions per kWh by the TES system, respectively. The reason is that the hot and cold salt tanks are constructed of large quantities of materials, and their weights are 2248 t and 2120 t, respectively. The carbon emissions per kWh by the account for about 9.8% of the total WLC carbon emissions per kWh by the plant. The solar tower and its foundation consume large amounts of high-grade reinforced concrete.
Construction and installation phase	0.48	2.11%	The carbon emissions per kWh in the construction stage are 0.41 gCO_2e/kWh, and the carbon emissions per kWh in the installation stage account for a relatively small proportion.
Operation and maintenance phase	1.62	7.16%	The carbon emissions per kWh during the operation and maintenance phase include emissions from one-time energy consumption for plant commissioning, electricity consumption for heating, and energy consumption for employee canteens and transportation. The energy consumption modes adopted during the operation and maintenance of different types of CSP plants have great impacts on the carbon emissions per kWh by these plants.
Abandonment phase	0.75	3.33	The carbon emissions per kWh during the dismantling of plant buildings and equipment account for 57.33% of the total carbon emissions per kWh during the abandonment phase.
Prepared by CSTA			

Calculations show that the total electricity output of 135 new solar tower plants (each with a capacity of 135 MWe) is equivalent to 1% of the electricity generated by all thermal power plants in China, and these new solar tower plants can reduce CO_2 emissions by 49 million tons per year and by 1.225 billion tons over their whole lifecycle.

Chapter VIII Challenges and Recommendations for CSP Development in China

8.1 Challenges faced by China's CSP industry

Challenges to CSP industry development mainly include:

8.1.1 China's CSP industry is developing rapidly, and the costs of CSP plants are declining rapidly but are still higher than those of solar PV and wind power plants.

In September 2016, NEA organized the implementation and construction of a number of CSP demonstration projects in order to promote the development of China's CSP industry, create a domestic CSP equipment production chain, and develop system integrators. For these projects, the benchmark electricity price approved by NDRC CNY 1.15 /kWh [10] (which is the same as that of solar PV-generated electricity in 2011; the total installed capacity of solar PV power plants in China as of 2011 is 3 GW). Through the construction of CSP demonstration projects, China has fully mastered the core technologies for solar concentrators, receivers, and heat storage and exchange systems of CSP plants and technologies for the design, integration, construction and operation of CSP plants suitable for application in in high-altitude alpine areas in China, broken foreign monopoly in the CSP industry, and developed CSP technologies with complete intellectual property rights. In addition, the number of enterprises and institutions engaged in the CSP industry and their product supply capacity have increased significantly. These advances have provided a solid foundation for the future development of China's CSP industry.

In the *Notice of the National Development and Reform Commission on Matters Related to the 2021 New Energy Feed-in Tariff Rate Policy*, it is stated that, after 2019, China will improve the policy for CSP-generated electricity prices at the opportune time and gradually reduce the prices of electricity generated by newly constructed CSP plants based on the development status of the CSP industry and the reduction of power generation costs. However, according to the *Opinions on Promoting the Healthy Development of Non-hydro Renewable Power Generation* issued by the Ministry of Finance in January 2020, new CSP projects will no longer receive financial subsidies/assistance from the Chinese government[41]. According to the *Notice of the National Development and Reform Commission on Matters Related to the 2021 New Energy Feed-in Tariff Policy* (NDRC Pricing Document [2021] No. 833), from 2021 onwards, the electricity prices for newly approved (registered) CSP projects shall be determined by competent provincial authorities (pricing authorities) and may be determined through competitive allocation if conditions allow. If the electricity price for a CSP project is higher than the local benchmark price of coal-fired power plants, the part within the benchmark price will be settled by the responsible power grid enterprise[37].

As of the end of 2024, the total installed capacity of grid-connected CSP units in China was less, about 900 MW; China's CSP industry is in the early stage of development, and the LCOE still remains at high levels; therefore, unlike the wind power industry that has been developed under subsidies for decades, the CSP industry does not have conditions for grid parity. In addition, importance has not been attached to the quality of electricity from CSP plants, and the value

of CSP plants in promoting new energy consumption has not been evaluated in a scientific manner and reflected in electricity prices.

8.1.2 The CSP industry chain is complete with supporting services, but the limited number of CSP plants cannot provide sufficient driving force.

The application of CSP technologies started later in China compared with the case in other countries. The world's first commercial solar power plant was built in the 1980s (in the United States), and Europe's first commercial solar power plant was put into operation in 2007[42]. In comparison, China's first 50 MW solar power plant was put into operation in 2018[43]. CSP involves complex systems and multiple disciplines such as thermodynamics, heat transfer, optics, materials science, and automatic control. Through the construction of CSP demonstration projects, China's overall technical capability for CSP development has been improved to such an extent that it is basically on par with the level of second-generation commercial CSP plants in foreign countries, and the design, operation and maintenance of some CSP plants in China have reached the international leading level. However, due to the high initial investment of CSP projects and the absence of favorable national feed-in tariff policies and subsidies, there is a lack of activity in CSP investment; the opportunities for iterative upgrading of CSP technologies are insufficient; standardization and centralization have not been achieved in some aspects, such as design, construction, and equipment manufacturing; economies of scale have not been fully achieved; the LCOE still remains at high levels. These factors limit the large-scale development of China's CSP industry. Moreover, the new energy + grid-forming energy storage technology is gradually maturing, and the costs of powerful battery energy storage systems that have emerged with the development of electric vehicles are declining continuously. Therefore, how to rapidly reduce costs and improve efficiency is a huge challenge for the development of China's CSP industry.

8.1.3 CSP plants have been used for peak shaving, but their installed capacity is insufficient to reflect their values.

CSP is a renewable power generation technology that is capable of being adjusted flexibly and supporting power systems, and it is the only renewable energy technology having the potential to replace coal-fired power plants. However, the main purpose of the first batch of CSP demonstration projects is to verify the feasibility of the CSP technology. For existing large wind and solar power bases, the installed capacity and system configuration of CSP plants are subject to the economic considerations for grid parity, CSP plants are positioned as "power sources for peak shaving", and their installed capacity accounts for a relatively small proportion of the total installed capacity of energy bases (the CSP to wind/PV capacity ratio is 1:6 or 1:9), making it difficult for them to support the power grid/system. In addition, there is no quantitative data demonstrating the values of CSP plants in the construction of a new electric power system where new energy plays a dominant role, including the role played by CSP plants in improving grid stability and increasing the installed capacity of wind and PV power plants, and such values have not been reflected in electricity prices.

8.2 CSP industry development goals

It is stated in the *Energy Law of the People's Republic of China* that "actively develop the CSP industry"[6], so the development goals of CSP industry are to replace thermal power as a base load and peak-shaving power and as the power core combined with wind and PV generation.

The overall goal is to be capable of replacing thermal power by 2030.

1) Single-unit or multi-unit GW-level CSP plants can be built based on current solar collection technology and modular concentrator field;

2) Replacing thermal power can be achieved in 2030 by building wind and PV hybrid plants based on current solar collection technology, and thermal power can be completely replaced by supplementing 10% capacity;

3) At the end of the "15th Five-year Plan" period, the electricity rate of CSP projects can be CNY 0.39/kWh; by reducing the cost of concentrators and improving thermodynamic cycle parameters and other technical progresses,

4) During the early "16th Five-year Plan" period, the electricity rate of CSP projects can be CNY 0.35/kWh, and 50 MW-level supercritical CO_2 CSP Brayton cycle technology and 1,000 MW-level solar supercritical Rankine cycle can be realized.

8.3 Recommendations for the development of China's CSP industry

8.3.1 The first recommendation is to investigate and develop a two-part electricity pricing system and capacity pricing system for CSP plants during the transition from subsidy removal to market-based development.

The initial investment for CSP plants is high. Currently, CSP plants at existing large wind/solar energy bases are positioned as "power sources for load regulation" and developed together with wind/solar farms in an integrated manner. Under the prevailing operation strategy for such energy bases, PV power plants operate during noon hours when solar radiation is high, while CSP plants only generate electricity during peak hours in the morning and evening, and the annual service hours of CSP plants have decreased from about 4,000 hours to 2,000 hours or even lower levels. It is recommended to first carry out a market-oriented reform of the current electricity pricing mechanism for new energy bases; investigate and develop a two-part electricity pricing system for CSP units; determine the applicable electricity prices and national compensation standards for CSP plants based on the costs of typical CSP plants across China; create relatively stable profit expectations and income sources for CSP plants; give full play to the role of CSP plants in providing load regulation and ancillary/supporting services to the electric power system, and thereby increase the proportion of electricity from renewable sources at new energy bases.

In addition, it is recommended to, based on TGU capacity pricing, couple and monetize the electric energy value (medium- to long-term or spot electricity markets), load regulation value (auxiliary services) and environmental value (CCER, green electricity, green electricity certificates) of CSP, improve activity in investment for CSP projects, ensure the continuous healthy operation of the CSP industry, and promote new energy consumption at a larger scale in the context of gradual de-coaling and "dual carbon" goals. In the future, with the development of China's electricity market

and the continuous improvement to top-down design, the prices of electricity generated by CSP plants will eventually be determine by the market rather than the government, the competitive advantage of CSP plants in the electricity market will be enhanced continuously, and CSP plants will adapt to the needs of system load regulation in the current stage and baseload power supply in the future, thus ensuring the long-term adequacy of power generation capacity in the electric power system.

8.3.2 The second recommendation is to conduct research on the grid support capability of CSP plants.

CSP technology is a renewable energy generation method which integrates the characteristics of CSP, large-scale TES and grid synchro. CSP has the characteristics of synchro and can provide moment of inertia, primary frequency regulation and other supports, and shows better regulating characteristics than conventional thermal power units and thus features high ramping rate and short start and stop time, etc.; CSP plants are usually provided with high-capacity TES systems and thus can fulfill steady functional output and flexible regulation.

Due to economic considerations for grid parity, the CSP/PV capacity ratios of large new energy projects are very low, and the role of such projects in improving grid stability and reliability still remains unclear. The low capacity ratios of large new energy projects are probably far from sufficient to meet the power quality and transmission requirements. It is recommended to conduct research on the grid support capability of CSP unit as soon as practicable;

build new energy bases based on the characteristics of DC power transmission from 10,000 MW-scale large energy bases, the characteristics of the power grid in West China, and the electricity demand of end users to provide 100% new energy and participate in peak load and frequency regulation in the electric power system; conduct research on the optimization of grid operation and control strategies; optimize the transmission and consumption capacity configuration and control of large energy bases based on the analysis and study of the characteristics of various energy storage technologies (such as CSP, electrochemical energy storage, pumped hydro energy storage), the response characteristics and technical and economic aspects; verify the actual performance of CSP plants in peak load regulation and their grid support capacity using project data; Moreover, it is suggested in the planning phase and in the places where the solar thermal energy resource conditions permit to put the flexible regulation and supporting capacity of CSP into full consideration, make a reasonable planning and fully coordinate the flexible resources of wind power, PV power and CSP, optimize the generation capacity and TES capacity of CSP plants in consideration of the resource characteristics and operation characteristics of new energy to promote the consumption of new energy and support the safe and stable operation of new electric power system.

8.3.3 The third recommendation is to carry out demonstration projects for cutting-edge CSP technologies and continue to deepen basic research.

Technological innovation is a driving force for the sustainable development of the CSP industry. It is recommended to contact research on disruptive cutting-edge technologies as soon as practicable; provide support for the research and development of new CSP technologies and the implementation of demonstration projects for such technologies;

carry out basic research on low-cost solar concentration techniques covering the shape of the sun, the energy properties of solar radiation, adaptive control methods for curved optical surfaces, the effects of high-density concentrated solar energy on surface microstructures, solar-to-chemical energy conversion, storage and reaction equipment, and supercritical steam generators; carry out research and demonstration projects for 20-50 MWe CSP plants with HT supercritical CO_2 power cycles based on the basic research conducted on solar energy generation with supercritical CO_2 during the "13th Five-Year Plan"; apply CSP plants using environmentally friendly heat transfer and storage fluid and 50 MW-scale solar thermochemistry gas-fired power plants. carry out theoretical research on cutting-edge CSP technologies such as energy conversion based on the second-law efficiency and power generation coupling solar concentration and HT hydrogen fuel cell systems.

8.3.4 The fourth recommendation is to continuously summarize the experiences of existing commercial CSP plants, make technological innovation, and reduce costs.

As of December 31, 2024, China has built different types of independent CSP plants about 550 MW in different places, and in 2021, China initiated the CSP plants with the total capacity of 500 MW respectively in Baicheng, Jilin and Golmud which are complementary to PV and wind power plants, and in 2023 and 2024, China also organized relevant projects. Relevant ministries and commissions in China shall organize scientific research and industrialization strength and break corporate boundaries to track and summarize technologies of the plants and find the scientific and technological problems thereof in combination with the actual operation, then concentrate on making breakthroughs in the development of key technologies, build a complete industrial chain and system integration capacity, and optimize product structure, which will play an important role in the advancement of CSP technology and is also the original intention of China to establish demonstration projects. The fifth measure is to organize specialized third-party technicians to summarize the experiences of CSP demonstration projects and test/evaluate the demonstration CSP plants in operation. It is recommended to test the performance parameters of the core equipment, subsystems, systems and auxiliary equipment of demonstration CSP plants, prepare detailed test reports, review experiences and lessons learnt, and develop equipment design methods, operation procedures, system design specifications, and accident management guidelines based on the test data.

Since CSP plants integrated with solar PV and wind power stations will need to be started up and shut down frequently and operate at significantly different loads in the future, thermal stress problems may occur frequently in solar receivers, heat storage and exchange equipment, and steam turbines. The fatigue and safety issues arising from frequent startups and shutdowns are not to be neglected. Therefore, it is necessary to conduct relevant research and further improve the safety and reliability of materials and equipment. It is recommended to conduct research on equipment such as solar-specific steam turbines, 1,000 MW-scale solar receivers, MS storage tanks, and large-capacity steam generators and carry out the research, development and validation of lightweight tube collectors with large apertures and intercept factors and related products such as supports/brackets, mirror reflectors, and collectors.

The low-cost PV heating molten salt technology has a huge impact on the collector fields of CSP plants. Among

the systems of a CSP plant, the collector field has the highest cost of capital. On the one hand, it is necessary to develop all-weather concentrators and collector field error detection, calibration and control systems based on the needs of existing commercial CSP plants, improve the dynamic accuracy of concentrators, and reduce spillage losses in solar collector systems. On the other hand, it is necessary to adopt new solar concentration/collection methods to reduce cosine loss and truncation loss, improve the average annual optical efficiency of concentrator fields, and use smaller concentrator fields to provide energy output, thereby reducing the costs of concentrator fields.

It is necessary to develop high-temperature and high-stability photo-thermal conversion materials with a wide temperature range, high-temperature alloy, high-temperature long-life, high energy density and low-cost "thermal energy charge/storage/release" materials, flexible reflective materials and high-temperature (above 600℃) transparent aerogel materials for collector tubes to fulfill high parameters for CSP and further improve the efficiency.

8.3.5 The fifth recommendation is to launch CSP demonstration projects with large 1,000 MW capacity as soon as practicable.

