Blue Book for Industry Development of Chinese Concentrated Solar Power and Solar Heating in 2016

China National Solar Thermal Energy Alliance

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Abbreviation list

Alliance	China National Solar Thermal Energy Alliance
BP	British Petroleum
BRI	Belt and Road initiative
BTES	Borehole-duct Thermal Energy Storage
CC	Combined Cycle
CHP	Combined Heat and Power
CSP	Concentrated Solar Power
DNI	DNI direct normal irradiance (W/m2)
DSG	direct steam generation
EPC	Engineering, Procurement and Construction
FIT	Feed in Tariff
FYP	Five-Year Plan
HTF	Heat Transfer Fluid
IEA	International Energy Agency
IEC	International Electro-technical Commission
IoE	Internet of Energy
IRENA	International Renewable Energy Agency
IRR	Internal rate of return
ISCC	Integrated Solar Combined Cycle
ITC	International Electro-technical Commission
LCOE	Levelized Costs Of Electricity
NEB	National Energy Board
ORC	Organic Rankine Cycle
PTC	parabolic trough collector
PV	Photovoltaic technology
R&D	Research and Development
RMB	Chinese currency
SDH	Solar District Heating
SDRC	State Development and Reform Commission
SRC	Solar Rankine Cycle
ST	Solar Tower
STS	Solar thermal systems
TES	Thermal Energy Storage
UHVDC	Ultra-High-Voltage Direct-Current
USD	The United States dollar
VCC	Vapor Compression Cycle

An introduction About China National Solar Thermal Energy Alliance.

The Alliance was proposed and established by the Ministry of Science and Technology (MOST), Ministry of Finance, Ministry of Education, State-owned Assets Supervision and Administration Commission of the State Council, All China Federation of Trade Unions, and China Development Bank in 2009 to lead the R&D innovation and promote the solar thermal development and application under the guidance of the MOST. In the assessment of 104 alliances organized by the MOST from 2012 to 2015, the Alliance has been graded among the top 3 successively.

As a non-profit membership organization, by May 2017, the Alliance has 73 members, with corporate members accounting for 71%. The members' products and services cover ultra-white glass, parabolic glass reflector, parabolic trough concentrator, heliostats, evacuated tube receiver, tracking driver, tracking controlling system, and molten salt as well as overall system integration and plant engineering construction and etc.

As a window to know China's solar thermal industry, the Alliance is able to:

- Introduce reliable solar thermal product suppliers to you
- Seek business and technology partners in China for you
- Communicate with related governmental departments with you

1. Development of Concentrated Solar Power in China

In recent years, China has made some achievements in the field of Concentrated Solar Power (CSP), but there is still a certain distance from realizing its full industrial potential. There are many parts of CSP system that could be already supplied to the market, as different types of concentrators, receiver tubes for parabolic trough collector (PTC) among others, while other commercial technologies are in the maturity process, as high-precision concentrators, high-performance receiver and large-scale Thermal Energy Storage (TES) devices.

Although national production of key equipment in CSP system is gradually emerging, Chinese industrial base of CSP is still relatively weak due to the limited engineering practice and lack of large-scale CSP projects. Besides, a sizable gap still exists in Chinese industry compared with international level of preparation and production of materials used in CSP systems. Design and manufacturing capacities regarding quick starting of steam turbine, dish Stirling engine and other major equipment require additional improvements, while technologies of large-scale CSP plant's design and integration, as well as system optimization still need to be tested.

With newly installed capacity of 10.2 MW, Chinese CSP market had a quick start in 2016. Including 10MW molten salt tower CSP plant built by Shouhang Resources Saving, which went online on December 26th, and the 200 kW molten salt PTC test loop with total length of 800m, which went online on October 12th in Gansu Aksay, the total installed capacity of CSP in China had achieved 28.3 MW.

Yet, there were some other projects connected to the grid in 2016, which were not accounted for in the statistics due to various reasons, but are important to be mentioned. Although the SUPCON Delingha 10MW molten salt Solar Tower (ST) power plant was connected to the grid on August 20th of 2016, it was not included in the 2016 newly increased statistics because the plant was transformed from a previous water-based 10MW ST plant. In addition, heat collecting system of 1MW molten salt ST power plant, developed by Institute of Electrical Engineering, Chinese Academy of Sciences (IEE, CAS) was also completed and put into operation in July, 2016, but not included in the statistics of 2016, because it was not connected to the grid.

During the 12th FYP (FYP) and based on the support of the National High Technology Research and Development Program (known as the 863), IEE, CAS has developed the research project with 9000 m^2 parabolic trough thermal collector and evaporation system technology. Moreover, there were other plants launched in 2016: 15 MW Fresnel CSP demonstration plant in Zhangjiakou by Huaqiang TeraSolar; 10 MW Fresnel molten salt plant in Dunhuang by Lanzhou Dacheng; 50 MW parabolic trough CSP plant in Delingha by China Guangdong Nuclear Power Group.

Commercial-scale demonstration projects also have started their wide deployment, as 100 MW ST power plant in Dunhuang by Shouhang Resources Saving, 50 MW plant in Delingha by SUPCON, and 50 MW thermal oil-based parabolic trough plant in Yumen East Town by Zhongshang Mingde among others.

The development of CSP has received further high-level government support, when Premier Li Keqiang during the meeting of the State Council on January 22nd, 2016, argued for promotion of a new type of people-centered urbanization. The meeting highlighted that further efficient urbanization is a key leverage point for China's development. Thus, the western regions with its greater demand for urbanization and urgent need of development cannot overlook the new energy source to become its driving force.

In September 2016, National Energy Board (NEB) issued the *Notice on the construction of CSP demonstration projects*, up to 20 projects with the total capacity of 1.35 MW were included in this first demonstration project list. Furthermore, the State Development and Reform Commission (SDRC) announced that the demonstration projects could enjoy the Feed in Tariff (FIT) price of 1.15 RMB/kWh solar thermal power benchmark price, but only if they are in operation by 2019.

In December 2016, NEB and SDRC successively released *the 13th FYP for energy development*, *the 13th FYP for energy technology innovation*, *the 13th FYP for renewable energy development*, *the 13th FYP for solar energy development*, and *the*

13th FYP for electric power development (2016-2020). Through all these documents, the urgency of renewable energy and clean energy development has been emphasized, as well as many potential challenges faced in the process of its development have been clarified.

The 13th FYP for solar energy development aims by the end of 2020 to reach more than 110 GW of the total solar power installed capacity, where Photovoltaic (PV) energy would account for 105 GW and CSP will achieve 5 GW. Thus, by 2020 the amount of annual utilization of solar energy will reach over 1.4 tons of standard coal. The price level of PV expects to decrease by more than 50% from the 2015 price, thus the goal of grid parity in many regions could be achieved.

According to *13th FYP for energy development* the share of non-fossil fuel in primary energy consumption shall be higher than 15% by 2020, natural gas has to reach 10% and the percentage of coal in primary energy consumption will be below 58%. Setting these ambitious goals means that annual increase of non-fossil energy and natural gas would be 3 times more than energy from coal, accounting for more than 68% of the total expected increase in energy consumption. Thus, low-carbon clean energy will play the main role in increasing energy supply during the 13th FYP period.

The 13th FYP for renewable energy development targets the main problems faced by the renewable energy and defines the objectives and development paths during 2016-2020. The plan covers hydropower, wind, solar, biomass, tidal and for the first time the plan has included the geothermal energy. Moreover, around RMB 2.5 trillion (USD 361 billion) are expected to be invested into the development of renewable energy sources, creating 13 million new jobs.

The 13th FYP for electric power development (2016-2020) suggests that the northwest area should focus on expansion of transmission capacity, enabling better renewable energy integration. In particular, to accelerate the construction of ultra-high-voltage direct-current (UHVDC) transmission systems in eastern Huai River, eastern Ningxia, Jiuquan, and northern Shaanxi, and promote the research and demonstration projects of transmission systems in Xinjiang, Longbin and Qinghai according to the market demand.

On December 22nd, 2016, Xi Jinping chaired the 14th meeting of the Central Finance Leading Group, where the promotion of winter clean heating in northern regions was specially emphasized. Moreover, Premier Li Keqiang presided in the Political Bureau of the CPC Central Committee, where *the 13th FYP for Development of Western regions* was discussed and adopted. The plan guides further development of the western areas emphasizing the importance of infrastructure and environmental protection as key elements for sustainable development of regions. In addition, the plan encourages the improvements in regulation to guide industries to become environmentally friendly, create more jobs in central and eastern parts to transfer them later to the west. Moreover, manufacturing industries in the East have been encouraged to invest and set up factories in the western areas.

The western areas that would be suitable for the operation of commercial CSP plant are precisely those where socioeconomic conditions are below the national average. The construction of CSP plant would not only create new direct and indirect jobs associated to the construction and maintenance of the plant, but also CSP electricity might bring additional source of revenues if exported to the centers of electricity demand in South-eastern states.

For the renewable energy sector, one of the biggest landmarks of 2016, was the incentive given to CSP technology in China. This policy could result in a massive growth of installed capacity of CSP in the next years.

As for solar thermal energy of low temperature, the market still focuses on offering domestic hot water, but the industry is in urgent need to be upgraded in order to optimize different types of solar energy application. Solar heating is an important direction for low temperature solar thermal power. Yet, the technical research lacks the innovative technology and mainly concerned with Direct-gain passive solar system[1], Thermal Storage Wall[2] and Sunspaces[3]. The additional costs, long term

[1] Direct-gain passive solar systems rely on south-facing windows to bring solar energy directly into a house.
[2] A thick mass wall built on the solar side of the house, which absorbs the heat and stores by the solid masonry wall. At night, the wall re-radiates the stored heat into the cooler house.
[3] Sunspace is an integration of the direct gain and thermal storage concepts, which heats up the air in the room.

payback and strong influence in architectural design among other barriers prevent the passive solar heating from a massive adoption. As far as the active solar heating concerned, the heat collection efficiency of hot water system is around 40%, and the guaranteed rate of return is less than 35%, meaning the system cannot recover the initial investment cost during its life period. Research on solar heating in architectural complex of villages and cities are still in its early stages and further relevant technology-based research has to be done.

In the solar air conditioning system, gas or oil fired boilers are generally used as auxiliary heat source to guarantee its continuity. The solar air conditioners combine medium-temperature collectors and double-effect lithium bromide, yet in a large scale the technology still needs further breakthroughs, especially regarding the application of variable temperature grades.

Nationally developed medium temperature solar collectors laid the foundation for solar thermal application for industrial and agricultural heating. However, the challenges still exist regarding multi-energy solar heating systems, thermal energy storage materials and others, in order to achieve large-scale, low-cost reliable technology, which could meet different application demands.

1.1 Overview of enterprises and production capacity in CSP sector

1.1.1 Overview of enterprises related to CSP industry

The current overview of enterprises related to CSP industry can be seen in table 1. The figures in brackets denote the number of relevant enterprises, including manufacturers, engineering construction companies, design and research institutes, universities, and professional mass media sources and among others, with total number of 228 entities.

Table 1. Number of enterprises by industrial chain (up to December 31st, 2016)

No.	Categories	Products
1	Special purpose materials (19)	1. Primary ultra-white glass (3) 2. Reflecting mirror (6) 3. Molten salt (4) 4. Thermal oil (3) 5. High temperature heating belts for pipelines (3)
2	Concentrators and gear reducers (40)	1. Heliostats (5) 2. Parabolic trough concentrators (12) 3. Dish concentrators (5) 4. Fresnel concentrators (12) 5. Gear reducers for concentrators (6)
3	Heat receivers (21)	1. Parabolic trough receiver tubes (12) 2. Tower receivers (5) 3. Linear Fresnel receivers (3) 4. Dish receivers (1)
4	Fluid Transportation (8)	1. Salt pumps (2) 2. Oil pumps (6)
5	Heat exchangers (38)	1. Oil / water evaporators (10) 2. Salt / water evaporators (5) 3. Oil / salt heat exchangers (3) 4. Gas / water heat exchangers (20)
6	Power generation equipment (14)	1. Steam turbines (4) 2. Generators (5) 3. Micro-turbines (2) 4. Stirling engines (3)
7	Control system (13)	1. Solar field integrated control system (5)

		2. Distributed Control System (DCS) (8)
8	Research institutes specialized on CSP plant design (12)	Research institutes at provincial, regional and central levels (12)
9	Investment and construction enterprises (48)	1. Solar field (3) 2. Heat Island (4) 3. Power Island (5) 4. EPC General Contacting (6) 5. Investment enterprises, including state-owned and private enterprises (30)
10	Service providers (2)	Performance testing and consultancy companies for different kind of equipment and components (2)
11	Educational Institutions (8)	1. Universities with CSP related programs (5) 2. Research Institutions (1) 3. Training agencies (2)
12	Professional mass media sources (5)	Specialized news websites, Newspapers and other mass media sources(5)

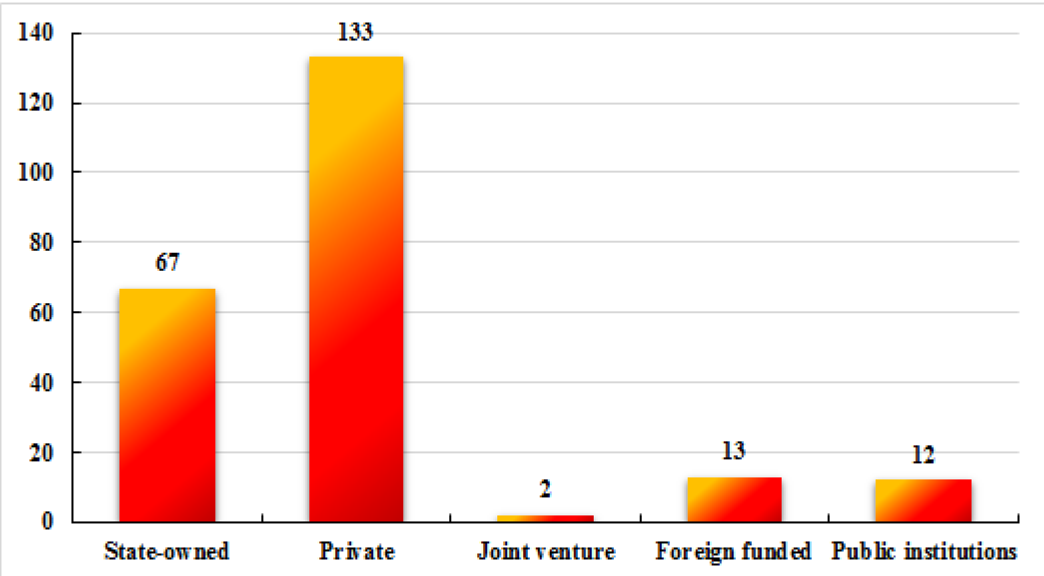

Figure 1. Number of enterprises classified by types of activity

We observe from table 1 that among all the CSP related entities, power plant investment and construction companies predominate, accounting for 48, while service providers concerned with performance testing and consulting companies are the least presented, accounting for only two. In addition, there are only five professional mass media sources, where the China National Solar Thermal Energy Alliance (hereafter the Alliance) is included, which indicates the lack of sources to spread the information about CSP.

Regarding the production capacity, it was found that there is considerable number of enterprises, producing concentrators and various types of heat exchangers, with the total number over 100, which demonstrates that China has a relatively strong capacity of manufacturing the equipment. Among the above mentioned manufacturing enterprises: concentrators account for about 40 %, while receivers, especially vacuum receiver tubes, account for much less, which illustrates that concentrators are taking a higher proportion of investments, thus it is the focus of investors.

Moreover, as demonstrated in Figure 1 the majority of these enterprises are the private (133), while state owned accounts for only 67 enterprises. This trend indicates the increasing participation of private companies in CSP sector.

1.1.2 Newly emerged enterprises during the 12th FYP period

Table 2. Newly emerged CSP enterprises from January 1st to December 31st, 2016

No.	Categories	Products
1	Special purpose materials (1)	1. Primary ultra-white glass (0) 2. Reflecting mirror (0) 3. Molten salt (0) 4. Thermal oil (0) 5. High temperature heating belts for pipelines (0)
2	Concentrators and gear reducers (3)	1. Heliostats (1) 2. Parabolic trough concentrators (2) 3. Dish concentrators (1)

		4. Fresnel concentrators (0) 5. Gear reducers for concentrators (0)
3	Heat receivers (1)	1. Parabolic trough receiver tubes (0) 2. Tower receivers (1) 3. Linear Fresnel receivers (0) 4. Dish receivers (0)
4	Fluid Transportation (0)	1. Salt pumps (0) 2. Oil pumps (0)
5	Heat exchangers (0)	1. Oil / water evaporators (0) 2. Salt / water evaporators (0) 3. Oil / salt heat exchangers (0) 4. Gas / water heat exchangers (0)
6	Power generation equipment (1)	1. Steam turbines (0) 2. Generators (0) 3. Micro-turbines (0) 4. Stirling engines (1)
7	Control system (1)	1. Solar field integrated control system (1) 2. Distributed Control System (DCS) (0)
8	Research institutes specialized on CSP plant design (3)	Design institutes at provincial, regional and central levels (3)
9	Investment and construction enterprises (27)	1. Solar Field (3) 2. Heat Island (0) 3. Power Island (0) 4. EPC General Contacting (4) 5. Investment enterprises, including state-owned and

		private enterprises (20)
10	Service providers (0)	Performance testing and consultancy companies for different kind of equipment and components (0)
11	Educational Institutions (0)	1. Universities with CSP related programs (0) 2. Research Institutions (0) 3. Training agencies (0)
12	Professional mass media sources (0)	Specialized news websites, Newspapers and other media sources(0)

The table 2 shows us that the number of enterprises related to energy investment and construction had the fastest rates of emergence, while the number of entities related to manufacturing activities, service, education and mass media sources nearly remain the same. The investments, driven by the FIT price in 2016, are expected to push the gradual growth in the downstream industries in CSP sector in 2017-2018.

Design Institutes[4] work mainly with feasibility studies of CSP projects and as well with the Engineering, Procurement and Construction (EPC). Due to a shrinking domestic thermal power market, many design institutes began to focus on CSP projects since late 2015. However, fewer design institutes had presented the demonstration projects, according to the results of government tenders in the beginning of 2016.