It is necessary to promote the implementation of GW-scale large-capacity, low-cost CSP plants. The electric output of plants is an important factor to affect the economical efficiency of plants. Commercial CSP plants apply TGUs for generation. When other conditions remain unchanged, the thermoelectric efficiency of TGU directly affects the electric output, and the installed scale and design parameters of TGU have an important influence to its efficiency. Larger installed scale can reduce the thermal energy losses output by unit energy to further improve the overall efficiency; therefore, higher thermal efficiency can usually be achieved by large TGUs; moreover, with the expansion of TGU scale, the investment in generation system per KW and the operation and maintenance cost are reduced, and the economic efficiency of plants are improved. Therefore, it is recommended to carry out demonstration projects for large CSP + hybrid energy bases with large single-unit capacity and high capacity ratios as soon as practicable, summarize the characteristics of such energy bases with respect to power generation and peak shaving, and increase the capacity of CSP plants to the 1,000 MW scale to support the construction of the new electric power system where renewable energy plays a dominant role.

8.3.6 Quality assurance - establishing quality testing standard system

The relevant testing and measuring equipment in China are mainly imported equipment. Considering that most of the testing and measuring instruments used in China are imported products, it is recommended to focus on the development and engineering application of instruments such as high-energy flow density measurement systems, error measurement instruments for production lines, onsite solar concentrators and parabolic trough collectors, and HT molten salt and solids flow meters. Strengthen the building of systemic and standard CSP testing technologies, support and match industrial development needs, and particularly establish normalized and rationalized CSP plant design and acceptance standards in overall planning. In the light of improving the research and development as well as engineering application of high-precision testing and measuring equipment, it is recommended to develop the research, development and engineering application of instruments of high-energy flow density measurement systems and those on production

lines and on site such as concentrator error measurement instruments, tube collector error measurement instruments, HT MS thermal conductivity coefficient analyzers, HT MS simultaneous thermal analyzers, HT MS and solids flow meters, and make the relevant quality testing standards and performance testing standards and establish the relevant quality testing and performance testing capability.

8.3.7 The sixth recommendation is to promote the application of multi-energy complementary low-carbon power generation technologies where CSP plays a dominant role.

It is recommended to promote the application of multi-energy complementary power generation technologies in which CSP, thermal power and nuclear power complement each other, CSP is combined with the HT hydrogen fuel cell technology, or CSP and biomass energy complement each other; for large energy bases, consider the use of 1,000 MW-scale hybrid energy systems where CSP and thermal power are integrated and CSP plays a dominant role. The objective is to increase the peak shaving capacity by 4 times and reduce coal consumption per kWh by 70%.

Chapter IX Annexes

9.1 CSP-related News in 2024

Looking back at 2024 full of opportunities and harvests, the CSP industry wrote wonderful and productive chapters. CSTA was committed in promoting the development of CSP industry. It forged ahead bravely with industry colleagues, and resonated with the industrial chain with the same frequency, planning a new chapter. Relevant technological achievements of CSP industry were actively promoted on the WeChat Official Account of "CSTA". In 2024, it released (including reprinted) 1,375 industry information, increased by 21% than 2023. The top 100 most-read hot news are below, from which we can also see the major events in China's CPS industry in 2024.

Table 9.1-1 High-profile News 2024 (released on the WeChat ID of CSTA)

No.	Title	Reading volume	Enacted/issued on
1	The excellent engineering consultation results of China Electric Power Planning and Engineering Institute (EPPEI), Inner Mongolia Electric Power Survey & Design Institute Co., Ltd., PowerChina Northwest Engineering Corporation Limited & Zhongnan Engineering Corporation Limited, and Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited in 2024 achieve great success project profile attached	17,125	October 29
2	Shandong Electric Power Engineering Consulting Institute Corp., Ltd. won the bid for EPC of two CSP plants in succession.	15,547	March 28
3	People's Daily: China leads the world to successfully research and develop the first supercritical CO_2 CSP plant.	14,111	November 29
4	NDRC and other five ministries and commissions: Promote the large-scale development of CSP and joint operation of CSP-wind-PV power systems.	11,160	October 30
5	Mr. JianhuaZhang, Director of the National Energy Administration: The pricing mechanism of new-type energy storage and CSP is not yet sound, and the energy transition policy synergy is urgent to be strengthened.	11,145	February 19
6	Proposed ratio among Inner Mongolia, Qinghai and Xinjiang: Explore modes for the stable supply of green power through joint operation of CSP, wind and solar PV power plants.	9,916	August 16
7	Good news! *Key Technologies for Safe and Efficient Solar Photo-thermal Conversion and Storage in CSP Plants and Their and Application* for CSP plants of PowerChina Northwest Engineering Corporation Limited, Xi'an Jiaotong University and Shouhang Hi-Tech Energy Technology Co., Ltd. won the first prize of Science and Technology Progress Award of Shaanxi Province.	9,901	April 11
8	SPIC, CGN, CSSC, Dongfang Electric Corporation (DEC), China National Chemical Engineering Group Corporation Ltd.… are listed on the A-level central enterprise list upon Assessment of the Operational Performance of Persons in Charge of Central Enterprises in 2023.	9,519	July 25
9	XiaohuiZhao of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited presides over the discussion of "Key Development Technologies of CSP under electricity market" participated in by 8 experts.	9,133	September 20

No.	Title	Reading volume	Enacted/issued on
10	The 300 MW MS TES + Electrochemical Energy Storage Project (with a total investment of CNY 2.395 billion) is implemented in Xinjiang Changji National Agricultural High-tech Industry Demonstration Zone.	9,251	November 2
11	The successful candidates of Jixi 100 MW CSP EPC Project of SPIC Jilin Electric Power Co., Ltd. are publicized.	9,023	February 28
12	Shandong Electric Power Engineering Consulting Institute Corp., Ltd. reaches a strategic cooperation agreement with SEPCOIII Electric Power Construction Co., Ltd.	8,527	April 13
13	Processor Ruzhu Wang's Team: Heat pump - phase change TES coupling technology contributes to the global energy transition.	7,517	December 11
14	Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited won the bid of feasibility report technology service of Datang 200 MW CSP + 1,800 MW PV Hybrid Project.	7,262	December 3
15	Comments: the next hotspot of energy storage - long-duration energy storage	7,213	October 17
16	SEPCOIII Electric Power Construction Co., Ltd. won the bid of the owner's engineer service of Delingha 200 MW Solar Tower Plant of CGN New Energy Holdings Co., Ltd.	6,651	April 4
17	2025 National Energy Work Conference: Drive the large-scale development of CSP plants, actively promote the construction of the second and third batches of large-scale wind and PV power base project in deserts.	6,403	December 15
18	The solar tower of PowerChina (Ruoqiang) New Energy 100 MW CSP Plant is topped off smoothly.	6,377	August 26
19	Kubuqi Desert 2×300 MW HT MS Extraction Energy Storage Deconstruction Project of Inner Mongolia Three Gorges Mengneng Energy Co., Ltd. (with a total investment of CNY 2.486 billion) is put on record.	6,362	July 29
21	CNY 190 million! CHN Energy invests to construct the world largest single zero-carbon seasonal solar TES project.	6,291	June 13
22	The first linear Fresnel CSP plant in Xinjiang under EPC of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited passes successfully the first and foundation treatment supervision and inspection.	6,225	April 28
23	XueliangMa, the secretary of Turpan Municipal Party Committee, investigates and surveys the PowerChina Toksun CSP + PV Hybrid Project.	6,205	February 21
24	Gansu Province Installation & Construction Group Co., Ltd. won the bid for PC of two bid sections of Dunhuang 100 MW MS Linear Fresnel CSP Plant and TES System Science and Technology Project (with investment more than CNY 1.2 billion).	6,113	October 8
25	PowerChina Northwest Engineering Corporation Limited won the bid for EPC of the world first artificial storage compressed air energy storage project.	5,929	January 13
26	Good news! Processor RuzhuWang' Team won the second prize of National Prize for Progress in Science and Technology!	5,648	June 24
28	The global largest in-progress single solar tower plant is officially commenced.	5,769	March 15

No.	Title	Reading volume	Enacted/issued on
29	CSP plants in Qinghai, Gansu, Xinjiang and Tibet are promoted steadily; the CSNP Urat Parabolic Trough CSP Plant is under steady operation; for products and services related to CSP and energy storage of more than 70 units, refer to…	5,678	March 31
30	The solar tower of Turpan CSP Project of Tangshan Haitai Solar undertaken by Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited is above 50 m.	5,589	April 30
31	The core equipment for compressed air energy storage makes a great breakthrough! Dongfang Boiler Co., Ltd. won the bid of the complete equipment of heat transfer system of the world first artificial storage compressed air energy storage project.	5,383	March 23
32	Latest development of CSP projects in Gansu, Qinghai and Xinjiang; a 400 MW CSP project will be newly built in Tibet; SunSum Technology Co., Ltd. will co-host China Concentrating Solar Power Conference 2024…	5,443	May 12
33	The construction progress of CGN Delingha 200 MW Solar Tower Plant Project is updated, and the pouring height of solar tower is above 100 m.	5,331	September 5
34	Good news! The global largest MS linear Fresnel solar TES project is combined to the grid, and China's first "solar TES+ PV + wind power" project is put into production in full capacity.	5,844	September 20
35	ShuqiangJiao and XiaozeDu: Solar tower plant research and industrialization - take Lanzhou University of Technology as an example.	5,452	October 11
36	The first solar receiver tube panel of CTGR Qingyu DC 100 MW CSP Project, under EPC of PowerChina Northwest Engineering Corporation Limited, is lift successfully.	5,240	September 27
37	Summary of the latest progress of CSP / MS TES projects; the feasibility study of Gansu Tengger Desert 11,000 MW New Energy Project is initiated; Enesoon Holding Group Company and Xiangxi strengthen cooperation in energy storage and new energy industries…	5,065	June 23
38	The green comprehensive development and utilization of 10,000 tons of battery-grade lithium carbonate project in Zabuye Salt Lake of Tibet, under EPC of East China Engineering Science and Technology Co., Ltd., is put into commission gradually.	5,025	November 21
39	The commencement ceremony for solar tower wall pouring is performed for PowerChina (Ruoqiang) New Energy 100 MW CSP Project that is under EPC of SEPCOIII Electric Power Construction Co., Ltd.	4,863	May 15
40	The international first supercritical CO_2 CSP plant is built, and the national key R&D project "Research on key issues in supercritical CO_2 CSP systems" passes the acceptance successfully.	4,843	August 20
41	The heliostat for 100 MW CSP plant of Haitai Solar Technology Co., Ltd. under EPC of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited enters full construction.	4,797	May 29
42	Progress summary of 16 CSP hybrid projects; proposals raised during the Two Sessions: promote the development of CSP and MS TES; Feiting who won the bid of multiple MS system pipeline projects joins the CSTA…	4,347	March 10
43	Dongfang Boiler Co., Ltd. won the bid again!	4,533	January 17

No.	Title	Reading volume	Enacted/issued on
44	Thumbs up! US satellites captured the spectacular Dunhuang CSP Plant of Shouhang High-Tech Energy Technology Co., Ltd.	4,273	August 21
45	Shandong: Encourage to equip electric boiler TES, MS TES and other facilities for coal-fired power plants to improve the deep peak-shaving capacity.	4,199	December 19
46	The main equipment of CTGR Xinjiang Hami 100 MW CSP Project under EPC of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited is lift into place successfully.	4,235	November 26
47	CCTV1: Yumen 100 MW "CSP+" Project of Xinhua Hydropower Company Limited reappears on CCTV Spotlight".	4,159	July 13
48	Huadian Electric Power Research Institute Co., Ltd. signs a strategic cooperation framework agreement with PowerChina Northwest Engineering Corporation Limited.	4,148	October 31
49	The Feasibility Study Report Review Meeting of Longren 100 MW CSP + 800 MW PV Hybrid Project in Damxung, Lhasa of Huadian Tibet Energy Company Limited is successfully held.	4,140	September 23
50	Governor HaoWang leads the Zhejiang delegation to investigate Qinghai SUPCON Delingha 50 MW CSP Plant, accompanied by Governor XiaojunWu of Qinghai Province!	4,328	July 8
51	Oiling for Zabuye 40 MW Parabolic Trough CSP Plant in Tibet (of the global highest altitude), under EPC of SEPCOIII Electric Power Construction Co., Ltd., is completed successfully.	4,069	November 8
52	Contracts are signed for multiple MS TES projects; PowerChina Jilin Electric Power Engineering Co., Ltd. and Shandong Electric Power Engineering Consulting Institute Corp., Ltd. won the preliminary-bid of EPC of 100 MW CSP projects; two Ministries: Give full play to the peak-shaving role of CSP…	4,073	March 3
53	Shanghai Electric-SPX Engineering & Technologies Co., Ltd. won the bid of direct air cooling system of CGN Delingha 2,000 MW Solar Storage (200 MW CSP) Hybrid Project.	4,052	April 11
54	Dongfang Turbine Co., Ltd., Dongfang Electric Machinery Co., Ltd. and Shanghai Boiler Works Co., Ltd. won the preliminary-bid for procurement of three main equipment of Datang Shichengzi 100 MW MS Linear Fresnel CSP Project.	3,971	June 15
55	Professor YutingWu of Beijing University of Technology: Wide-temperature-range HT MS TES technology.	3,930	October 28
56	The major node works of CTGR Hami 100 MW CSP Project under EPC of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited are completed, ensuring smooth progress of construction in winter.	3,912	November 28
57	Inner Mongolia Electric Power Survey & Design Institute Co., Ltd. won the preliminary bid for feasibility study at early stage and for preparation, service and procurement of related topics of the new energy project at Northeast Ulan Buh Desert, including 200 MW CSP Plant.	3,898	December 4

No.	Title	Reading volume	Enacted/issued on
58	Progress of CSP plants in Qinghai, Gansu and Xinjiang; China's first led SolarPACES project is approved; the central government proposes clearly: Accelerate the construction of new energy bases in deserts, and rectify "cutthroat" competition…	3,889	December 15
59	CGN New Energy Holdings Co., Ltd. signs a cooperative agreement with SEPCOIII Electric Power Construction Co., Ltd.	3,803	March 1
60	EnergyChina Hami 50 MW CSP Plant becomes a market sensation | gaining global recognition! Beyond melons, Hami leads in solar energy development!	3,788	June 28
61	The MS storage tank of Datang Shichengzi 100 MW MS Linear Fresnel CSP Project under joint EPC of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited starts successfully.	3,787	November 4
62	Northwest Electric Power Design Institute Co., Ltd. (NWEPDI) of China Power Engineering Consulting Group participates in the 18th China Concentrating Solar Power Conference	3,775	September 12
63	A "solid anchor" standing in "sand sea" of Guazhou, Gansu - solar tower of Three Gorges SunSum Guazhou 700 MW "Solar TES+" Plant.	3,721	August 23
64	Rotor installation of generators for CTGR Golmud 100 MW CSP EPC Project under EPC of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited is completed successfully.	3,713	July 29
65	China Concentrating Solar Power Conference 2024 is held in Dunhuang.	3,666	September 11
66	Latest development of CSP projects in Qinghai, Gansu, Xinjiang and Tibet; CCTV and other media focus on the construction of CSP projects; the Closed Session for council representatives of CSTA is held in Dunhuang…	3,652	September 29
67	The 600 MW electrode boiler of the flexible peak-shaving project of Guoneng Ningxia Lingwu Power Generation Co., Ltd. operates at full load.	3,639	January 17
68	Challenges and Recommendations for CSP Development in China	3,636	February 1
69	PowerChina Sepco1 Electric Power Construction Co., Ltd. won the double bid of China's first batch of large-scale wind and PV power bases in "deserts".	3,635	March 30
70	The ratio between compressed CO_2 MS TES CSP and PV power is planned as 1:9! The Paramilitary- Civil Cooperation 3 GW PV Base Project constructed with the participation of Shouhang High-Tech Energy Technology Co., Ltd. is officially launched.	3,628	May 16
71	The total investment is about CNY 2 billion! ZDI has completed the signing of the 125 MW PV + 50 MW CSP hybrid project in Turuo, Anduo County, Tibet.	3,589	April 27
72	Under the EPC of PowerChina Northwest Engineering Corporation Limited, Qingyu DC Phase II 100 MW CSP Project of CHN Energy is being built.	3,567	June 17
73	2024 Government Work Report: Strengthen the construction of large-scale wind power and PV power bases and outbound transmission channels to develop new-type energy storage.	3,546	March 5
74	All-round opening up! The virtual simulation teaching platform of the solar power tower plant in Zhejiang University delivers all-in-one "quality courses"!	3,519	May 28
75	PowerChina Northwest Engineering Corporation Limited won the bid for EPC of 330 kV power transmission and transformation of Gonghe 1,000 MW PV and CSP Project.	3,490	December 16

No.	Title	Reading volume	Enacted/issued on
76	Video 丨 Mr. HongzhiWang, Director of the National Energy Administration: Actively promote the large-scale development of CSP.	3,459	December 16
77	Cosin Solar Technology Co., Ltd.: Exploration and Practice of MS TES.	3,435	December 3
78	Dongfang Boiler Co., Ltd. won the bid for flexible transformation of MS TES coupled coal-fired power plant.	3,414	February 29
79	The electric output of PowerChina Gonghe 50 MW CSP Plant surges to historic peak.	3,259	April 9
80	JianfengLi of Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited: design sharing of CSP and "CSP+" projects.	3,240	October 23
81	Innovation, cooperation and development, China Concentrating Solar Power Conference 2024 is closed, see you in Xi'an next year.	3,375	September 12
82	PowerChina Renewable Energy is ramping up efforts to ensure progress on the Ruoqiang 100 MW CSP (TES) + 900 MW PV demonstration project.	3,545	October 5
83	Latest development of CNNC / CTGR / CHN Energy / PowerChina / CGN / CEEC / Tangshan Haitai CSP plants; explore modes for the stable supply of green power through joint operation of CSP, wind and PV power plants…	3,389	August 11
84	Stored in summer for use in winter, heating with "zero carbon"! Documentation of the seasonal thermal energy storage and central heating project invested by Guantao, Hebei in CNY 110 million.	3,345	November 14
85	PowerChina 2×300 MW, CEEC 350 MW salt cavern compressed air energy storage plants are started, and contracts are signed for the energy storage equipment manufacturing project.	3,341	January 5
86	First Ever! Inner Mongolia Electric Power Survey & Design Institute Co., Ltd. won the bid for EPC of urban heating projects.	3,337	July 20
87	Leaders of Gansu Construction Investment (Holdings) Group Co., Ltd. conducted an inspection and research on the Three Gorges SunSum Guazhou 700 MW "Solar Thermal Energy Storage +" Project.	3,321	October 26
88	Three CSP projects in Yumen, Guazhou and Aksay enters "crunch time" ahead of grid connection; SDIC/CGN/CSNP/Dongfang Electric Corporation / China National Chemical Engineering Group Corporation Ltd. are listed on the Grade A Enterprise List; construction of CSP plants shall be promoted in Three-North regions…	3,316	July 28
89	PowerChina Zhongnan Engineering Corporation Limited and Hunan University: Temperature Distribution and Settlement Deformation of MS Storage Tanks in Parabolic Trough CSP Plants under Multi-field Coupling.	3,313	March 15
90	Northwestern Electric Power Design Institute of China Energy Engineering Corporation Limited, "the pioneer of carbon development", will co-organize China Concentrating Solar Power Conference 2024.	3,313	September 2
91	PowerChina Zhongnan Engineering Corporation Limited and Hunan University and Guangdong Construction Engineering Group Co., Ltd. won the bid of power supply guarantee new energy competitive allocation projects in Shigatse City in 2024, namely two 50 MW CSP projects.	2,362	May 6
92	PowerChina Northwest Engineering Corporation Limited won the preliminary bid of EPC of Datang Shichengzi 100 MW CSP Project.	3,253	April 3

No.	Title	Reading volume	Enacted/issued on
93	Xi Jinping: To tackle China's energy development challenges, the solution is to actively promote new energy.	3,249	March 1
94	First in China! The system commissioning for Yumen 100 MW Solar Thermal Energy Storage Plant is completed.	3,235	August 13
95	China's first supercritical CO_2 CSP plant is successfully researched and developed.	3,234	August 23
96	The total investment is CNY 2 billion! The CO_2 MS TES demonstration project of Shouhang High-Tech Energy Technology Co., Ltd. is commenced.	3,223	February 29
97	The Vice Chairman LupingLiu leads a delegation to visit PowerChina Guiyang Engineering Corporation Limited.	3,222	November 11
98	ChangshengHu, Secretary of Gansu Provincial Party Committee, and ZhenheRen, Governor of Gansu Province, present! The "Multiple power towers + One turbine-generator unit" CSP technology of SunSum Technology Co., Ltd. showcases full-strength advantages at Lanzhou Investment and Trade Fair.	3,219	July 7
99	Research on the program of replacing thermal power with CSP at the large-scale new energy outbound transmission base is launched; the Solar Tower Plant Project proposed by PowerChina Northwest Engineering Corporation Limited won the first prize of National Science and Technology Progress Award; PowerChina Zhongnan Engineering Corporation Limited received the CSP plant EPC orders…	3,204	April 14
100	Winning three bids in succession! Dongfang Boiler Co., Ltd. won the CSP and MS TES peak-shaving projects.	3,187	January 4
Prepared by CSTA			

9.2 Brief Introduction to CSTA Members from 2023 to 2024

Company (listed in alphabetical order)	Business Profile
Beijing	
Beijing University of Technology	The Key Laboratory of Enhanced Heat Transfer and Energy Conservation, Ministry of Education, Key Laboratory of Heat Transfer and Energy Conversion, Beijing Education Commission, Beijing University of Technology is mainly committed to the research on MS heat transfer and storage, phase change TES and cold storage, heat pump refrigeration, compressors and expanders, efficient conversion of heat into power of low-grade heat source, pressure energy generation, enhancement of heat transfer and fuel battery, and have achieved world-leading research results in terms of preparation and modification of mixed molten salt with low melting point, high operating temperature and wide liquid temperature range, measurement and estimation theory of thermal properties of molten salt, convective heat transfer of molten salt, development of molten salt TES and HT molten salt heat transfer application system, single screw compressor and expander, microscale flow and heat transfer, etc.

Company (listed in alphabetical order)	Business Profile
Beijing Aerospace Petrochemical Technology & Equipment Engineering Corporation Limited	Beijing Aerospace Petrochemical Technology & Equipment Engineering Corporation Limited is one of the companies with the strongest technical strength in combustion engineering and fluid control and delivery areas of China. It consists of five business divisions: thermal energy engineering heating furnace, special valve, safety valve, fluids and rotating machinery, and energy conservation and environment protection divisions and is mainly engaged in providing heating furnace, special valve, special pump products, combustion thermal energy equipment and unit engineering EPC services. It provided thermal oil boilers, safety valves and breathing valves for Urat Middle Banner 100 MW CSP Demonstration Project in Inner Mongolia and Zabuye CSP Project in Tibet.
Beijing TRX Solar Technology Co., Ltd.	It is affiliated to China Aerospace Science and Technology Corporation and is specialized in the R&D and manufacturing and technical services of core products in solar line-focus CSP technology areas. As a national high-tech enterprise, it has more than 110 core intellectual property rights and has built a 140 mu aerospace new energy industrial park. The HT solar collector tube product of the Company has been exported all over the world and passed the test of DLR, PSA and CENER. After demonstration and commercial application in a series of products, it has mastered the core technology about HT collector tube production and system integration and is capable of deploying large-scale line-focus solar concentration and collection systems.
Beijing Frontier Power Technology Co., Ltd.	The Company specializes in advanced and cutting-edge energy power technologies, and its technical team consists of doctors, senior engineers and principal engineers who have accumulated years of professional experience in turbomachinery at large state-owned enterprises and renowned foreign corporations. They have been extensively involved in the design, commissioning and operation of multiple major power machinery projects, demonstrating robust expertise in practical product design and manufacturing. Its main product - supercritical CO_2 generation technology and hydrogen fuel cell oil-free air compressors are revolutionary products in energy industry. At present, it can provide precise rotary reducers and turbine plants and also the thermal and control system optimization process package for CSP plants.
Beijing TeraSolar Photothermal Technologies Co., Ltd	The Company specializes in providing Fresnel CSP technology consultation, equipment integration and engineering service as well as the development, investment, construction and operation services of Fresnel CSP projects. Its Fresnel-like technology and HT-resistant concrete TES technology researched and developed with complete and independent intellectual property rights can be applied in areas like industrial steam, industrial hot water, flexible transformation of thermal power plants, urban heating, sea water desalination, oilfield heating, agriculture and animal husbandry heating and CSP plants. The company developed and constructed the 15 MW CSP Plant of Zhangbei Huaqiang Zhaoyang Energy Co., Ltd. During the project, it pioneered to apply the linear solar concentration and collection system and solid concrete TES system with the east and west axes inclined to store thermal energy for 14 h. It also undertook the construction of the solar heating work of 20,000 tons of potassium carbonate project of Qinghai Salt Lake Industry Co., Ltd. and has successfully achieved the key goal that the cost of energy supply from solar thermal energy is lower than the cost by the traditional energy.

Company (listed in alphabetical order)	Business Profile
China Electric Power Planning & Engineering Institute	It is a national-level high-end consulting institution and specializes in providing research on industry policies, development strategy, development planning and new technologies and project review, consultation and technical services for government sectors, financial institutions, energy and power enterprises, organizing and developing scientific research standardization and informatization, and international communication and cooperation, etc.
SunSum Technology Co., Ltd.	Being established in CSP core technical products and specialized in "solar thermal energy storage+" hybrid plants, the company specializes in providing all-in-one core technology and product solutions covering development, investment, construction, operation and maintenance. Presently, it has more than 80 patents for inventions and utility models and masters the core technologies, such as heliostat field system assembly, field control system, heliostat graphical design, mirror field design, design of heat absorption, thermal energy storage and heat transfer systems, assembly technology, etc. It is now leading the development and construction of the national demonstration project, Gansu Guazhou 700 MW "Solar Thermal Energy Storage+" Project (including 100 MW CSP + 200 MW PV + 400 MW Wind Power), and also undertakes Xinjiang Bozhou 100 MW CSP Plant.
China Renewable Energy Engineering Institute	It is approved by the State Council, and is specialized in participating in the preparation of hydropower and wind power long-term development plan, preparing and deploying preliminary work plans, organizing preliminary review of river planning and wind power planning reports on behalf of ministries, reviewing the pre-feasibility study and feasibility study (originally the preliminary design) of large and medium-sized hydropower and wind power works under the administration of ministries, organizing the preparation and review of hydropower and wind power survey and design technical standards and quota, putting the surveying and designing institutes under the administration of ministries into centralized management, and performing industry management for nationwide hydropower and wind power survey and design institutions.

Company (listed in alphabetical order)	Business Profile
China State Shipbuilding Corporation New Energy Co., Ltd.	It is a subsidiary of China State Shipbuilding Corporation Limited and is a military-civilian integrated clean energy industrial cluster platform company centered on CPS and TES. It consolidates the Group's core technologies and industrial chain resources across various power sectors, including gas, steam, chemical, all-electric, nuclear, diesel engine, and thermopneumatic power, and integrated energy microgrid systems for naval vessels (featuring combined cooling, heating, and power supply), leveraging both internal and external strengths. The Urat Middle Banner 100 MW parabolic trough CSP project with 10 h thermal energy storage in Inner Mongolia designed, constructed, commissioned, operated and maintained by China Shipbuilding New Power Co., Ltd. (CSNP) ranks first in terms of single-unit capacity and TES period among the first batch of national CSP demonstration projects. The construction of the plant was officially commenced in June 2018, and the plant started operating (generating electricity) at full load in December 2020. In July 2021, the TES system was put into full operation, and the plant achieved 24-hour continuous and stable high-load operation. The Solar thermal conversion efficiency and the thermoelectric conversion efficiency of the plant are above the designed value; the maximum electric output from pure solar thermal per day / month is above 2,210 MWh and 52,000 MW, the electric output from pure solar thermal throughout a year is above 330 GWh, the both are above the designed value, achieved the goal of commencing production and meeting the targets within the same year. The company participated in the supply project for Zabuye Source-Grid-Load-Storage Integrated Comprehensive Energy Station in Tibet as the core technology and equipment provider. In the project, it overcame the difficulties and technical challenges of high altitude (4,500 m) and islanded operation, and provided reliable, steady and safe technological design schemes and economic, applicable and reliable equipment supply and all-process technical services for the owner.
China Power Engineering Consulting (Group) Corporation (CPECC)	It is a wholly-owned subsidiary of China Energy Engineering Corporation Limited to provide project construction integration solutions for governmental sectors, financial institutions, investors, developers and project legal person on Chinese and international markets. It is specialized in the planning research, consultation, evaluation, engineering survey, design, service, EPC, investment and operation, development of related special technical products in energy and infrastructure areas. In 2020, the company acquired the engineering consulting companies EA and Ghesa in Spain at 100% equity (the two has practical experiences in multiple CSP projects), enhancing its technical and investment & financing capability.

Company (listed in alphabetical order)	Business Profile
CGN New Energy Holdings.Co., Ltd.	CGN New Energy Holdings Co., Ltd. is an independent generation company featuring diversified types and geographical distribution of power supplies and is specialized in acquiring clean and renewable energy generation projects. Its asset portfolio comprises wind, solar energy, gas, coal-fired, oil-fired, hydropower, combined heat and power (CHP), and fuel cell generation projects located in China and South Korea. It serves as the host organization of the China National Solar Thermal Power Technology R&D Center and possesses core capabilities in the system integration of large-scale CSP plants. It invested, constructed and operated & maintained China's first 50 MW commercial parabolic trough CSP demonstration plant which achieved a non-stop operation for 230 days. The project is the first large-scale commercial parabolic trough CSP plant in China, successfully filling the technological gap in large-scale parabolic trough CSP plants in China. It has officially positioned China as the 8th country worldwide possessing large-capacity CSP plants. Phase I project of CGN Solar Delingha 2,000 MW PV + CSP Project (the PV + CSP project with the highest energy storage allocation ratio in China) that is selected in the second batch of large-scale wind power and PV base construction projects, 200 MW Wind Power + 100 MW PV + 100 MW CSP Plants (jointly constructed) (2 units) of Jixi Base DC 1,400 MW DC Power Outbound Transmission Project in Lugu County, Baicheng City, Jilin, "Zero Carbon" CSP Demonstration Project in Ali Snowy Plateau, CGN New Energy CSP + PV Hybrid Project in Wumatang, Damxung, Tibet, and other projects are being under an orderly construction. Next, CGN will continue to intensify its efforts in areas including large-scale bases in deserts", Source-Grid-Load-Storage integrated plants, CSP demonstration plants, offshore wind power plants, PV and hydrogen production plants. It will lay stress on the construction of "CSP+" projects in Sichuan and Gansu to stabilize the output from new energy, give support to stable operation of the electric power system and continue to promote the high-quality development of new energy.
IEECAS	The Research Department of Solar Thermal Utilization started its research on CSP and medium and low temperature utilization from the 1970s and has achieved many research results: it has built in succession the first MW-scale tower and parabolic trough CSP experiment demonstration system in Asia, China's first large-scale seasonal solar water TES project, the global first solar CHP system, and the global first supercritical CO_2 CSP unit, etc. It has built the world-class all-round subject experiment platform and science popularization education base (passed the test of CNAS) in Yanqing, Beijing. The department has the following specialized testing platforms: a wind tunnel-enabled aerodynamic testing platform, an optical testing platform, a thermal energy storage/heat transfer materials and system performance testing platform, a material aging resistance assessment platform, a tube collector and vacuum tube system steady-state thermal performance testing platform, a medium and low temperature collector thermal performance testing platform, a reflecting surface precision testing platform, a heliostat tracking accuracy tester, a tube mirror reflector accuracy online measuring instrument and other test experiment platforms. It initiated and organized "Sanya International CSP Forum" in 2007 (renamed as China Concentrating Solar Power Conference in 2015), and initiated and founded the China Solar Thermal Alliance (one of the 26 Level A alliances under the Ministry of Science and Technology) in 2009. It is the initiating unit of 973 Program "Basic Research on Efficient and Large-scale CSP" and the National Key Research and Development Program of China "Research on Basic Problems of Supercritical CO_2 CSP" project.