1.1.3 Number of production lines

Among all 22 enterprises which have replied to the survey of Blue Book, 15 of those are working with production lines of following equipment: receivers, molten salt, heliostats, concentrators, mechanical & hydraulic drives or tracking systems, control equipment for DCS, and glass reflecting mirrors. The total investment of companies reached RMB 4.18 billion (USD 698 million).

[4] The example of Design Institute could be - North China Power Engineering Co., Ltd. of China Power Engineering Consulting Group - large state-owned enterprise established by reforming the original North China Electric Power Design Institute.

1.1.4 Production capacity

Table 3. Annual production capacity

Categories	**Annual production capacity**
Receiver tubes for parabolic trough	Capacity to equip plant (without TES) of 1.2 GW
Concentrators for parabolic trough	Capacity to equip plant (without TES) 2 GW
Heliostats for solar tower	Capacity to equip plant (without TES) 1 GW
Concentrators for Fresnel	Capacity to equip plant (without TES) 0.1 GW
Molten salt	70 thousand tons
Thermal oil	1.1 million tons
Gear reducer for sun tracking system	340 thousand units (about 1.7 GW)
Coated steel pipes for high temperature heat collectors	120 km
Ultra-White glass	700 tons / day, 2 GW
Reflecting mirror (different types)	Capacity to equip plant (without TES) 2 GW
Control System for solar field	600 sets

1.2 Economic overview

1.2.1 Total assets of CSP Industry

The newly increased investment in 2016 reached RMB 600 million (USD 87 million), including professional equipment, experimental systems, scientific research, design, testing platform, production lines and etc. The CSP industry has total assets of about RMB 16 billion (USD 2.3 billion), without counting the stock market value of listed companies. With the start of construction of demonstration projects in 2017 the total assets are expected to reach RMB 40 billion (USD 5.8 billion) in 2017 due to the development of value chain.

1.2.2 Realized profits

As the FIT policy was announced only in 2016, the entire industry has almost no realized profits from selling electricity, while revenue from manufacturing is also relatively low.

1.2.3 Industrial scale

The industrial scale is expected to gradually expand with the increment of demonstration projects. The industry is currently focusing on research and development, as well as on the preliminary work of power plants' design. The whole industrial chain, including special equipment, experimental loops, project design capacities and others, is still in its infancy.

1.2.4 The structure of industrial sector

Almost all the parts of CSP value chain are well presented currently in China. The number of companies working with concentrators and reducers are expected to increase together with further deployment of CSP projects. The design institutes which start with the first demonstration projects will gain additional experience and become more competitive in the future projects. Moreover, the number of service providers, as inspection and testing are also expected to grow rapidly. There are already certification institutions to initiate the work in CSP sector.

1.2.5 Analysis of production lines during 2010-2016

Since 2010, the national production of many CSP components was increasing rapidly, while the production of core equipment remained unchanged during 2015-2016. In 2016, only two production lines were newly built, with one producing high-temperature molten salt and the other, vacuum tubes.

1.3 Large-scale enterprises

1.3.1 Production capacity

Companies working with large scale production mainly focus on 3 products: production of heliostats, concentrators and vacuum tubes for parabolic trough. In China there are 3 companies which could supply heliostats, with a production capacity of 400 thousand m^2 per year; 12 enterprises can supply concentrators for parabolic trough, with the capacity of 1.5 GW or 15 million m^2 per year; and 5 enterprises supply vacuum tubes, being 1 GW and 400 thousand units / year.

1.3.2 Overview of total assets

Table 4 demonstrates the overview of total assets divided into the following technical categories: the special purpose materials, special equipment, research institutions specialized in CSP plant design, investment and construction companies and etc.

Table 4. Total assets divided into technical categories

No.	**Technical categories**	**Total assets (RMB 100 million)**
1	Special purpose materials	350
2	Concentrators and reducers	5
3	Heat receivers	100
4	Fluid transportation	2
5	Heat exchangers	75
6	Equipment for electricity generation	300
7	Control systems	5
8	Research institutions specialized in CSP plant design	8
9	Investment and construction of power plant	600
10	Service providers	0.3
11	Educational institutions	1
12	Professional mass media sources	0.03
Total		**1446.33**

1.3.3 Results of independent innovation in recent five years

1) July 2016: the IEE, CAS successfully put into operation the power plant of 1 MWth molten salt receiver and heat exchanger.

2) August 20th, 2016: SUPCON launched online the ST plant combine with 5 MW water-based and 5 MW of molten salt-based fluids.

3) August 2016: Xi'an Aero-engine LTD built 1 MW demonstration plant with dish Stirling technology (50*20kW) in Tongchuan, Shannxi province.

4) October 12th, 2016: the 200 kW demonstration project based on molten salt fluid, with total length of 800 m, was successfully put into operation in Aksay, Gansu.

5) December 26th, 2016: Shouhang Resources Saving launched online the 10 MW molten salt tower plant in Dunhuang.

1.3.4 Global suppliers

Table 5. International suppliers

Categories / Countries	Special-purpose materials	Special equipment	Solar receiver
Spain	×		×
Germany	×	×	×
France	×	×	
India	×	×	×
Iran	×		
Thailand	×	×	
Japan	×		
Sri Lanka	×	×	
South Korea	×	×	
USA	×	×	

The categories listed in the above table include: thermal oil, molten salt, tower receivers, trough concentrators, mechanical & hydraulic drivers, Fresnel concentrators, vacuum receiver tubes, and Fresnel receivers. Moreover, there are already some manufactures, which supply their products globally.

1.3.5 Analysis of Chinese enterprises

Based on the collected data, table 6 illustrates the number of entities classified by types of activity and technical categories. From table 6 it's apparent that private companies mainly focus on the production of concentrators and receivers, as well as on project investment and construction. Moreover, most of the enterprises, which designed the selected demonstration projects in 2016, are as well their owners.

With further deployment of CSP projects by 2018, capital-intensive sectors are expected to be occupied by the entities with strong financial foundation, as central government-owned enterprises and state-owned enterprises, while the private company might focus rather on the equipment manufacturing.

As shown in the Figure 3, state-owned enterprises focus mainly on the investment, design and construction of CSP plant, equipment manufacturing, as the production of tower receivers and various heat exchangers. Moreover, CSP technology can enjoy already existing advances in thermal power sector that could further boost CSP industry.

Table 6. Number of entities classified by types of activity and technical categories

NO.	Technical categories	State-owned Enterprise	Private Enterprise	Joint-venture Enterprise	Foreign-funded Enterprise	Public Institution
1	Special-purpose materials	2	13		4	
2	Special equipment	3	35	2		
3	Heat receivers	4	17			
4	Fluid transportation	1	7			
5	Heat exchanger	11	23		4	
6	Equipment for electricity generation	10	4		1	
7	Control systems	9			4	
8	Research institutions specialized on CSP plant design	10				1
9	Investment and construction of power plant	18	30			
10	Service providers		1			1
11	Educational institutions					8
12	Professional mass media sources		3			2