Company (listed in alphabetical order)	Business Profile
Tianjin	
School of Mechanical Engineering, Tianjin University	The School of Mechanical Engineering, Tianjin University compresses three departments, including Mechanical Engineering, Mechanics and Energy, and Power Engineering, as well as a Mechanical Engineering Practice teaching Center. It sets up 5 undergraduate programs: Mechanical Design, Manufacturing and Automation, Engineering Mechanics, Energy and Dynamical Engineering, Industrial Design, and Intelligent Manufacturing Engineering, etc. and has State Key Lab of Internal Combustion Engine, Key Laboratory of Mechanism Theory and Equipment Design of the Ministry of Education, Key Laboratory of Efficient Utilization of Thermal Energy at Medium and Low Temperature of the Ministry of Education, Key Laboratory of Advanced Ceramics and Processing Technology of the Ministry of Education (jointly built with School of Materials Science and Engineering), 3 key laboratories of Tianjin City and several high-level scientific research bases and cooperative platforms. LiZhao's research group has carried out a lot of fruitful researches in areas of heat pump system optimization, research and analysis on the circulation characteristics of new refrigerant, efficient utilization of solar, etc.
Hebei	
Hebei Jindong Technology Group Co., Ltd.	It is an comprehensive production enterprise centering on heat medium production and fine chemical engineering, with biphenyl as its flagship product. For the past few years, the company researched, developed, optimized and technically improved in succession the hydrogenated terphenyl, diphenyl and diphenyl ether dominated by biphenyls and other environmental protection new energy HT thermal oil series products. It launched the HT heating medium new material project at a total investment of CNY 669 million in Shexian County, Hebei Province. It provided 5,000 t biphenyl - diphenyl ether products for Urat 100 MW CSP Demonstration Project and signed a 20,000 t supply agreement with Saudi Arabia.
Hebei Yujian Energy Saving Technology Co., Ltd.	The Company is a high-tech enterprise integrating technology R&D, core equipment manufacturing, engineering construction integration, project operation and EPC and a national demonstration "Little Giant" enterprise. Presently, it has built a technical system of a series of proprietary intellectual property rights, and the efficient photothermionic tube steam generation system can generate stable high-quality steam on the premise of ensuring the cost performance. The system can be widely applied in industrial areas such as electric power, metallurgy, chemical engineering, food, pharmaceutical and medical treatment, textile, service, military industry, and for steam supply, domestic hot water, concentrated refrigerating by air conditioning, winter heating, electric power supply for urban heating, schools, hospitals, villages and other public facilities.

Company (listed in alphabetical order)	Business Profile
Shanxi	
Shanxi Wojin New Materials Co., Ltd.	Shanxi Wojin New Materials Co., Ltd., a subsidiary of Shanxi Changsheng New Energy Technology Co., Ltd., is a professional manufacturer of new materials using nitric acid molten salt for energy storage, and another nitric acid molten salt manufacturing base built to improve the creative advanced ceramic membrane manufacturing technology and also product quality by ways of innovating, optimizing, upgrading and expanding the production scale of Jiaocheng County Bingsheng Chemical Co., Ltd. It is the manufacturer and service provider of core raw materials for molten salt who integrates R&D, design, manufacturing, sales and recycling, and has built brands "Bingsheng", "Wojin Jinjia", "Wofengyu" for industrial potassium nitrate, sodium nitrate, and nitrate. Its subsidiaries "Shanxi Wojin New Materials Co., Ltd.", "Jiaocheng County Bingsheng Chemical Co., Ltd.", and "Qinghai Salt Lake Wojin Solar Storage Technology Co., Ltd." contribute to totally 320,000 t molten salt potassium nitrate per year (maximum in China at present) and 260,000 t high-purity molten salt potassium nitrate per year. It is the only manufacturer of potassium nitrate and sodium nitrate molten salt in China and can provide binary eutectic nitrate. It has researched, developed and innovated the next generation of molten salt material products featuring low melting-point, low cost and low chloridion, and developed the one-off potassium nitrate and sodium nitrate production and innovation process. The products are applicable to fields such as chemical strengthening of optical glass, CSP projects, MS TES projects for deep peak-shaving in coal-fired units of thermal power plants, MS-based new energy storage and heating, and gas-fired (electric) MS boilers, and have been extensively utilized in these areas.
Sinosteel Stainless Steel Pipe Technology (Shanxi) Co., Ltd.	It is committed to the R&D, production and sales of the tubes and fittings used for nuclear power, thermal power, petroleum, coal, chemical and natural gas and other energy engineering, tubes and fittings of high performance and high corrosion resistance used for gas and liquid pipe facilities for urban drinking water, food hygiene, pharmaceutical, electronics industry, environmental engineering, biological engineering, marine engineering, ultra-low temperature engineering, and tubes and fittings of high temperature and pressure resistance for related mechanical structure, boilers, heat exchangers and condensers. Its products are widely applied in important areas like petrochemical industry, new energy, etc. The company can produce all kinds of (of different steel grades) austenite and super austenitic stainless steel tubes, ferrite stainless steel tubes, duplex steel and super duplex steel tubes, nickel-based alloy tubes, titanium alloy tubes, copper alloy tubes, and composite tubes (outer diameter ϕ8 mm - ϕ3,600 mm, wall thickness 0.2 mm - 120 mm), so it is a manufacturer of stainless steel welded pipes with the most complete product range and the broadest coverage of specifications and dimensional intervals in China, boasting an annual production capacity of 150,000 tons.

Company (listed in alphabetical order)	Business Profile
Inner Mongolia Autonomous Region	
Inner Mongolia Baichuan Solar Technology Co., Ltd.	Inner Mongolia Baichuan Solar Technology Co., Ltd., wholly funded by Roton Solar Thermal Fund, operates a manufacturing facility located in the Solar Thermal Intelligent Equipment Manufacturing Industrial Park in Ordos, Inner Mongolia. It has built a complete CSP concentration mirror industrial chain system and is capable of manufacturing 10 million m^2/year high-precision solar concentrators (curved mirrors 3.5 million m^2/year and plane mirrors 6.5 million m^2/year) and can provide global CSP customers with the first-class CSP concentration mirrors. The company has established its own reflective mirror testing laboratory, benchmarking against the overseas OPAC Laboratory, to carry out comprehensive tests for the surface precision, reflectivity and weather resistance of reflective mirrors. Rooted in the CSP industry specializing in reflective mirror equipment manufacturing and system integration, the company advances its strategic initiatives in the development and construction of zero-carbon energy power islands, zero-carbon industrial steam utilization, distributed solar heating and "CSP+" PV and wind power energy storage projects.
Inner Mongolia Electric Power Survey & Design Institute Co., Ltd.	Established in 1958 and operating as a subsidiary of Inner Mongolia Energy Group Co., Ltd., the institute is a national Class-A power survey and design enterprise and a full-service EPC (Engineering, Procurement, Construction) contractor in China's energy sector. The institute holds over ten national Class-A certifications spanning power engineering design, surveying, consultation, surveying and mapping, EPC (Engineering, Procurement, Construction), environmental impact assessment, water and soil conservation programming, telecommunications and thermal engineering, as well as the licenses about engineering contracting overseas and special equipment designing in China, so it can provide full-spectrum solutions for power generation, transmission & distribution, new energy projects in terms of consultation, surveying, designing, supervision, and EPC and the new energy project investment and operation. It started the planning and research of CSP design technology from 2007. In 2011, the institute won the bid of China's first parabolic trough CSP franchise plant. For the past few years, the institute undertook in succession dozens of design and consultation work for CSP plants spanning (thermal oil) parabolic trough, (MS) parabolic trough, solar tower, linear Fresnel and parabolic dish as well as CSP, joint heating, and wind power, PV, CSP and TES. It won the bid in succession for design of Xinjiang Fukang 100 MW CSP+ 900 MW PV Plants, CGN "Zero-carbon Lithium Extraction" Source-Grid-Load-Storage Project in Lhaguo Tso, and CGN "Tiegelong Rongna Copper-gold Deposit" Source-Grid-Load-Storage Demonstration Project in Gaize County of Ali, Tibet, for design supervision for Source-Grid-Load-Storage Hybrid CSP Project in Ali, Tibet, and Jixi DC Comprehensive Energy Project in Lugu County, Da'an, Jilin, and as an owner engineer for Three Gorges SunSum Guazhou CSP Project. The institute is one of the few institutions in China that possesses successful project track records across multiple domains including solar thermal design, design consulting, design supervision, and owner engineer services.

Company (listed in alphabetical order)	Business Profile
Inner Mongolia Lenon New Energy Co., Ltd.	The Company is specialized in the preparation of preliminary work application reports, project registration application reports, energy audits, contract energy management, feasibility study reports, project proposals, project application reports, funding application reports, planning reports, energy conservation assessment reports, and social stability risk assessment reports, and the mapping and geotechnical investigation for projects including UAV aerial surveying and the most advanced technology topographic map in China.
Inner Mongolia Xinyuan Photothermal Co., Ltd.	The Company's business scope covers intelligent pipeline network heating in the fields of industrial waste heat recovery and utilization, solar-powered industrial steam supply, ice-snow water parks, and agricultural greenhouse farming. This achieves multi-energy complementarity through the integration of solar thermal collection, gas-assisted heating, power plant supplementary heating, and industrial waste heat collection and utilization. It has successfully built China's first large-scale parabolic trough solar thermal collection and supply project in Qingshan District, Baotou City, Inner Mongolia that has the area of the thermal collector field achieving 71,000 m^2 and can heat for 355,000 m^2. Moreover, it paved solar thermal collectors of 22,000 m^2 on roof of its factory, with the total area of the solar thermal collector field achieving 93,000 m^2.
Inner Mongolia Xuchen Energy Co., Ltd.	Established on April 13, 2016 with the registered capital of CNY 300 million and located in the newly planned zone of Qingshan Equipment Manufacturing Industrial Park in Baotou City, Inner Mongolia, the Company is mainly engaged in the R&D, manufacturing and sales of CSP systems. It is the first one in China engaged in the R&D, production and promotion of urban heating by mid-to-high temperature solar technology and is the world's leader in the field of production capacity and technology. Guided by the core philosophy of "technological innovation and continuous refinement", the company maintains dedicated focus on mid-to-high temperature solar thermal project research. To date, it has accumulated 59 core patents and over 100 proprietary intellectual property technologies.
Liaoning	
Dalian Yaopi Glass Co., Ltd.	The Company is mainly engaged in the production and sales of high-quality ultra-clear float glass for solar projects, TCO coated glass for solar PV projects, online low-emissivity coated glass for industrial and building projects, and float clear glass for buildings, automobiles and all kinds of industrial purposes. Its production capacity for solar ultra white glass for CSP plants has achieved 700 t/day, and the annual supply capacity has achieved 2 GW. The order totals of CSP plants constructed, in construction and received are nearly 1.7 GW, and the supply quantity is above 151,000 t.
Shenyang Microcontrol New Energy Technology Co., Ltd.	The Company holds the world's leading full-magnetic bearing and control technology, flywheel material and technology, high speed motor technology, high power PWM conversion, safety protection and other core technologies and also more than 40 domestic/international patents for invention. It serves as the host organization of Liaoning Province Active Magnetic Levitation Technology Application Engineering Research Center and undertakes major scientific and technological special research and development projects in Liaoning Province and Shenzhen City, and is a standard-setting enterprise for flywheel energy storage in China. It has now established China's only production and testing line for mass-production magnetic levitation flywheel energy storage equipment, with the global deployment scale of approximately 3,000 flywheel energy storage systems, achieving stable operation for over 100,000 hours.

Company (listed in alphabetical order)	Business Profile
Shanghai	
Shanghai Feiting Pipe Manufacture Co., Ltd.	The Company specializes in the manufacturing of pipeline, fittings and flanges made from materials such as carbon steel, alloy steel, stainless steel, duplex stainless steel, special alloy steel, and bimetallic composites, as well as pipeline optimization design, factory-prefabricated pipelines, and comprehensive pipeline engineering services. It possesses industry-leading prefabrication technology, high-temperature pipeline engineering experience and design capabilities. Shanghai Feiting Pipe Industry Manufacturing Co., Ltd. sets foot in the CSP field early. In November 2018, it won the bid for PowerChina Hami 50 MW MS Solar Tower Plant Project. Subsequently, it collaborated with the project's general contractor on the secondary design of pipelines and participated in the prefabrication and production of the pipelines. It has supplied MS system pipelines for 100 MW CSP Project of CNNC Yumen "Solar Thermal Energy Storage+PV+Wind Power" Demonstration Project, and now is engaged in supplying MS system pipelines for CTGR 100 MW Solar Thermal Energy Storage Project at Haixi Base, purchasing 347H stainless steel fittings and tubes materials for PowerChina CSP Plant in Toksun County, Turpan City, and purchasing in centralization the MS pipe materials and fittings for 100 MW CSP Project in Qiketai, Shanshan County, Turpan City, Xinjiang of Guodian Investment Henan New Energy Co., Ltd. and 100 MW CSP Project of CTGR Comprehensive Energy Demonstration Project in Hami, Xinjiang.
School of Mechanical Engineering, Shanghai Jiao Tong University	Engineering Research Center of Solar Power and Refrigeration (Shanghai Jiao Tong University), Ministry of Education is one of the first batch of ministerial-level engineering research centers approved by the Ministry of Education. It specializes in the R&D of high-efficiency solar heating and refrigeration, solar PV technology and system applications, distributed energy and energy storage, new technologies for heat pumps and air conditioning, and cutting-edge interdisciplinary innovations in energy-water-air systems. The center has led and completed national science and technology projects such as "Medium-temperature Solar Technology and Industrial Applications" and "Low-grade Waste Energy Recovery Technology and Heat Pump Equipment Research & Development and Demonstration". It serves as the leading unit for the China-Norway Low-carbon Community Cooperative Project, transformative technology scientific issues, and the BRICS International Cooperation TES Project. It has established large-scale R&D and innovation technology collaborations with Huawei, Midea, Gree, Linuo, Shuangliang, Zhejiang Provincial Energy Group Company Ltd., SAST, and other entities. Its achievements such as "heat pump heating system utilizing air source at small temperature difference terminal" and "air source heat pump boiler" have been industrialized.
Shanghai Yahe Valve Completion Co., Ltd.	The Company is a high-tech enterprise specialized in the professional design, manufacturing and sales of all kinds of valves and fluid automated instrument integrated equipment. The company's offerings encompass valves and related automated instrument integrated equipment for diverse industries including thermal power, chemical engineering, petroleum, hydropower, nuclear power, military industry, offshore oilfield drilling platforms, shipbuilding, metallurgical industry, food processing, and pharmaceutical manufacturing. It can design and manufacture all kinds of non-standard/special valves as required by customers, undertake pressure pipeline maintenance and maintenance and service for imported valves and specialized valves. So far, it has successfully implemented more than 40 CSP/MS TES projects.

Company (listed in alphabetical order)	Business Profile
Sociedad Quimica Y Minera De Chile S.A.(SQM) (Shanghai) originally known as SQM (Shanghai) Chemical Co., Ltd.	As a wholly-owned subsidiary to SQM - a world's leading manufacturer and retailer of natural nitrate, SQM (Shanghai) Chemical Co., Ltd. specializes in the market expansion and sales operation of five major product lines - specialty plant nutrition, iodine, lithium, industrial chemicals, and potassium, in the Chinese market. SQM has delivered nitrate products to numerous CSP projects over the world.
Shanghai Topfm Technology Development Co., Ltd.	The Company is an original technology company specialized in the R&D, production and sales of industrial field instruments. The company is focused on the development and manufacture of ultrasonic flowmeter products and supporting solutions, and has accumulated more than 10 years of experience. In view of the large temperature fluctuation of molten salt fluid in the operation of CSP plant and the characteristics of molten salt such as high temperature, low temperature condensation, corrosion and salt mist, the company introduced a new generation of flow meter dedicated for the flow measurement of high temperature molten salt, with dual-channel design, measurement accuracy of ±0.5% and the maximum applicable temperature of 600°C.
Shanghai Institute of Applied Physics, Chinese Academy of Sciences	Targeting at the research for advanced energy technologies, such as thorium-based molten salt reactor nuclear energy system, efficient energy storage and conversion, the Company is committed to the R&D of key technologies in the fields of molten salt reactor, thorium-uranium fuel cycle and comprehensive utilization of nuclear energy. The company's molten salt heat transfer and storage team has established five platforms, namely molten salt physical properties, analysis, preparation and purification, heat transfer and storage test and corrosion evaluation, and has developed eight technical capabilities, namely new molten salt system design, molten salt analysis and testing, molten salt quality evaluation and life evaluation, corrosion control and protection, molten salt purification and recovery, key equipment development and life evaluation, circuit design and development, and molten salt heat transfer and storage technology development and verification. The company possessed CNAS and CMA qualifications. The company is engaged in research on clean energy such as optothermal, energy storage. Guided by engineering application, the company provides operation, maintenance and commissioning services for working medium design, test analysis and evaluation, equipment R&D, system design and HTF & TES. The company developed 700°C ultra-high temperature molten salt pump jointly with Lanzhou Lanpump Co., Ltd. and others.
Zhongqing Solar Thermal (Shanghai) New Energy Co., Ltd.	The Company is mainly engaged in the full-value industrial chain businesses including project development, EPC, power plant design, system R&D, product development and manufacturing, system integration, operation and maintenance, etc., covering the intersection and integration of more than ten technical disciplines: civil engineering, mechanical design, telecommunications, pipelines, software, electronics, electrical control, thermal control, optics, machine vision and mathematics. The company is one of the earliest Chinese companies engaged in technology R&D and commercialization in the CSP field. As a leading international integrator of solar power tower system with secondary reflectors, the company has developed two core systems, namely, heliostat field solar concentration and collection system with secondary reflectors and distributed MS TES system.

Company (listed in alphabetical order)	Business Profile
Jiangsu	
Royal Tech CSP Limited	Specializing in the R&D of CSP technology and equipment, the Company is one of the pioneers in the field of CSP, and also a provider of CSP and comprehensive green energy solutions. Through years of technical research and engineering practice, the company has successfully mastered the whole process technology of CSP plants (e.g. parabolic trough type). It now has systematic independent R&D and production capacity, and possesses core technologies of parabolic trough CSP plant, namely high-temperature vacuum receiver tubes, solar concentrators and collectors, realizing the industrialization and localization of core equipment. The self-developed high-temperature MS receiver tube has been applied firstly in the most advanced scientific research demonstration project in Europe for the first time; a new generation of cost effective ROYALTROUGH™ RT86 Collector based on world-leading completely independent ETFH was developed after 4 years of research, and put into production in Royal Solar Thermal Energy Storage Technology Innovation Park, realizing the continuous iteration of domestic parabolic trough collector. Through the construction and operation of the Urat 100 MW CSP Demonstration Project, the company has successfully mastered the integrated operation technology of the 1000,000-square-meter-scale line-concentrating heliostat field and the overall solution of the 100 MW-scale heat CSP plant with TES, and established the most complete domestic parabolic trough heliostat field system integration and equipment manufacturing industrial chain, which covers the whole process from collector manufacturing to system integration, realizing import substitution and entering the international market. In terms of system integration, the company provides one-stop system integration solutions, including design, installation, debugging and maintenance services. In terms of equipment manufacturing, the company has advanced large-scale production lines of high-quality collectors and related equipment. In 2020, the company's first production line with an annual output of 120,000 high-temperature vacuum receiver tubes was accepted. In terms of technical support, the company provides all-round technical support to ensure the smooth implementation and efficient operation of the project.
Changzhou Shenneng Metal Product Co., Ltd.	Founded in 2008, the Company has the most advanced stainless steel pipe production and testing equipment in China. The company is committed to the R&D and production of industrial stainless steel, corrosion-resistant alloy, high-temperature alloy and other special materials pipeline systems for a long term. After systematic research from the chemical composition optimization design, smelting process and purity control, welding process, forming process, heat treatment and structure uniformity control technology, the company finally developed GH3625 nickel-based alloy pipe for GSP successfully.

Company (listed in alphabetical order)	Business Profile
Jiangsu Feiyue Pump Co., Ltd.	Founded in 1957, the Company has maintained long-term industry-university-research cooperation with Jiangsu University, Institute of Metal Research, Chinese Academy of Sciences (IMRCAS) and other colleges and universities, and jointly established "Jiangsu High-temperature High-pressure Pump Engineering Technology Research Center" and "Jinyan New Materials R&D Center". The company is a national high-tech enterprise, a technologically advanced enterprise and a provincial enterprise technology center in Jiangsu Province. The company has undertaken several major equipment research and scientific research achievements transformation projects at the national, provincial and ministerial levels; its pump products were applied in the launch of China's launch vehicle and were recognized and commended by the CPC Central Committee, the State Council and the Central Military Commission. In the field of CSP, the Company's cold salt pump, hot salt pump, temperature regulating pump, salt dissolving pump, salt replenishing pump, salt dredging pump and salt drain pump and salt discharge pump have been applied in domestic CSP projects such as SUPCON Delingha, Shouhang Hi-Tech Dunhuang, EnergyChina Hami and Luneng Haixi Prefecture, and all molten salt pumps already operated showed stable performance. The Company has won the bid for the contract of supplying various types of molten salt pumps for Jinta Zhongguang Solar 100 MW CSP Project in Wind and Solar New Energy Base, the CGN Jixi DC 100 MW CSP Project in Lugu County, Da'an City, CNNC Yumen 100 MW CSP Project, Zabuye 40 MW CSP Project in Tibet, Aksay Huidong New Energy 100 MW CSP Project, Three Gorges SunSum Guazhou 100 MW "Solar Thermal Energy Storage +" Project, Turpan CSP + PV Hybrid Project in Xinjiang, 100 MW CSP Plant of the CSP + PV Hybrid Project in Wusitong, Toksun County, Turpan, 100 MW CSP Plant in Bid Section 3 of the Qingyu DC Phase II, CGN Delingha New Energy 200 MW CSP Project, 100 MW CSP Plant of CSP + PV Hybrid Project, Haitai Solar Technology Co., Ltd., Xinhua Hydropower Bozhou 100 MW CSP Project with TES, CTGR Hami 100 MW CSP Demonstration Project, and; hot/cold molten salt pumps of the 2*660 MW Unit MS TES and Peak Shaving Heating Project in Guoxin Jingjiang Power Plant, hot/cold molten salt pumps of the Energy Storage and Peak Shaving Project, Xi'an Thermal Power Research Institute Co., Ltd., high-temperature/low-temperature molten salt pumps and salt melting tank molten salt pumps of the Liaohe Oilfield's Molten Salt Heat Storage and Steam Injection Test Station Project.

Company (listed in alphabetical order)	Business Profile
School of Mechanical and Power Engineering of Nanjing Tech University	The School of Mechanical and Power Engineering of Nanjing Tech University is originated from the chemical machinery major established by Nanjing Institute of Technology in 1956. It now sets up first-level doctor station and postdoctoral research mobile station of power engineering and engineering thermophysics, and first-level master station of mechanical engineering, as well as 6 undergraduate majors: process equipment and control engineering, mechanical engineering, vehicle engineering, new energy science and engineering, welding technology and engineering, and emergency equipment technology and engineering. Furthermore, the school has established a chemical machinery research institute and a chemical equipment design institute, 5 departments, a center and a teaching and research room. The school has set up characteristic disciplines such as advanced design and manufacturing of extreme pressure-bearing equipment, process reinforcement and efficient energy-saving technology, major equipment safety theory and risk assessment technology, and advanced equipment digital manufacturing technology, and established 12 scientific research and innovation teams such as process reinforcement and efficient process equipment and advanced equipment manufacturing. The school has seven provincial and ministerial research bases, including National Center for Research and Promotion of Heat Pipe Technology, Jiangsu Key Laboratory of Process Reinforcement and New Energy Equipment Technology, Jiangsu Key Laboratory of Industrial Equipment Digital Manufacturing and Control Technology, Jiangsu Laboratory of Energy Saving and Environmental Protection Technology and Equipment Engineering of Process Industry, Jiangsu Key Laboratory of Extreme Pressure-bearing Equipment Design and Manufacturing, Sinopec Nanjing Equipment Failure Analysis and Prevention Research Center, and Sinopec Engineering Risk Analysis Technology Research Center. The school has a high reputation around the world for its research on structural integrity and life assessment technology of pressure-bearing equipment. It has made remarkable achievements in time-related design and redesign theory and damage and destruction of high-temperature equipment, and has won three second prizes of National Science and Technology Progress Award. In recent years, the school has promoted characteristic R&D and engineering of high-efficiency compact heat exchanger. The hot pipe heat exchanger and compact heat exchanger developed by the school have been applied by more than 200 large Chinese petrochemical and metallurgical enterprises, and have won 6 national science and technology awards such as the Second Prize of National Technological Invention, the Second Prize of National Science and Technology Progress Award, and the Science and Technology Achievement Award by Ho Leung Ho Lee Foundation. It developed the first spacer comprehensive performance testing machine in China, laying the foundation of Chinese static seal testing standards and changed the fact that China relies on importing high-parameter sealing components for a long time.
Wuxi Xinchang Steel Pipe Co., Ltd.	The Company is an enterprise that develops, produces and sells stainless steel seamless pipes, stainless steel welded pipes, seamless titanium pipes, titanium alloy welded pipes, high-performance copper alloy pipes, high-efficiency heat transfer pipes, high-temperature alloys, nickel-based alloys and multi-element complex brass, with an annual output of 30,000 t. Production specification: external diameter 6 mm - 526 mm, and wall thickness 0.8 mm - 35 mm. Its products are widely applied in coal chemistry, oil refining, petrochemical equipment, nuclear industry, TGU, shipbuilding, seawater desalination, chemical fiber, medicine, food, textile, printing and dyeing, machinery and other industries. In 2023, the company participated in the Yumen High-temperature MS CSP Pipeline Project of the PowerChina Northwest Engineering Corporation Limited.

Company (listed in alphabetical order)	Business Profile
Zhejiang	
Aozhan Industrial Co., Ltd.	Its main products include high quality precision stainless steel, special stainless steel, nickel-based alloy, chromium stainless steel, high-temperature alloy, titanium alloy, aluminum alloy, copper alloy and high quality carbon steel fastening parts and premium stainless steel wires and bars. The company is now participating in several CSP projects, such as the standard parts of Jinta Zhongguang Solar 100 MW CSP + 600 MW PV Project.
Hangzhou Runpaq Energy Equipment Co., Ltd.	Founded in 1978, the Company was originally the 9084th factory of the General Logistics Department of the PLA, and now it is affiliated to China Energy Construction Group. The company is a national technologically advanced 'little giant' enterprise, a national high-tech enterprise, a single champion enterprise in manufacturing industry in Zhejiang Province, a "solution service provider of energy saving, carbon reduction and water saving project" approved by Economy and Information Technology Department of Zhejiang, and a patent pilot enterprise in Hangzhou City. The company has established Zhejiang Enterprise Research Institute of Thermal Energy Equipment and Large-scale TES Technology Joint Laboratory jointly with College of Energy Engineering, Zhejiang University. The company holds Grade A boiler manufacturing license, Grade A3/D pressure vessel manufacturing license, CCC for electrical products, and ASME boiler and pressure vessel manufacturing license. Its core independent patented technology covers heat source equipment, energy storage (battery) system and system integration technology, and it is a leading enterprise in thermal energy storage industry. Its core products and technologies include electric boilers (including high-pressure electrode boilers and molten salt electrode heating furnaces), efficient and environmentally-friendly oil-fired and gas boilers, biomass boilers (including biomass gasifiers), temperature stratified water heat storage system, saturated water phase-change steam storage system, molten salt/thermal oil storage system, large-scale compressed air energy storage power station - heat storage technology, micro-piezoelectric heat storage technology, biomass gasification and molten salt electrode boiler coupling energy storage and peak shaving technology, electric cold and hot dual thermal storage and thermal pump system coupling technology and etc. Main honors granted to core technologies: 1. The electrode boiler was included into the *Recommended Catalogue of Scientific and Technological Innovation Achievements of Central State-owned Enterprises* (2022 Edition) by SASAC, and the *Recommended Catalogue of National Energy-saving Technical Equipment in Industry and Information Technology* (2022 Edition) by MIIT, and it is the first set of key project in Zhejiang Province. 2. The MW-scale molten salt electrode heater was granted to the "Golden Apple Award" for scientific and technological achievements in the electric power industry in 2023, and was included in the *EnergyChina Technical Catalogue of the First Set of Major Equipment*, and the *Catalogue of the First Set of Major Equipment in Zhejiang*. 3. The electrode boiler heat storage system (medium: water and molten salt) was included in *GEF Advanced Technology Catalogue*, *China Good Technology Class A Project Library*, the *Catalogue of the Fourth Batch of Reference Products (Technologies) for Power Demand Side Management in the National Industrial Field* by MIIT, the *Zhejiang Quality Products* and the *Catalogue of Recommended New Energy Saving Technologies, New Products and New Equipment in Zhejiang Province*. 4. The Company undertook the electric thermal storage technology and national torch plan of quick-loading boiler, and supplied thermal storage system equipment for compressed air energy storage power station. The company's products were included the *Catalogue of the Third Batch of the First Set of Major Technical Equipment* by NEA. Up to date, the Company has carried out thousands of practical application cases in auxiliary boilers of plants, clean heating, industrial steam, flexible peak shaving of thermal power, MS TES, compressed air energy storage and other fields.