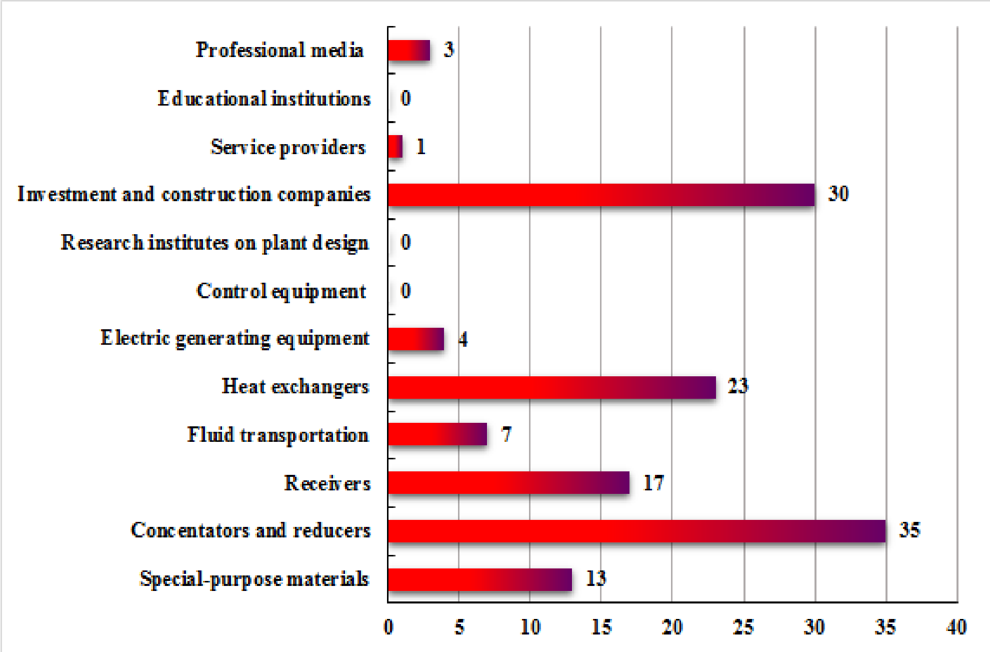

Figure 2. Number of private enterprises classified by technical categories

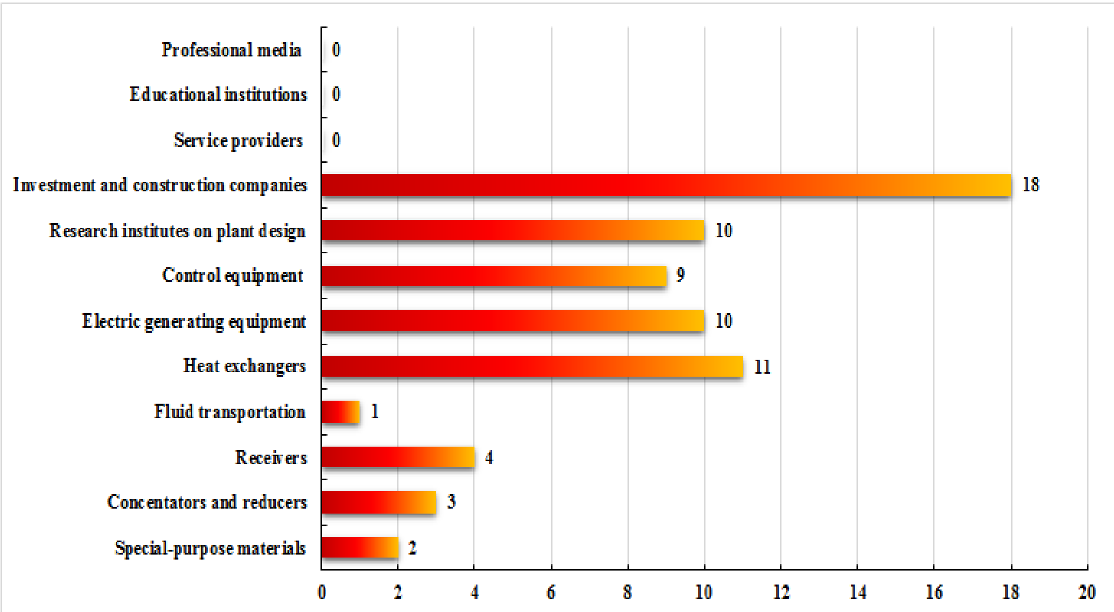

Figure 3. Number of state-owned enterprises classified by technical categories

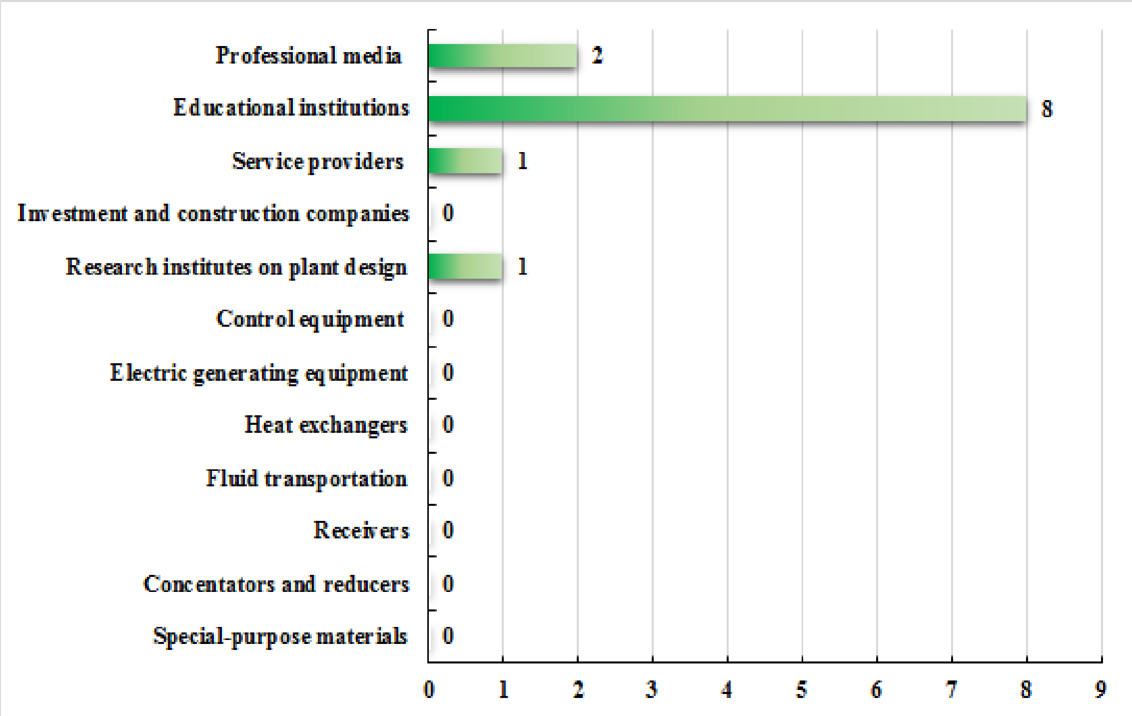

Figure 4. Number of educational institutions engaged in CSP research activities

Currently Chinese educational institutions are focusing on education itself, rather than on scientific research. Due to the lack of research Institutions specialized in CSP scientific research, there is a weak research base. However, it is worth noticing that many large research institutions of state-owned enterprises have already announced their intention to work with CSP research: *Central Research Institute of State Power Investment Corporation, State Grid Electric Power Research Institute, China Electric Power Research Institute, Huaneng Clean Energy Research Institute*, etc.

1.3.6 Implementation of the 12th FYP

By the end of 2015 there were 6 pilot demonstration CSP plants completed with installed capacity of 13.88 MW. In September 2016, which was mentioned before, the National Energy Board published the *Notice on the construction of CSP demonstration projects* (NEB, New Energy, NO. [2016]223), selecting 20 CSP demonstration projects with total installed capacity of 1.35 GW. There are 9 towers, 7 parabolic troughs and 4 Fresnel projects, no dish projects were selected. Figure 5 illustrates the number of projects by selected technologies.

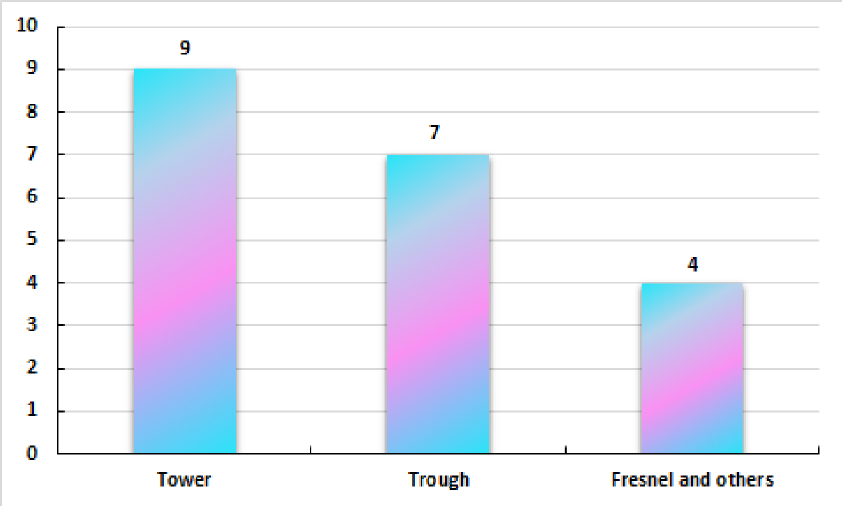

Figure 5. Number of projects by selected technologies

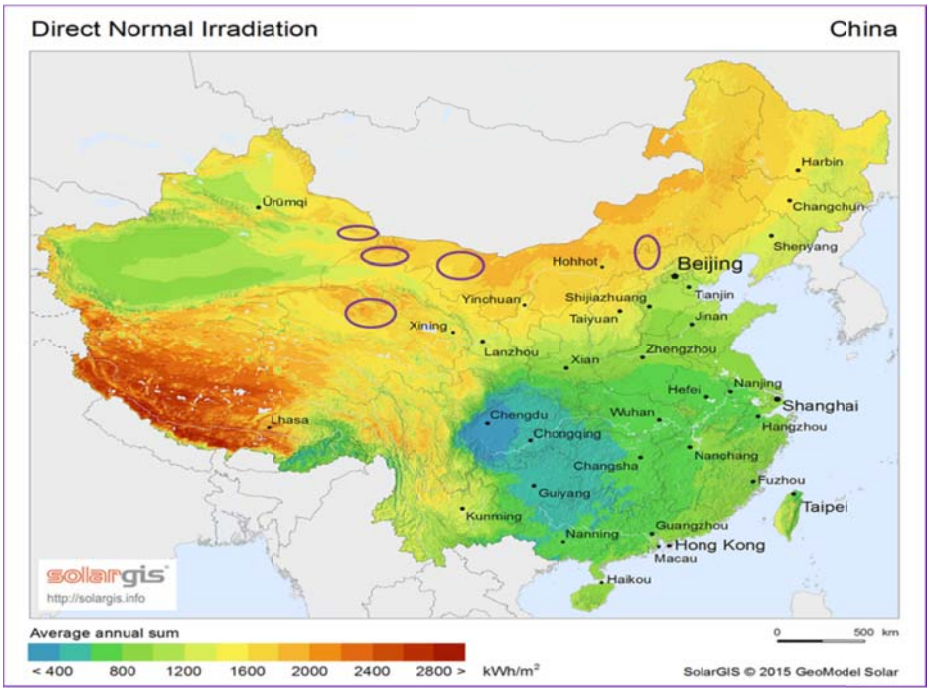

Figure 6. Location of demonstration projects

The projects are mainly located in five provinces, i.e. Qinghai, Gansu, Hebei, the Inner Mongolia Autonomous Region, and autonomous region Xinjiang, as illustrated in the Figure 6. Moreover, we observe from figure 6 that the annual Direct Normal Irradiance (DNI) values of project locations are basically around 2000 kWh/m^2. From figure 7 it can be seen that the efficiency of the demonstration projects range from 15-22%.

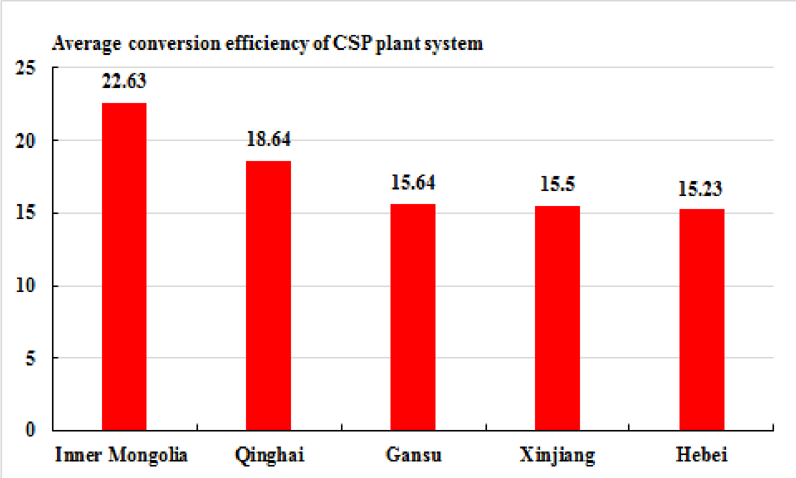

Figure 7. Average conversion efficiency of demonstration projects by location

Figure 8 shows an important correlation between the GDP of regions in China and the projects location. As we mentioned above, the high DNI values are usually in the regions where socioeconomic conditions are below the national average. Thus, the construction of thermal solar power plants fits the purpose of increasing the participation of renewables in the energy matrix, as well as promoting "coordinated and interactive" regional development, especially in those Western provinces, whose socioeconomic improvement is currently given "high priority".

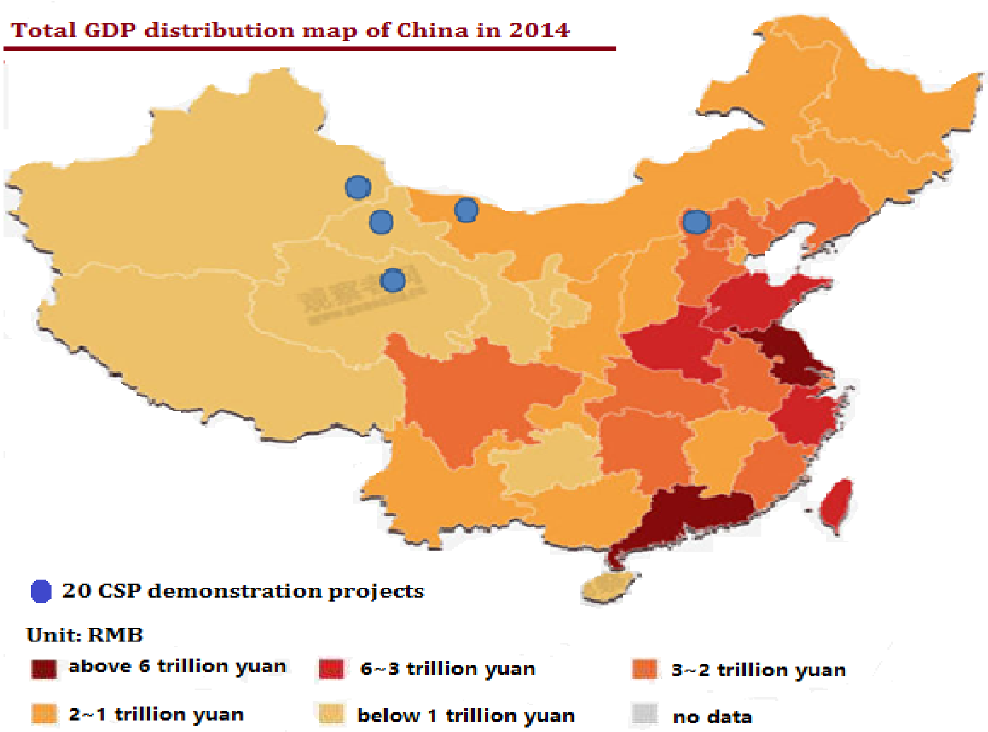

Figure 8. Location of demonstration projects on the map with provincial GDP

distribution across China

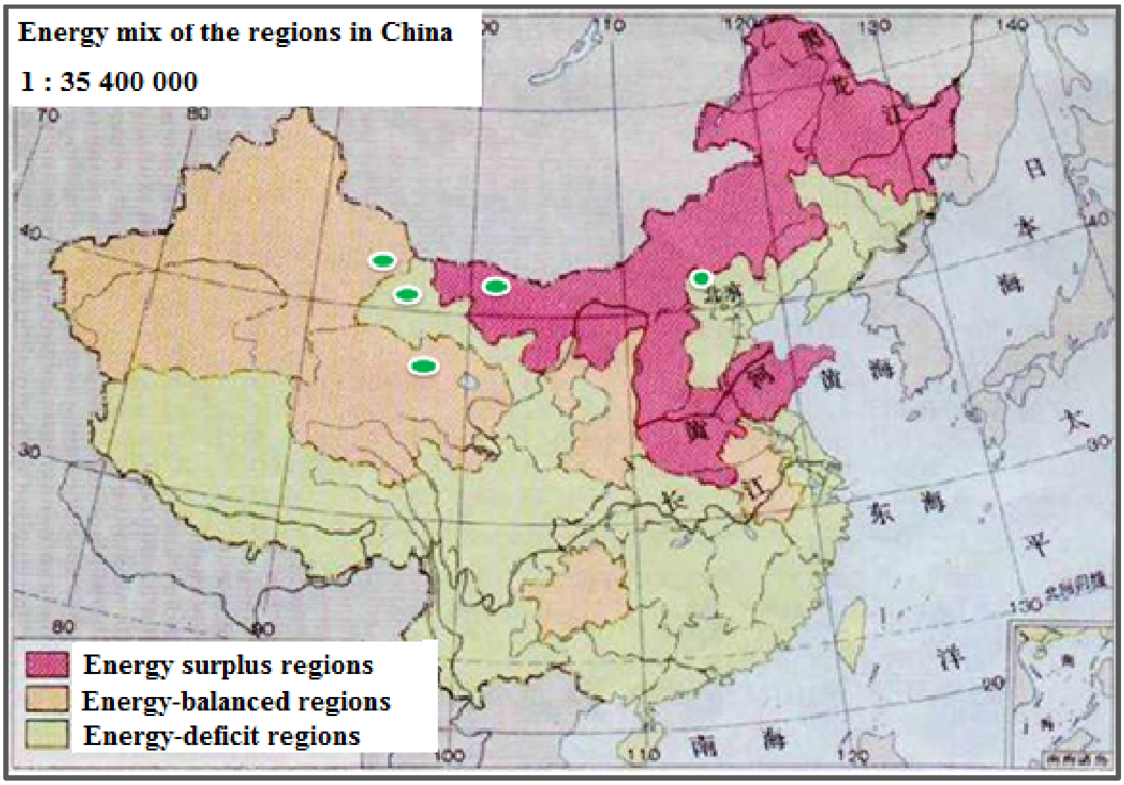

Figure 9. Location of 20 demonstration projects in China according to the energy balance of provinces

As shown in Figure 9, Chinese regions could be divided into three categories: energy surplus, energy-deficit and energy-balanced regions. Energy-deficit regions are situated mainly on the central and costal area and have high demand for energy supply. The map shows the correlation between the demonstration CSP projects and energy mix of the regions where they are located.

1.4 Industrial trends

1.4.1 Decentralization of the market

Commercial CSP power plants have already existed for 30 years and currently the technology has proven to be reliant. The constant growth of CSP plants made the equipment manufacturers become more experienced in producing trough vacuum tubes, curved glass mirrors and etc. A new breed of multinational company has emerged, as SCHOTT and Rioglass that supply the receiver tubes for almost all the commercial CSP plants. Regarding the curved glass reflectors, Glasstech became a leader in hot bending tempered glass and related production equipment. Abengoa, Sener, Brightsource, SolarReserve and others are the leading global developers of utility-scale solar power.

Following the decrease of government incentives in developed countries, the global developers and investors turned to the emerging markets, as South Africa, Chile, Middle East, China and India. Together with further deployment of CSP plants, the capacity of equipment production, system integration, EPC and whole value chain, firstly monopolized by developed countries such as Europe and USA, nowadays distributed throughout the world.