Company (listed in alphabetical order)	Business Profile
Hengfengtai Precision Machinery Co., Ltd.	The Company is committed to the R&D and manufacture of rotary reducers for CSP and PV tracking systems, and independently developed precision rotary transmission devices such as HVE, HDR and HSE for solar tower plant, parabolic trough CSP plant, parabolic dish CSP plant and Fresnel CSP plant and flat single-axis tracking systems for PV power plant. Since 2008, the company has provided the most comprehensive solutions and customized products and services for more than 40 domestic and foreign enterprises in the industry. The company is now fulfilling the order of nearly 40,000 rotary reducers for a CSP project in Gansu.
Huadian Electric Power Research Institute Co., Ltd.	The Company is the only scientific research institution directly under China Huadian Corporation Ltd. It sets up 7 national R&D centers in national distributed energy and EEI testing, Zhejiang Key Laboratory of Energy Storage and Building Energy Conservation, 11 group-level technical centers in China Huadian, such as China Huadian hydropower, new energy, intelligent energy, environmental protection supervision and power market; the China Huadian Dam Management Center sets up academician workstations and postdoctoral workstations; it has more than 20 qualifications such as CMA, special inspection, measurement, grade A engineering consulting, special grade debugging and grade B engineering design; the company is the organizer of a core journal of Chinese science and technology -*Power Generation Technology*.
Xizi Clean Energy Equipment Manufacturing Co., Ltd.	Formerly known as Hangzhou Boiler Group Co., Ltd., the Company is mainly engaged in providing products and solutions in new energy, new equipment, new service and other fields. The company's new energy business includes clean energy products and services such as CSP, MS TES, zero-carbon factory (park), multi-energy joint storage, electrode boiler, PV, nuclear power and hydrogen energy. It has successfully built the first aviation zero-carbon factory and the first MS TES zero-carbon park in China based on new energy technology; the company invested in the construction of the first large-scale solar thermal energy storage plant in China, and the applied energy storage technologies were included in the first set major technical equipment project in the national energy field in 2021. The Company's new equipment business includes energy-saving and emission-reduction products such as waste heat boiler, circulating fluidized bed boiler, gas boiler, pressure vessel heat exchanger and shield machine, and the company's electrode boiler technology was recognized by EU and CNPE standards. The company's new services include engineering installation, operation and maintenance service, system transformation, spare parts, smart boilers, smart factories and other services, providing life cycle service in the energy field and extending the business chain to new energy investment and operation.
Institute for Sustainable Energy, Zhejiang University	The Institute for Sustainable Energy, Zhejiang University is committed to the research in CSP and efficient utilization, covering CSP (air, particles, supercritical CO_2, molten salt, etc.), thermochemistry and sensible heat storage, high-temperature working medium heat exchange (such as particles and supercritical CO_2, etc.), Brayton cycle (air, supercritical CO_2, etc.), Stirling cycle, and multi-energy complementary and waste heat stage utilization. The CSP R&D team guided by Professor Mingjiang Ni and Gang Xiao has built a CSP test platform in Qingshan Lake area, with a floor area of about 10,000 m^2. The platform is used for the research and demonstration of advanced technologies such as CSP (endothermic temperature: above 900°C), thermochemical heat storage, high-temperature Brayton cycle system, thermal performance test and high-temperature protection research of MS receiver, Stirling engine and PETE.

Company (listed in alphabetical order)	Business Profile
Cosin Solar Technology Co., Ltd.	Founded in 2010, the Company is a national high-tech enterprise that is specialized in the research and industrialization promotion of CSP and MS TES technology. It focuses deeply on CSP and multi-energy complementary power generation business, and actively plans MS TES-oriented layout in the field of comprehensive energy application. It has independently developed, constructed and operated Qinghai SUPCON Delingha 10 MW Solar Tower Plant Project and Qinghai SUPCON Delingha 50 MW Solar Tower Plant Project; as the main technical provider and the supplier of solar concentration and collection system, it participated in the construction of PowerChina Qinghai Gonghe 50 MW Solar Tower Plant Project, and Jinta Zhongguang Solar "CSP + PV" Pilot Project. Qinghai SUPCON Delingha 50 MW Solar Tower Plant has broken the industry records for several times since its commissioning. It is the first Solar Tower Plant with MS TES that reached the design capacity in the world. In 2022 and 2023, the electric output of the plant exceeded the annual design electric output for two consecutive years. Up to now, the installed capacity of CSP of the company has reached 1,360 MW, and plants are distributed in Qinghai, Gansu, Xinjiang, Jilin and other provinces, making the company the only technology provider of solar tower plant with performance of above 1 GW in the world.
Zhejiang Zhongguang New Energy Technology Co., Ltd.	The Company is committed to becoming a new energy scientific and technological enterprise that owns several technologies such as "CSP+", "operation and maintenance+", "MS TES+", multi-energy complementary and smart energy management. It is accelerating the layout of the entire industrial chain of investment, construction and operation. SUPCON Solar Power (Qinghai) Co., Ltd., the company's first wholly-owned and holding subsidiary has constructed the first (third in the world) large-scale TES solar tower plant in China - Qinghai SUPCON Delingha 10 MW Solar Tower Plant, and one of the first batch of CSP demonstration projects in China - Qinghai SUPCON Delingha 50 MW Solar Tower Plant, and has participated in the application of three energy storage demonstration projects in Zhejiang Province: Xizi Aviation Zero-carbon Smart Energy Center Source-Grid-Load-Storage Integrated Demonstration Project (completed), Huangyan CSP Plant with TES Demonstration Project and Hangzhou Medical Port Zero-carbon Plant with MS TES Demonstration Project. The installed capacity of CSP projects undertaken and participated by the Company exceeded 900 MW.
CGDG-Cosin Engineering Technology Co., Ltd.	The Company is a engineering and technical joint venture established by CGDG and Cosin Solar Technology Co., Ltd. It focuses on the development, application and promotion of MS TES by combining the strong strength of central state-owned enterprise CGDG and the technology accumulation of the industry leader Cosin. It is mainly engaged in providing technical R&D, technical consultation and services for CSP plant integration based on molten salt (thermal) energy storage system, flexible transformation of thermal power plants and clean heating in the park, as well as the production and installation of electromechanical equipment, the sales, installation and service of electromechanical complete equipment, the installation and construction of electromechanical engineering, the sales, installation and service of complete plant equipment, industrial investment, import and export business, and the construction and management of electric power projects.

Company (listed in alphabetical order)	Business Profile
Anhui	
East China Engineering Science and Technology Co., Ltd.	Being affiliated to CNCEC, the Company is a listed modern scientific and technological enterprise that undergone stock reformation early in the engineering survey and design industry. It has obtained Grade A national comprehensive qualification for engineering design. It is specially engaged in the whole process services such as process R&D, consultation, design, procurement, construction management, startup guidance, engineering supervision, EPC, PMC management and operation of engineering construction in chemical engineering, petrochemical engineering, medicine, municipal administration, architecture and environmental protection. The Company undertook the design of HTF and TES Island for the Urat 100 MW Parabolic Trough CSP Plant, and accumulated engineering achievements in related fields such as CSP, PV, wind power and hydrogen production from electrolyzed water.
Jiangxi	
PowerChina Jiangxi Electric Power Construction Co., Ltd.	As a national high-tech enterprise, the Company has more than 40 qualifications, including Grade A general contracting of electric power project, building project and municipal public project, and Grade I professional contracting of building electromechanical project, Grade I license for installation and testing of power facilities, Grade III professional contracting of environmental protection engineering, Grade I design of construction industry (construction engineering), Grade A chemical cleaning of thermal equipment of power plant, and Grade A debugging of power supply/grid power engineering, Grade A design qualification for power industry (substation engineering), Grade B design for power industry (power transmission engineering, new energy power generation and wind power generation), Grade B design for building curtain wall engineering, Grade C urban and rural planning, and high-tech enterprise certificates. It developed regional distributed digital solutions, water environment comprehensive management technology, digital cultural tourism equipment products and other technologies. The Company focuses on the fields of renewable energy, ecological environment protection, the development of new urbanization and national carbon neutrality and green transformation, and becomes a provider and servicer of integration of investment, construction and operation in the field of low-carbon economy in the new era. In the field of CSP, the Company completed commissioning, operation and maintenance of 100 MW tower units and the commissioning of 3*200 MW parabolic trough units of Dubai 700 MW CSP Project with high quality, and the service scope covers the commissioning of subsystems and whole set machines of tower/parabolic trough unit (excluding heliostat field), operation and maintenance of tower units, technical services of tower unit heliostat field, etc. It has completed the application of three invention patents for the Subject of *Research on Key Technologies of Wind Power, PV, CSP and TES Hybrid Energy System* under the "Double Thousand Plan" in Jiangxi Province, and obtained five construction methods and two provincial-level QC results. Relying on the successful performance of Dubai CSP Project, the Company can provide the owner with comprehensive technical services such as installation/overhaul, unit commissioning and operation and maintenance, setting value calculation, automation optimization, unit coordination optimization and performance test. The Company is now undertaking several new CSP projects.

Company (listed in alphabetical order)	Business Profile
Shandong	
Shandong Enesoon New Material Technology Co., Ltd.	The Company focuses on providing energy storage materials and overall technical solutions for clean heat (industrial steam), clean electricity (CSP, power grid peak shaving, plant peak shaving), industrial industry (industrial TES and heat transfer, electronic materials), construction industry (thermal insulation and fireproof materials), aerospace TES, nuclear power TES and heat dissipation. The Enesoon New Material Production Base, located in Delingha Industrial Park, Qaidam Circular Economy Experimental Zone, has the world's first intelligent production line for TES new materials with independent intellectual property rights, with an annual capacity of 300,000 t of binary, ternary and multicomponent molten salts and salt melting capacity of 30 t/h. The company can satisfy TES and HT demand of high- and medium-grade products of commercial CSP and industrial steam and fine chemicals, supply high-quality new energy storage materials, and provide services for energy storage systems. The Company is the world's only enterprise that has the R&D and production capacity for new materials with binary, ternary and multi-melting points.
Shandong Aobo Energy Storage Technology Co., Ltd.	The Company's main businesses include R&D, promotion and sales of MS TES materials, and main products cover solar molten salt, molten salt-grade potassium nitrate, molten salt-grade sodium nitrate and sodium nitrite. As a modern enterprise, the Company's core products are widely used in CSP, multi-energy complementary integration of wind power, PV, CSP and TES, flexible transformation of thermal power plants, peak shaving and frequency regulation energy storage of power grid and other fields. Annual supply capacity of 120,000 tons of compound MSs such as MS-grade potassium nitrate, sodium nitrate and sodium nitrite. The Company has professional teams to provide salt supply, preheating and salt melting services. It is a supplier and professional service provider of high-quality energy storage materials.
Shandong Electric Power Construction Corporation III (SEPCOIII)	The Company has an industrial chain covers all links of R&D, design, procurement, manufacturing and construction, commissioning and operation and maintenance. Globally, the company undertook EPC of parabolic trough CSP plant and solar tower plant with the largest single unit capacity in the world - Noor Phase II and III 350 MW CSP Plant in Morocco (won 2019 & 2020 National High-quality Project Gold Awards), and Luneng Golmud Multi-energy Complementary Project 50 MW MS Solar Tower Plant, and participated in the construction of the largest Urat 100 MW Parabolic Trough CSP Plant in China. The South African Redstone 100 MW MS Solar Tower Plant, Zabuye Source-Grid-Load-Storage Integrated Comprehensive Energy Supply Project in Tibet and 40 MW Parabolic Trough CSP Plant contracted and construed by the company have been connected to the grid. The company is now fulfilling the performance of EPC of PowerChina (Ruoqiang) New Energy 100 MW CSP (Energy Storage) Demonstration Project. The Company participated in technical consultation and scheme design of more than 30 domestic and overseas CSP projects. The company can provide solar concentration and collection system, EPC/design/engineering/construction, commissioning and operation, as well as solar tower plant technology, equipment and services. The Company's core technology products include heliostat, heliostat field control system, calibration system, cleaning system and auxiliary technical products of sun island.

Company (listed in alphabetical order)	Business Profile
PowerChina Sepcol Electric Power Construction Co., Ltd.	The Company is a comprehensive, collectivized and diversified large state-owned power construction company that integrates thermal power, nuclear power, new energy power, design, commissioning, maintenance and operation of power plants, power transmission and transformation, design and manufacture of infrastructure and hoisting machinery, trade and logistics, investment and financing. The Company has successively undertaken the installation and commissioning works of conventional islands and TES islands of Dacheng Dunhuang 50 MW MS Linear Fresnel CSP Plant, the installation and commissioning works of HTF & TES system of PowerChina Qinghai Gonghe 50 MW Solar Tower Plant Project, the custody of equipment and materials for PowerChina Hami 50 MW MS Solar Tower Plant Project, and the initial commissioning, operation and maintenance of Yumen Xinneng 50 MW Solar Tower Plant with Secondary Reflectors. As a member of the consortium, the Company won the bid for ZDI 100 MW CSP + 800 MW PV Hybrid EPC Project in Tushuo, Anduo County, Tibet, and will mainly undertake all construction, installation, acceptance and commissioning of buildings within the outer edge of the first ring road of the conventional island and the start-up of the whole system (including heliostat fields), the procurement of some equipment and materials, the construction, installation and decoration of the integrated centralized control exhibition center, the commissioning of single machines and sub-systems, and start-up and commissioning of completed equipment within its responsibility.
Shandong Shengtuoke Energy Co., Ltd.	The Company is a scientific and technological group enterprise focusing on the R&D and production of flat panel solar systems. Headquartered in Dezhou, Shandong Province,it has six production bases and seven subsidiaries, namely Jinheng, Bangte, Feitian, Shengtuoke, Tibet Shengtuoke, Kangde and Jinnaier. The annual installed capacity of flat plate clean thermal energy is 3.7 GWh, ranking second in the world. The company has the core technology and production line of solar spectrum selective absorption coating. The company has 58 core patented technologies and industry solutions. The company provides quality comprehensive utilization services of clean energy such as thermal energy, heating, refrigeration and heat supply in the fields of civil buildings, military facilities, industrial heating, planting, breeding and drying.
Shandong Zhaowei Iron Tower Co., Ltd.	The Company is a large-scale modern enterprise engaged in design, production and sales of steel structure support and other products, with total assets of CNY 579 million and annual production capacity of 60,000 t. It has 3 laser cutting machines, 12 advanced CNC angle steel production lines, 11 welding robots, several plasma cutting machines and CNC sawing machines. The higher processing efficiency and lower material consumption realize lower cost in comprehensive processing in the industry. The Company's products are exported to more than 50 countries. It has signed a supply contract with relevant owners for support of CSP plants.
Shandong Yuying Optical Instrument Co., Ltd.	The Company has been deeply engaged in the R&D and production of Fresnel lenses for more than 30 years. The Fresnel lenses used in the CSP field mainly include large-size (more than 1 m in diameter) circular Fresnel lenses, linear Fresnel lenses and array Fresnel lenses. The production processes include molding and injection molding, as well as SOG process of toughened glass + silica gel composite. The manufactured lenses have been applied in the fields of solar concentration and collection systems, solar hydrogen production, and solar power generation.