1.4.2 The production capacity of concentrators

Concentrators and receivers are the core elements of solar field and their production often require mutual cooperation. As detailed in table 3, in 2016 the production capacity of trough concentrators in China was able to equip 2GW CSP plant, more than the capacity of vacuum tubes production, which is able to equip only 1.2 GW CSP plant. Meanwhile, the annual capacity of tower's heliostats production is enough to equip the 1.7 GW CSP plant.

The production of concentrators depends on the production capacity of glass reflectors. Architectural glass industry is well presented in China, facilitating faster transition and cheaper production of glass reflectors. Thus, an increasing number of architectural and automotive glass companies could easily re-direct their business to CSP sector that would insure the upcoming needs of primary glass, reflectors and machines to manufacture the concentrators.

Thus, the results of this study indicate that the production capacity of concentrators can meet the demand of planned demonstration projects.

1.4.3 Export of products

China's nascent CSP industry already exports globally some nationally fabricated products as trough reflector, solar ultra-white float glass, thermal oil, rotary gear reducer used in concentrator, high temperature coated steel tube, and trough receiver tube among others.

1.4.4 Intellectual property rights

Part of the companies participated in the Blue Book's survey had already developed some products that obtained intellectual property rights. Moreover, the Solar Thermal Power Alliance established the patent pool to cross-license patents related to the CSP technology among its members.

1.4.5 Energy consumption of equipment production

So far, the CSP related products have small production capacities due to the limited demand. Thus, data on energy consumption of equipment production is unavailable.

1.4.6 Technical Support

(1) Industrial technology innovation and property rights

Currently energy sector is in urgent need for technology innovation, promoting the ability to innovate in order to accelerate the energy transition to cleaner source of power. Government actively promotes the industrial technology innovation capability to transform from a factor-driven to an innovation-driven economy, supporting the strategic emerging industries.

According to the data of the World Intellectual Property Organization (WIPO), China has ranked the first on patent application for 5 years. The data collected by the Blue Book's survey revealed that 60% of interviewed research institutions and companies applied for the patents to protect their new products in 2016. Interestingly to note, that there has been a gradual increase in the CSP related patent applications from the private sector.

(2) New products emergence

In China there were a few new products that were invented in 2016, yet the commercialization of concentrators, receivers and system integration still depends on existing production technologies. A clear trend was observed in 2016 on increasing number of companies that professionally developed and produced new-type of concentrators.

(3) Fundamental Research Ability and the corresponding Application Ability

The fundamental CSP related research capability in China is quite advanced. Chinese companies produce many competitive products, as collectors, receivers, heat transfer enhancement in receivers, the research on various TES technologies, and transient concentrating-thermal system simulations and others.

Despite the fact that the transient efficiency testing method for CSP collectors in China is among the most advanced, the national research on test performance evaluation of CSP products lags behind other countries, such as Germany, Japan, USA and etc.

(4) Innovation capability of private sector

Chinese private sector invest in research and development activities around 12% of total investment, while the investments in scientific and technical personnel accounts for about 25%. Private and state-owned enterprises have high innovation ability and among all the 20 demonstration projects, the indigenous technology takes a relatively large part.

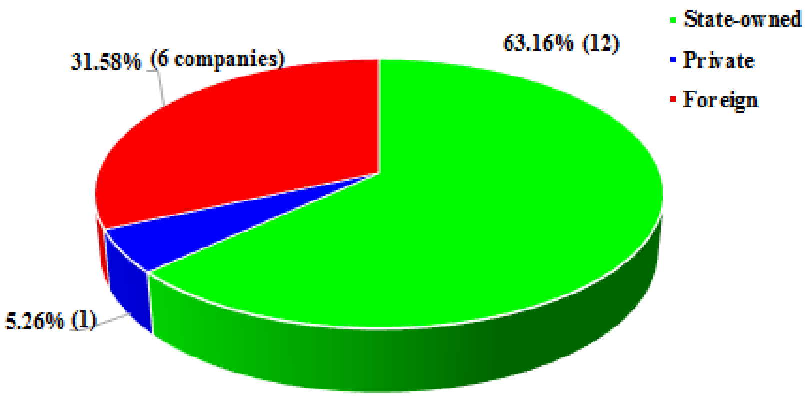

Figure 10. Enterprises supplied core technology for CSP demonstration projects by type of activity

Figure 10 shows companies classified by the type of activity, which supplied the core technology for the CSP demonstration projects. As shown in the figure, the state-owned enterprises provide the majority of core technology for the CSP demonstration projects, while private companies account only for 5 %.

2. Expectation of CSP development during the 13th FYP period

The period covered by the 13th FYP (2016-2020) will be decisive for the commercialization and large-scale domestic manufacturing of CSP equipment. With the successive construction of first CSP demonstration projects, the equipment production capacity, system integration and engineering construction is expected to increase. The market expects that the technical standards improve; reduction of investment costs and further large production. Moreover, the CSP is reliable source of renewable energy, which could contribute to carbon emissions reduction in China.

2.1 Domestic and international influence on CSP development

Economic and population growth are the key driving factors of the increasing energy demand. According to the findings of British Petroleum (BP) *World Energy Outlook* (2016 Edition), the world's population is expected to increase by 1.5 billion people to reach nearly 8.8 billion by 2035. Population and economic growth further increases the future energy demand. Thus, BP predicts the growth in world's energy consumption by 34% between 2014 and 2035. As for the Chinese development, Figure 11 illustrates the energy consumption and economic growth over the last years.

The national energy load center has weak capacity to supply locally the renewable energy resources, requiring the widespread of long-distance transmission lines. Figure 12 shows the forecast of clean electricity produced in western regions and transmitted to the eastern areas, where the horizontal axis represents the amount of electrical power transmitted. According to the forecast, by 2050 around 40% of the electricity produced in the Western regions, especially solar and wind power, will need to be transmitted to the east.

Items \ Year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**First half of 2015**
GDP/ trillion RMB	33.53	39.79	47.15	51.93	56.88	63.64	29.68
Growth / %	8.7	10.3	9.2	7.8	7.7	7.4	7.0
Total energy consumption / million tons of standard coal	31.0	32.5	34.8	36.2	37.5	38.4	
Growth / %	6.3	5.9	7.0	3.9	3.7	2.2	0.69
Total electricity consumption / trillion kWh	3.70			4.96	5.32	5.52	2.66
Growth / %	6.2	13.1	11.7	5.5	7.5	3.8	1.3

Figure 11. Energy consumption and economic growth in China during 2009-2015

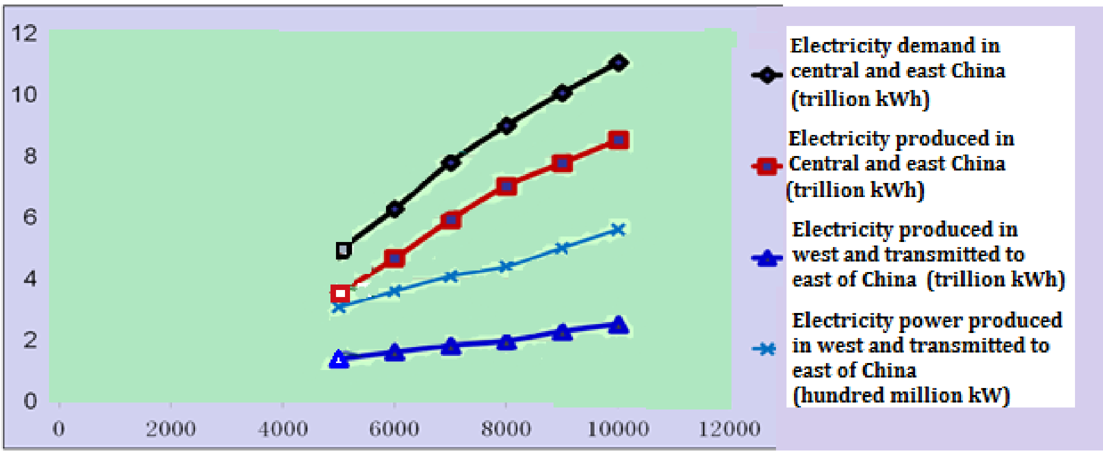

Figure 12. West-East electricity transmission forecast in the medium and long term in China

One of CSP advantages is the Thermal Energy Storage (TES) that stabilizes the power fluctuation and can significantly decrease the ratio of curtailed wind and solar energy, enabling more efficient transmission of clean energy between west and east or south. Taking the example of hybrid power system combined with PV plant of 10 GW and CSP plant of 2 GW, the CSP plant has the TES system of 2 h, 4 h, and 10 h, the solar curtailment of the PV plant would correspond for 10.17%, 7.53% and 5.82%, respectively. Therefore, CSP can effectively complement the PV plant providing the reliant electricity flow to the grid, as shown in the figure 13.