Company (listed in alphabetical order)	Business Profile
Henan	
Henan Ancai Hi-tech Co., Ltd.	As a national key high-tech enterprise, the Company has post-doctoral research centers and national enterprise technology centers. Its wholly-owned subsidiary developed CSP products, covering ultra-white glass, CSP glass, and LOW-E glass. After more than 40 years of independent innovation and leap-forward development, the Company has formed complete R&D systems, advanced process equipment and testing platforms, and accumulated profound technical heritages. Since the independent R&D and production of CSP glass original sheets, the Company has become a supply base for CSP glass original sheets, which supplied products realizing 1.4 GW in domestic and overseas CSP plants.
Hubei	
Hubei Shuoli New Material Technology Co., Ltd.	The Company can provide all kinds of refractory fiber products, including integral modules, engineering fibers, cotton, blankets, boards, and paper. The Company's products are widely applied in iron and steel metallurgy, non-ferrous metals, petrochemical industry, electric power, ceramics, glass, fire prevention, aerospace, home appliances, environmental protection, new energy vehicles, solar energy and other industrial fields. Currently, thermal insulation materials for solar power towers (central receivers), thermal insulation systems at the inlet and outlet of parabolic trough collector loops, and new thermal insulation systems for storage tanks have been successfully developed. The company is now implementing the procurement of high-temperature insulation protective materials for CTGR Qinghai Qingyu 100 MW CSP Project.
Hubei Yuntu Molten Salt Technology Co., Ltd.	Yuntu Holdings (a listed company) has the longest and the most efficient salt, phosphorus and coal chemical industry chain in the industry, and established a professional molten salt R&D, marketing and service platform. In order to give full play to the company's supporting advantages of nitric acid, soda ash and potassium salt industrial chain, Yuntu Holdings has formed molten salt-grade sodium nitrate and molten salt-grade potassium nitrate supporting production lines through technical transformation and new construction. At present, the company has a capacity of 150,000 tons of sodium nitrate and sodium nitrite, and it plans to build "sodium nitrate and sodium nitrite" project with a capacity of 200,000 tons. The quality of sodium nitrate and sodium nitrite products has reached the requirements of molten salt-grade products. The company's subsidiary (Shandoo) has participated in the preparation of a number of industry standards such as *Potassium Ammonium Nitrate for Agriculture Use* issued by MIIT. Up to now, the company has made a number of achievements, including CGN Delingha 2,000 MW PV, CSP and TES Hybrid Project, CGN Jixi DC 490 MW Integrated Energy Project in Lugu County, CTGR Gehlsen 100 MW CSP Project, PowerChina 100 MW CSP Project in Toksun County, PowerChina Gonghe 100 MW CSP Project, Luneng Fukang Multi-energy Complementary (and New Energy Market-oriented Grid Connection) Project, and 100 MW CSP project.

Company (listed in alphabetical order)	Business Profile
Wuhan Sunnpo Solar Technology Co., Ltd.	The Company is a professional supplier of reflectors for CSP and has established the world's richest product lines. The company has R&D and mass production capacity of a full range of reflective mirrors for parabolic trough CSP plants, solar tower plants, linear Fresnel CSP plants, secondary reflectors (CPC), parabolic dish and concentrated PV reflectors, with an annual production capacity of 300 MW parabolic trough plant and 400 MW tower/Fresnel plant. The company has successfully developed toughened glass reflector for the ultimate trough (openining: 7,512 mmUT), which has the capability to manufacture RP1-RP5 parabolic trough reflectors in batches. The company produced and delivered in batches 719,902 m^2 Stellio heliostats for Hami Solar Tower Plant of PowerChina Northwest Engineering Corporation Limited, primary and secondary reflectors for Yumen Xinneng 50 MW MS Solar Tower Plant, primary reflectors for Lanzhou Dacheng Dunhuang 50 MW MS Linear Fresnel CSP Plant, primary and secondary reflectors for Huangqiang Zhaoyang 15 MW Fresnel CSP Plant, 700,000 m^2 parabolic trough reflector for Zabuye Source-Grid-Load-Storage Integrated Comprehensive Energy Supply Project in Tibet. In the field of medium- to low-temperature solar energy utilization, the company's supply performance includes: the domestic largest Kunlewan Parabolic Trough Heat Utilization Project in Handan, PV Plant Solar Heating in Gamba County, Shigatse, Tibet, Sinopec Salt Water Desalination in Luntai Base in Xinjiang, Solar Heating of Yining Antivirus Center in Xinjiang, Solar Heating of the 15th Kindergarten in Lhasa, Tibet, Kelida CSP Steam in Changzhou, Jiangsu, and CSP Steam of Shandong Binzhou Xinrui New Energy Technology Co., Ltd.
Hunan	
PowerChina Zhongnan Engineering Corporation Limited	The company has "Grade A" comprehensive qualification of national survey, design, consultation and supervision. The company is among Top 60 Chinese Engineering Design Enterprises and Top 80 Chinese Contractor Enterprises. The company's business areas include energy and electricity, water resources and environment, and infrastructure. As an international first-class engineering company that is specialized in water and electricity engineering, planning and design, contracting of long-term project and investment and operation, and holding four Grade A comprehensive qualification of national survey, design, consultation and supervision, the company has entered the CSP field since 2013. After 10 years of R&D and practice, the company now have mastered core technologies, such as CSP multi-energy complementary coupling power generation technology, linear focusing multi-loop flow balance design technology, performance analysis of linear focusing solar CSP plant, anti-overturning technology of large-scale TES tank, research and application of large-scale MS parabolic trough CSP plant key design technology, and selection method of molten salt pump under different technical routes. The company has successively undertaken and implemented a number of key projects in Gansu, Xinjiang, Tibet and other regions, applied for more than 10 patents related to CSP and 3 software copyrights, and published 10 papers in EI journals and core journals. The company is one of the first echelon in the field of CSP technology in China. The company undertook EPC project of Lanzhou Dacheng Dunhuang 50 MW MS Linear Fresnel CSP Demonstration Project. In terms of construction of wind and solar new energy base, the company is implementing 100 MW CSP EPC Project of the CSP + PV Hybrid Project in Wusitong, Toksun County, Turpan, Xinjiang, and the EPC and preliminary design of the 100 MW CSP Project (2 units) of CGN Jixi Base DC 1,400 MW DC Power Outbound Transmission Project in Lugu County, Baicheng City, Jilin, all-stage survey and design of CGN New Energy Ali "50 MW CSP + 100 MW PV" Source-Grid-Load-Storage Integrated Demonstration Project in Tibet, Xinhua Hydropower Jinghe "Solar Thermal Energy Storage New Energy" Hybrid Base Project, the feasibility research of the CGN Solar Delingha 800 MW PV + 200 MW CSP Project, EPC Project of New 20 MW TES Supply Project of CGN Ali TES CSP Demonstration Project, the feasibility research and special technical service of ZDI 100 MW CSP + 800 MW PV Hybrid Project in Tushuo, Anduo County, Tibet.

Company (listed in alphabetical order)	Business Profile
China Energy Engineering Group Central China Electric Power Test and Research Institute Co., Ltd.	The company is mainly engaged in power engineering debugging, power equipment inspection and testing, power generation operation, power technical service and power technical consultation, etc. The company has Grade 2 qualification of debugging power supply and power grid power engineering. The company has experience in commissioning of large thermal power units, gas units, garbage incineration power generation, biomass energy power generation, CSP and other types of units, and its business has expanded to India, Vietnam, Mongolia, Turkey, the Philippines and other countries along the "Belt and Road". The company successfully completed start-up and commissioning of CSP unit conventional island system (BOP) EPC of CGN Delingha 50 MW CSP Project, and all single equipment commissioning of Dubai 950 MW CSP and PV Composite Plant Project. In the newly-built CSP project, the commissioning and technical service projects implemented by the company reached 510 MW. Among them, Yumen "Solar Thermal Energy Storage + PV + Wind Power" Demonstration Project, 100 MW MS Linear Fresnel CSP Project and Aksay 110 MW CSP Project have finished grid-connected power generation. Now, the company has accumulated rich experience in commissioning different types of CSP projects, such as parabolic trough, linear Fresnel and tower. The company set up a CSP commissioning research group and a CSP automation research group to optimize CSP commissioning process, realize APS one-button start-up and automatic coordinated control of CSP units, thus promoting the efficient, economical and stable operation of CSP units.
Sichuan	
Chengdu Chande New Energy Storage Technology Co., Ltd.	With a registered capital of CNY 160 million, the company focuses on the technical research, market development and system integration of CSP and new energy storage technologies, and deeply focuses on the planning and layout of application scenarios such as CSP, medium- and low-temperature heat utilization and thickened oil recovery. The company researches in-depth extension of the "CSP+" PV base TES combined cycle, flexible transformation of coal power and gas power TGUs, and actively develops comprehensive application of clean energy with new MS TES as the core. The company has its own core patented technology, and has formed complete system solutions for CSP and heat utilization, which are widely applied in CSP and heat utilization projects in Tibet, Inner Mongolia, Xinjiang and other regions. At the same time, the company has the manufacturing capacity of solar mirror equipment, including the annual production capacity of curved solar mirror of 3500,000 m^2, and the annual production capacity of flat solar mirror of 6000,000 m^2. The company's solar mirror products have been exported to more than ten countries, such as the United States and Germany, and its product performance and technical parameters rank among the world's leading levels.

Company (listed in alphabetical order)	Business Profile
Dongfang Boiler Co., Ltd. of Dongfang Electric Corporation	The company is a design supplier of thermal power equipment, CSP equipment, nuclear plant equipment, auxiliary equipment of plant, chemical containers, coal gasification and other equipment, and a service provider of energy-saving and environmental-friendly new energy projects, plant transformation, hydrogen energy production, storage and transportation, etc. As one of the earliest Chinese enterprises engaged in the development of CSP technology, the company has always regarded the CSP industry as an important direction of transformation and development. At present, the company has nearly 100 technical patents. It is also one of the main members in compiling the national standards and design specifications of solar tower plants. After more than 10 years of independent technology R&D and exploration, the company has formed the core competitiveness of key technical design and equipment manufacturing in the whole industrial chain, such as CSP heliostat field, receiver, HTF & TES system. The company has the supply capacity of complete tower solar concentration and collection system, and the design, manufacture and supply capacity of heliostats, receivers and steam generators. In the CSP sector of the new energy industry, the company has participated in the construction of the first batch of national CSP demonstration projects, such as Hami 50 MW MS Solar Tower Plant Project, Dacheng Dunhuang 50 MW MS linear Fresnel CSP Project and Yumen Xinneng 50 MW MS Solar Tower Plant Project. Relied on excellent system scheme and efficient and reliable product quality, the company deeply participated in the construction of domestic landmark commercial CSP projects, such as SDIC Aksay Huidong 110 MW CSP Project and PowerChina Gonghe 100 MW CSP Project Phase II, and provided core solar concentration and collection system and equipment for these projects. Since 2023, the company has successfully signed contract of batch supply of evaporators, with a market share of over 50%, and successfully achieved a breakthrough in the integration of evaporator equipment to system. In the comprehensive energy business sector with MS TES as the core, the company provides the supply chain of HTF & TES complete equipment to realize MS TES technology applied in the field of thermal power and solar power coupling.

Company (listed in alphabetical order)	Business Profile
Guizhou	
PowerChina Guiyang Engineering Corporation Limited	Founded in 1958, with a registered capital of CNY 2.1 billion, the company belongs to Power Construction Corporation of China. The company holds three comprehensive Grade A qualifications of engineering survey, design and consultation, more than 20 Grade A qualifications of engineering supervision, and Grade A qualifications of general contracting projects in water conservancy and hydropower, municipal administration, construction, electric power and other industries. The company has maintained "Top 60 Chinese Engineering Design Enterprises" for many years. The company is a national intellectual property demonstration enterprise and a national high-tech enterprise. It has many scientific and technological innovation and talent training platforms, such as the National Enterprise Technology Center, Guiyang Branch of the National Hydroelectric and Wind Energy Research Center, Guizhou Renewable Energy Academician Workstation, Post-Doctoral Research Workstation and Guizhou Renewable Energy Talent Base, and Guizhou Water Conservancy and Hydropower Talent Base. The company has won the Governor Quality Award of Guizhou Province, more than 700 science and technology and engineering awards, including more than 500 at the provincial and ministerial levels. The company holds more than 2,300 valid patents, ranking front among enterprises of PowerChina and in Guizhou Province for many years. The company is committed to the service in the global clean energy, water resources and environment, and infrastructure construction. The company mainly undertakes the planning, survey, design, scientific research, supervision, consultation and general contracting of large and medium-sized hydropower and water conservancy, new energy, transportation, municipal administration, construction, environment and geotechnical engineering. The company's business scope covers 30 provinces, districts and cities in China, as well as Southeast Asia, Africa, South America and the Middle East, and is capable of providing integrated services for the whole industrial chain of project construction.
Yunnan Province:	
School of Energy and Environment Science of Yunnan Normal University (Solar Energy Research Institute)	The school is a teaching and scientific research unit that integrates teaching, scientific research and engineering application, and it is also one of the earliest units engaged in research on solar energy utilization in China. The school formed its main advantages in the research on the utilization of renewable energy (e.g. solar energy and bioenergy) and the training of high-level talents. The school has a complete talent training system for undergraduate, master, doctoral and postdoctoral students. The research team of the Solar Heating and Refrigeration Key Laboratory for Yunnan University under the Solar Energy Research Institute has years of practical achievements in solar drying system, heat pump drying system and solar and heat pump combined drying system.