Year	GDP / trillion RMB	Growth / %	Total energy consumption / million tons of standard coal	Growth / %	Total electricity consumption / trillion kWh	Growth / %
2009	33.53	8.7	31.0	6.3	3.6973	6.2
2010	39.79	10.3	32.5	5.9		13.1
2011	47.15	9.2	34.8	7.0		11.7
2012	51.93	7.8	36.2	3.9	4.9691	5.5
2013	56.88	7.7	37.5	3.7	5.32	7.5
2014	63.64	7.4	38.4	2.2	5.5233	3.8
First half of 2015	29.68	7.0		0.69	2.6624	1.3

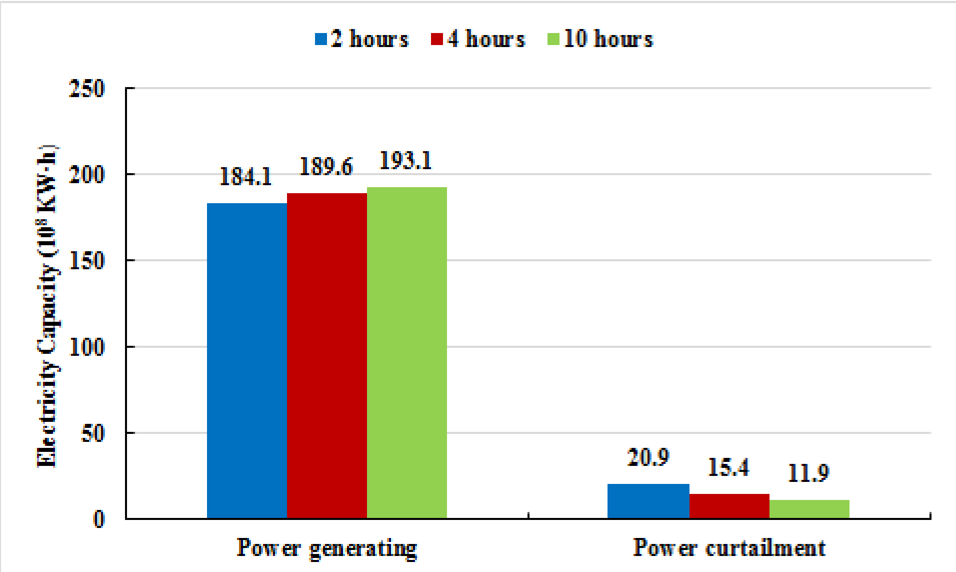

Figure 13. Influence of CSP on PV's capability of grid integration.

2.2 Opportunities Faced in Development

2.2.1 Grid stability demand

By 2020 China plans to increase a total installed capacity of solar energy not less than 105 GW (figure 14), therefore assuming that another 2 GW of PV or CSP is to be added. Two different options could be obtained, either 107 GW of only PV plants or

107 GW of combined (PV + CSP) plants. By comparing their power curtailment ratio, which is 13.02% for PV and 10.17% for PV+CSP, the second option shows its advantage over PV plant in dispatching energy. Hence, the addition of CSP power plants leads to the reducing of the PV energy curtailment, as well as delivering more reliant power supply to the grid.

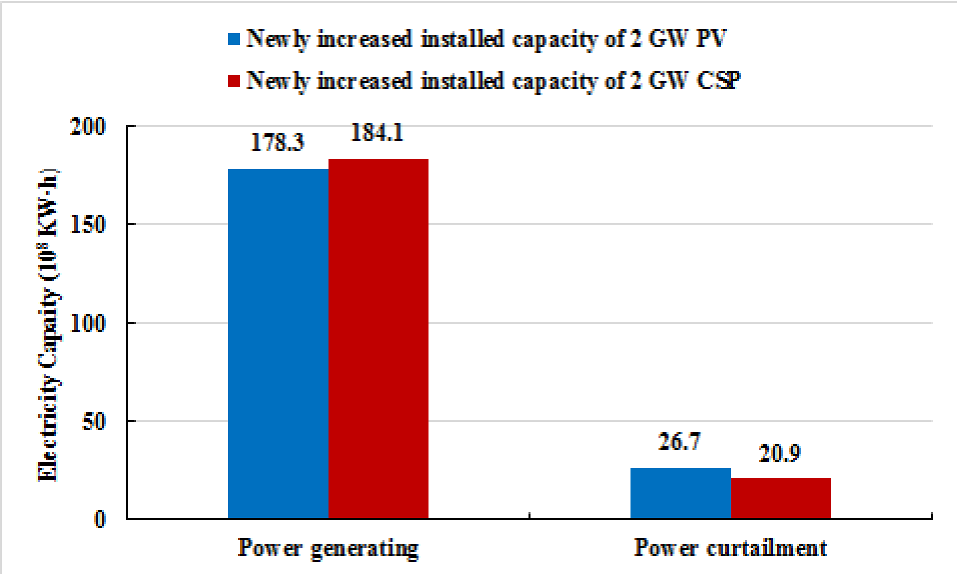

Figure 14. Influence of CSP on PV to be connected to the grid

2.2.2 Literature overview of CSP cogeneration systems

The essential conditions for renewable energy to become more competitive are the stable power supply and cost-effectiveness. Due to the fluctuant nature of renewable energies, the multi-energy complementary power system sometimes could be necessary. The energy storage and hybrid power plant, both play an important role in ensuring the continuity and stability of grid, supplying the reliable power supply as required (figure 15). However, CSP will become the main source of energy in the multi-energy complementary system due to the lower price of TES, comparing with electricity storage.

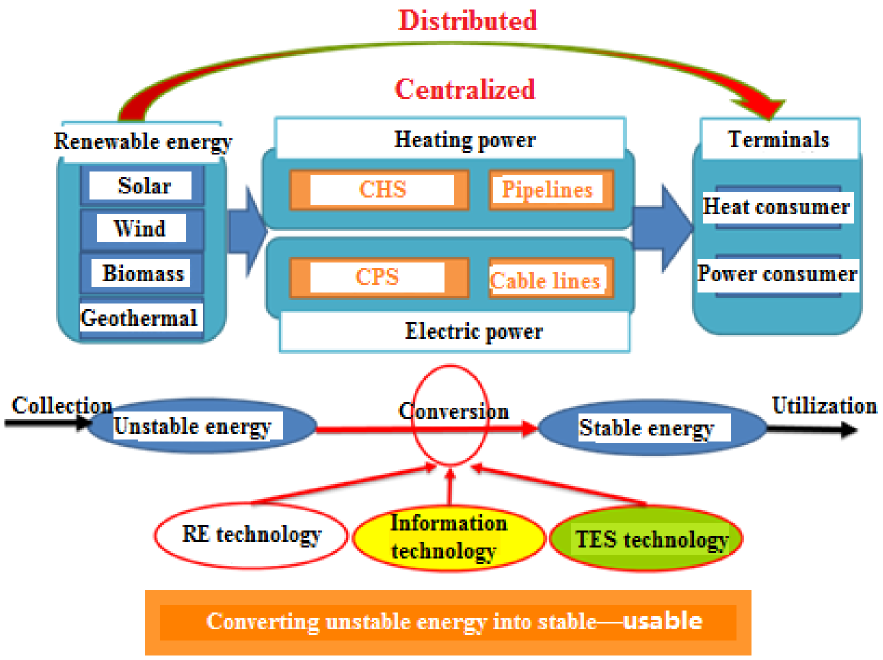

Figure 15. Multi-energy system with multiple energy vectors (objectives)

Internet of Energy (IoE) refers to the upgrading and automating of electricity infrastructures for energy producers. Updating electric infrastructures allows energy to flow efficiently, maximizing its potential and reducing energy waste. Yet, the IoE covers not only the electrical power, but as well the thermal power. The cogeneration CSP system or combined heat and power (CHP) is an important tool toward efficient utilization of renewable energy, enabling the total energy efficiency to reach over 65%. From the basic law of energy conversion we know that the collected solar energy of different grades can be fully used if matched with applications of different temperature, thus minimizing the potential exergy loss. Hence, the utilization of solar energy could follow the principle of "temperature counterpart and cascade utilization", combining power generation and heat supply to realize the energy cascaded utilization, and thus significantly increase the overall efficiency of energy utilization.

As mentioned above, the CHP technology can significantly increase its overall efficiency, reduce the load of local grid, and contribute to the local heat consumption and to the solar building heating. The cogeneration large-scale CSP system is an important innovation in building heating solutions, especially in western regions of China. It uses locally available source of energy, could be constructed near the consumers, and can supply electricity, refrigeration and hot water at the same time, offering to the consumers more reliable, efficient, environmentally friendly solution. Additionally, the system reduces pollutant emissions, transforms the traditional ways of supplying electricity, refrigeration or hot water separately, and most importantly, improves the efficiency of energy utilization, thereby, enhancing competitiveness and reducing the payback period.

Several studies were conducted on cogeneration CSP systems. In this section we would present the findings of several studies.

G. Franchini et al., 2013 carried out the comparative study between parabolic trough and solar tower technologies in Solar Rankine Cycle and Integrated Solar Combined Cycle plants. The Integrated Solar Combined Cycle (ISCC) coupled with a solar tower was found to assure the highest annual solar-to-electric efficiency of 21.8%. This is the result of both higher collection efficiency of solar tower compared to parabolic trough collector (PTCs) and higher conversion efficiency of solar energy introduced into the combined cycle, as compared to Solar Rankine Cycle (SRC).