Company (listed in alphabetical order)	Business Profile
	Shaanxi
Shaanxi Energy Electric Power Operation Co., Ltd.	The company is a specialized energy technology service enterprise under Shaanxi Investment Group Co., Ltd. The company sets up 1 subsidiary, 2 business divisions and 11 regular maintenance project departments, as well as professional technical teams with exquisite technology and excellent conduct. The company undertakes the daily operation and maintenance, grade maintenance and energy science and technology services of TGUs of thermal power, hydro power and new energy. At present, the company undertakes operation and maintenance capacity of 15,320 MW thermal power units and operation and maintenance capacity of 300 MW new energy units, so as to provide efficient and professional services for many customers inside and outside Shaanxi Investment Group. In May, 2024, the company won the bid for the operation and maintenance of CSP Project in Bid Section 3, CTGR Qingyu DC Phase II.
PowerChina Northwest Engineering Corporation Limited	The company is a modern science and technology engineering company engaged in integration of clean energy development, water ecological environment management, infrastructure construction project planning, survey and design, project general contracting, investment and operation. As one the first batch of Chines large-scale survey and design enterprises, the company holds "Grade A" comprehensive qualifications of engineering survey, engineering design, engineering supervision, and engineering consulting and credit evaluation, and holds Grade A qualification of water conservancy and hydropower engineering, electric power engineering and municipal public works construction general contracting, and a series of administrative licenses and credit evaluations to support multi-business development. Since 2010, relying on the first batch of national CSP demonstration projects contracted and participated, the company organized the establishment of PowerChina Concentrating Solar Power Engineering Research Center, Shaanxi Wind and Solar Power and Multi-energy Storage Engineering Technology Research Center, and Shaanxi Qinchuangyuan "scientist + engineer" team to comprehensively identify the urgent problems in the design and construction of tower and line-focusing CSP plants, and carry out in-depth and systematic research. The company has undertaken more than 10 national, group and provincial scientific research projects in the field of CSP, and has edited a number of relevant national industry norms and regulations in the field of CSP, such as the Preparation Method of Pre-feasibility Study Report of CSP Project, the Preparation Method of Feasibility Study Report of CSP Project and the Evaluation Method of Solar Resources of CSP Project. The company made great achievements in the research of solar energy evaluation technology, design of HTF & TES system and key construction technology, optimization of conventional island thermal system, structure and foundation design of 200 m-scale solar tower, anti-condensation and insulation technology of sun Island system, arrangement of megawatt linear Fresnel CSP heliostat field and key technologies of heat collection, etc. The company fully mastered core technologies in the field of CSP system integration, and successfully realized grid-connected power generation of one of the supporting projects of PowerChina Qinghai Gonghe 50 MW Solar Tower Plant Project. The company actively explores new energy utilization methods, such as wind energy, solar energy, biomass energy and geothermal energy. The company carried out planning, survey, design and general contracting of CSP in Qinghai, Gansu, Xinjiang, Tibet and other provinces and autonomous regions, and formed distinctive technical characteristics in the system design, engineering construction, performance evaluation and operation optimization of CSP plants. It has the capability to integrate the whole process system services for building first-class intelligent CSP plants. In recent years, the company has completed the feasibility study design of CSP with a total installed capacity of 3,000 MW and the survey design of 750 MW. At present, the company is carrying out EPC construction of a number of 100 MW-scale CSP projects, such as Qinghai Gonghe Phase II, CTGR Qingyu DC, CHN Energy Qinghai Gonghe, ZDI 100 MW CSP + 800 MW PV Hybrid Project in Tushuo, Anduo County, Tibet.

Company (listed in alphabetical order)	Business Profile
Northwest Electric Power Design Institute Co., Ltd. of China Power Engineering Consulting Group,	The company is a large state-owned enterprise with more than ten Grade A qualifications, such as Grade A comprehensive engineering design, Grade A engineering survey, and Grade A qualifications of engineering consultation, cost consultation, environmental impact assessment, surveying and mapping. The company is committed to senior consulting planning, engineering survey and design, general contracting and other business fields. As one of the earliest Chinese enterprises that carry out the design of CSP plants, the company set up a R&D team in 2013 to invest in the research of CSP related technology. In the development process of more than 10 years, the company has always adhered to the concept of innovative development, and established the advantages of the whole industrial chain of CSP in the fields of technology R&D, equipment manufacturing, planning consultation, survey and design, engineering contracting and investment operation, covering various types of CSP and heat utilization projects such as solar tower plant, parabolic trough CSP plant and linear Fresnel CSP plant. The company completed total installed capacity of the completed feasibility study and design of CSP projects exceeded 4,000 MW, and the total installed capacity of the project performance in the survey and design stage reached 750 MW, of which the EPC project capacity reached 550 MW, ranking among the top in China. Meanwhile, the company attaches great importance to the supporting and leading role of scientific and technological innovation in emerging businesses. The company has set up a number of high-level R&D and innovation platforms such as "PowerChina Concentrating Solar Power Engineering Research Center (established initiatively)", "Shaanxi Wind and Solar Power and Multi-energy Storage Engineering Technology Research Center (established initiatively)" and "National Innovation Platform (Center) for Industry-Education Integration of Energy Storage Technology, Xi'an Jiaotong University (established jointly)". The company edited and co-edited more than 20 specifications above the industry level, won more than 20 awards at national, provincial and ministerial level in related fields, and obtained more than 30 core patents. The company sets up technical teams consisting of domestically and internationally renowned superior talents, and has technological innovation competitiveness. In recent years, the company has taken the initiative in undertaking more than 20 high-level scientific research projects, such as national key R&D plans, fund programs of Department of Science and Technology of Shaanxi Province and key subjects of Qinghai Provincial Energy Administration. 10 achievements were appraised by industry authorities such as China Renewable Energy Society/China Electricity Council, among which 7 have reached the international advanced level, and 3 have reached the international advanced level. The company made a series of technical breakthroughs in solar concentration and collection systems, HTF & TES systems, steam turbine generator systems, performance evaluation of CSP plants and digital applications, and applied these technologies in many CSP projects.
Gansu Province:	
Gansu Kaisheng Daming Solar Energy Technology Co., Ltd.	The company was established in 2018, and it is an important member of CNG (stock code: 03300.HK). The company built a complete industrial chain covering an 600 t/d photothermal ultra-white float glass production line and a 800 t/d photothermal ultra-white glass production line. The company mastered the purification technology of low-iron quartz sand for photothermal glass, and became the world's only enterprise with the whole industrial chain manufacturing capacity of CSP reflectors. With the self-developed world's first total oxygen combustion process, the company produced photothermal ultra-white float glass, and reached a market share of over 80% in China. In 2024, the company successfully delivered more than 5000,000 m^2 of photothermal ultra-white float glass original sheets and more than 4000,000 m^2 of reflector products safely, punctually and efficiently, thus ensuring the smooth progress of 15 CSP projects. The company supplied 2.018 GW photothermal reflectors globally (including 1.5 GW photothermal glass original sheet).

Company (listed in alphabetical order)	Business Profile
Gansu Province Installation & Construction Group Co., Ltd.,	The company undertakes construction, installation, real estate development, infrastructure investment, construction and operation projects. It is mainly engaged in the project construction in the fields of electric power, electromechanical installation, municipal administration, steel structure, environmental protection, petrochemical industry, mining and metallurgy, water conservancy and hydropower, construction, etc., as well as housing construction and power engineering supervision. In the field of CSP, the company, as a consortium, won the bid for EPC of the Three Gorges SunSum Guazhou 700 MW "Solar Thermal Energy Storage+" Project, the PC of Xinhua Hydropower Bozhou 100 MW TES CSP and 900 MW New Energy Project, and the PC of Dunhuang CSP + (100 MW) CSP Project of Longyuan (Dunhuang) New Energy Development Co., Ltd. under China Longyuan, and TES System Science and Technology Project.
Gansu Building Materials Research and Design Institute Co., Ltd.	As a state-owned science and technology enterprise, the company is mainly engaged in the R&D of new materials, inspection, testing and identification, industrialization of scientific research achievements, engineering design consulting and supervision in industries such as new building materials, green buildings, new energy utilization, energy conservation and environmental protection. The company has 10 Grade A qualifications in building engineering design, building materials engineering design and construction engineering inspection, and sets up national technology transfer demonstration institution, industrial energy conservation and green development evaluation center of MIIT, Gansu green building technology key laboratory and other national and provincial technological innovation service platforms and institutions. Since its establishment for more than 40 years, the company has made a number of scientific research achievements in the fields of inspection and identification, advanced inorganic nonmetallic materials, green buildings, new energy-saving and environmental protection materials, green functional building materials, comprehensive utilization of resources, solar heat utilization, and thermal utilization of middle and deep strata. Among them, there are 12 thermal heating projects in the middle and deep strata under construction and put into operation, with a heating area of 1000,000 m^2.

Company (listed in alphabetical order)	Business Profile
Lanzhou Dacheng Technology Co., Ltd.	The company has been engaged in CSP research for 16 years, and has applied for more than 100 patents. It has developed key components such as vacuum receiver tube, reflector, heat exchanger and MS HTF & TES equipment, and has complete technology and manufacturing base for heating and power generation with MS linear Fresnel solar energy with independent intellectual property rights. The company has mastered key system technologies (e.g. solar concentrator and collection field, TES system, HTF system and power generation system), and built a number of CSP heating and power generation projects. The company has accumulated rich experience in the development, design, production, construction, installation, commissioning and operation and maintenance of CSP heating and power generation. In recent years, the company has undertaken 23 national and 44 provincial scientific and technological projects, including the National 863 Program, the National 973 Program, the National Energy Conservation and Emission Reduction Special Program the Central Newly-increased Investment Program by the State, the NSFC Program and NEA Major Special Program. Among them, 42 projects have been completed and accepted, and made several major landmark innovative achievements, and won two second prizes for National Science and Technology Progress Award and five first prizes for Provincial Science and Technology Progress Award. Among them, the "Key Technologies and Industrialization of MS Linear Fresnel Solar Concentration and Collection System" project won the first prize of Gansu Provincial Science and Technology Progress Award in 2022, and the "Complete Equipment of MS Linear Fresnel Solar Concentration and Collection System" was listed in the Catalogue of the Third Batch of the First Set of Major Technical Equipment (Projects) in the Energy Field by NEA. The Dunhuang 50 MW MS Linear Fresnel CSP Project is the first batch of CSP demonstration projects planned, applied, invested, constructed, provided with key technologies and operated and maintained by the company. Besides, it is also the first MS linear Fresnel CSP commercial plant under operation in the world, achieving a breakthrough in focusing technology of molten salt line from 0 to 1. At present, the company has an annual production capacity of 50,000 high-temperature MS vacuum receiver tubes, 2000,000 m^2 primary reflector and 500,000 m^2 secondary reflector, which can satisfy the construction requirements of 200 MW molten salt linear Fresnel CSP plant. In the wind and solar base, the company has won a number of "CSP"projects by virtue of its technical strength, including: CNNC Yumen 100 MW CSP + 200 MW Wind Power + 400 MW PV Project, CTGR Hami 1,000 MW Hybrid "CSP + PV" Demonstration Project, Datang Shichengzi 1,000 MW "CSP + PV" Hybrid Clean Energy Demonstration Project and China Longyuan Power 100 MW CSP + 480 MW Wind Power + 120 MW PV Project.

Company (listed in alphabetical order)	Business Profile
Lanzhou LS Heat Exchange Equipment Co., Ltd.	The company is engaged in R&D, design, production and service of plate heat exchangers mainly used in many fields, such as energy conservation and environmental protection, nuclear power and military industry, petrochemical industry, HVAC, shipbuilding, metallurgy, bioenergy, steel, electric power, pharmaceuticals, textile, paper making and food. The new (microchannel) high-efficiency compact welded printed circuit heat exchanger (PCHE) developed by the company can be applied mainly in the field of clean energy, such as supercritical CO_2 power generation, CSP, nuclear power, LNG ships, gas turbines, hydrogen refueling stations and heat pumps. Lanzhou LS Heavy Equipment Co., Ltd., the company's parent company undertook the CHN Energy Dunhuang "CSP+" Project, 100 MW MS Linear Fresnel CSP Project, TES Island System Technology Project, and the civil engineering and tank design and installation project of high-temperature and low-temperature molten salt tank foundation.
Shouhang High-Tech Energy Technology Co., Ltd.	Founded in 2001, the company is headquartered in Gansu Province and its production base is located in Tianjin. Adhering to the business development strategy of "clean energy, energy conservation and environmental protection", the company is a high-tech enterprise engaged in R&D, design, manufacturing, sales, installation, management, commissioning, training and general contracting of power stations in the fields of CSP, solar thermal energy storage + multi-energy complementation, hydrogen energy utilization, air cooling of plants, waste heat power generation, water technology and clean heating. The company invested, constructed and operated Dunhuang 100 MW + 10 MW MS Solar Tower Plant Projects; the company is also the subcontractor of sun island system integration of CGN Delingha 50 MW Parabolic Trough CSP Plant. After winning the bids for several CSP EPC projects in Wind and Solar New Energy Base successively, the company is steadily promoting the construction of Yumen Wind, Solar Thermal Energy Storage Multi-Energy Complementation Hybrid System, Qingyu DC 1,000 MW CSP + Multi-energy Complementary Project, Three Gorges Qinghai Golmud 1,100 MW PV + CSP Project, SDIC Ruoqiang 100 MW CSP Project EPC, Xinhua Hydropower Jinghe New Energy 100 MW CSP PC, tower solar concentration and collection system of Tangshan Haitai CSP+PV Hybrid Project, Compressed Carbon Dioxide CSP (with MS TES) 100 MW + 900 MW PV Hybrid Project, Luntai Industrial Park Project of the Second Division of the Southern Xinjiang Corps. In the field of R&D of supercritical carbon dioxide cycle solar energy technology, 100 MW/400 MWh new Compressed Carbon Dioxide MS TES Project invested by the company has been put into operation; the application of several CSP (with MS TES) technologies in deep peak shaving of CSP plants is also being promoted actively. In terms of international business development, in July, 2024, the company received a letter named "Letter of Designation of Shouhang High-Tech Energy Technology Co., Ltd. as the Independent Power Supplier for 200 MW CSP Project in Maun, Botswana", which specified that Shouhang High-Tech is designated as the independent power supplier for 200 MW CSP Project in Maun, Botswana, thus showing "China strength in constructing international CSP projects".

Company (listed in alphabetical order)	Business Profile
Ningxia Hui Autonomous Region	
Ningxia Zhonghao YinChen Energy Technology Service Co., Ltd.	The company is a national high-tech enterprise mainly engaged in space energy constant heating station, air source heat pump, air source heat pump assisted solar integrated heating and cooling system, clean energy heating big data platform, flat plate solar water heater, solar collector, PVT, BIPV, EIT intelligent constant heating station and other clean energy heating. The company's business integrates independent R&D, manufacturing, sales and technical consulting services. It is a "technologically advanced enterprise", "gazelle enterprise", "little giant enterprise" and "small and medium-sized high-tech enterprise" in Ningxia Hui Autonomous Region. In recent years, the company provided more than 2000,000 m^2 comfortable heating for rural houses (more than 20,000 houses), schools, township governments, hospitals, health centers, village committees and nursing homes in 22 counties, districts and five major cities in Ningxia Province.
Overseas	
ARI Solar	The company has more than 15 years of experience in the field of CSP. Its core team members have accumulated rich experience in design and field by working in internationally renowned CSP enterprises and plants. Its technical capability covers technical routes of parabolic trough CSP plants, steam solar tower plants, MS solar tower plants and linear Fresnel CSP plants, and its performance exceeded 2 GW. The company can provide consulting and commissioning services for domestic CSP projects.
Exera Energia	The company has been deeply engaged in CSP industry for 15 years, and provided professional technical consultation, operation & maintenance services for CSP plants, especially customized commissioning, operation & maintenance and training services for Chinese customers. Up to now, Exera has operated more than 225 renewable energy power projects worldwide, and served 260 customers. Among them, in the field of CSP, the company has undertaken 9 CSP EPC projects, provided consulting services for 95% CSP projects in Spain, provided full-range operation and maintenance services for 20 MW Gemasolar of the world's first Solar Tower Plant with MS TES, and undertook professional training for 11 CSP plants worldwide. The company has provided technical review services for 59 CSP plants (including those in US), and provided comprehensive operation & maintenance services or related support services for 15 CSP plants. In addition, in the field of wind energy and photovoltaic energy, the company made achievements in EPC / supervision service for more than 35 plants and 2 biomass projects. Its services mainly include: 1. Technical management service of plant; 2. Comprehensive operation & maintenance service of plant; 3. Technical review service of plant; 4. Training service for operation & maintenance personnel; 5. Supervision and technical support service for grid-connected commissioning, supervision and technical support service for operation & maintenance; 6. Design of operation & maintenance service; 7. Predictive maintenance tools of plant equipment through ExeControl - a plant operation & maintenance management system.
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