Suzan Abdelhady et al. 2014, presented the performance and economic assessment of a small scale stand-alone solar thermal co-generation plant in Egypt, providing electricity and heat to an isolated area satisfying the local loads. The results of the study indicate that the parabolic trough solar power plant can produce 6 MW of electric power and 21.5 MW of heat power with an overall efficiency of about 85% (figure 16 and 17). The produced heat and electricity are sufficient to fed about 3300 rural users near and two primary factories.

Jean-Louis Bouvier et al. 2015, conducted an experimental campaign on a solar parabolic trough collector feeding a micro-cogeneration system (Figure 16). The originality of the solar field is the direct steam generation (DSG) using a two axis tracker and a small size (46.5 m^2) collector. Thermal performances of the system were tested under sunny and cloudy conditions. The results show that the cogeneration system can be continuously operated all day long for 8 hours under DNI of 897 W/m^2, producing saturated steam with a flow rate of 33 kg/h, and at the same time supplying thermal power of 18.3 kW, and electrical power of 1.4 kW. The experiment data indicates that the system can obtain a higher efficiency under lower flow rates.

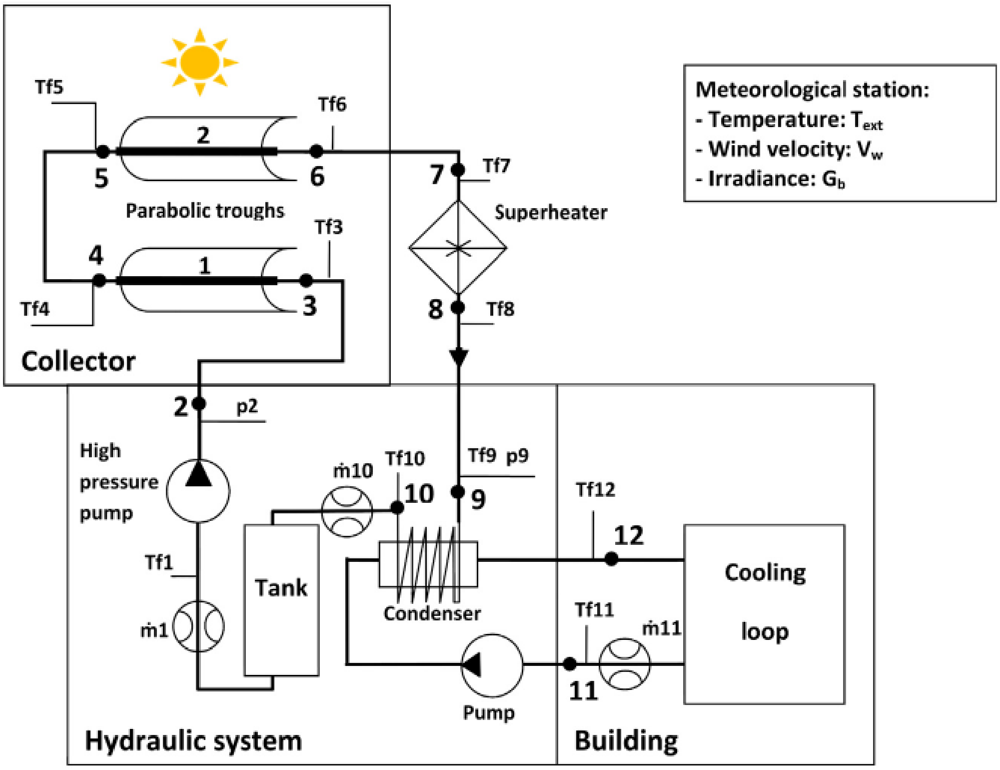

Figure 16. Schematic diagram of the micro solar cogeneration system

The new type of solar cogeneration system was experimentally investigated by M. Hasan Nia et el., using thermoelectric module and fresnel lens to preheat cold water in and supply electricity. The main components of this system consist of a monoaxial adjustable structure, a thermoelectric generator and a Fresnel lens with an area of 0.09 m^2. Results revealed that matched load output power is 1.08W with 51.33% efficiency under radiation intensity of 705.9 W/m^2, supplying thermal power of 30.93W.

Monica Borunda et al. 2015, present a study of a small CSP plant coupled to an Organic Rankine Cycle (ORC) with a novel configuration since useful energy is directly used to feed the power block and to charge the thermal storage. This configuration is a promising option for applications to medium temperature industrial processes with electrical and heat generation, as required. Results indicate that 55% of the energy can be recovered by effectively using waste heat, which substantially improves the overall operating efficiency. Figure 17 shows the distribution of related generating and thermal efficiency.

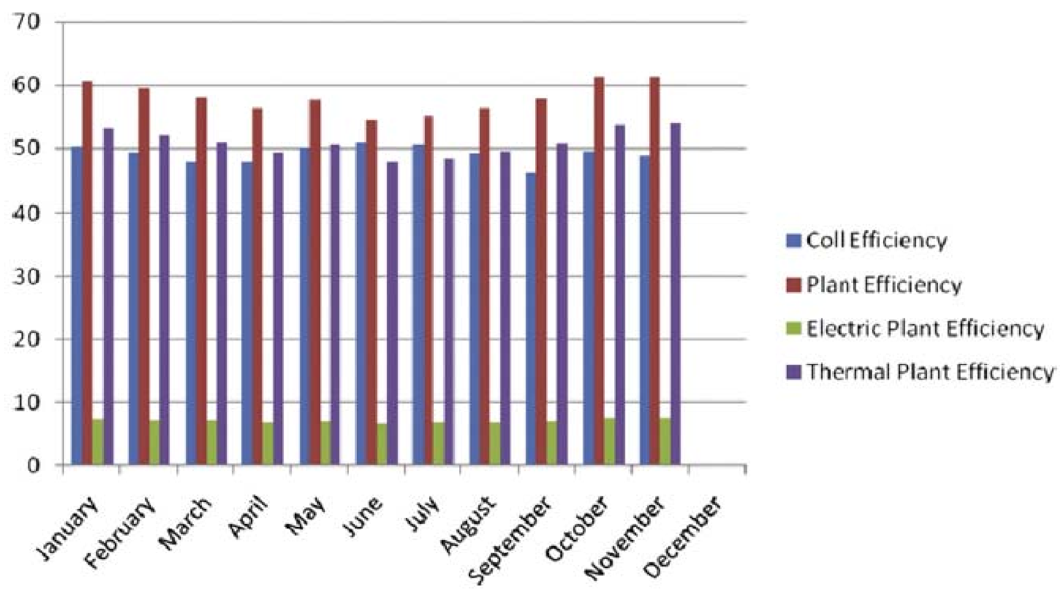

Figure 17. Monthly efficiency of the cogeneration system

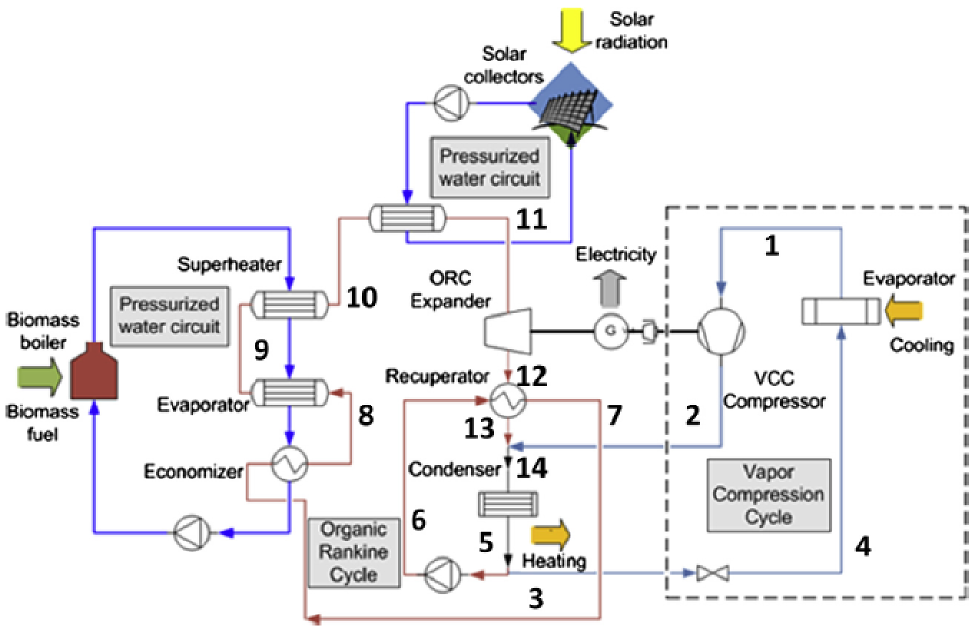

Figure 18. Schematic diagram of the solar PTC+ORC+VCC CCHP system

Finally, S. Karellas and K. Braimakis 2014, led thermodynamic modeling and economic analysis of a micro-scale tri/co-generation system capable of combined heat and power production and refrigeration, based on the joint operation of an Organic

Rankine Cycle (ORC) and a Vapor Compression Cycle (VCC). As shown in figure 18, the system can provide cooling or heating depending on season, as well as constant electricity generation. Finally the results outline that the system could provide an electricity output equal to 1.42 kW, while 53.5 kW_{th} are produced and cooling load of 5 kW_{th}, with an ORC exergy efficiency of about 7%. The savings in fuel oil and electricity consumption account for an IRR around 12 %, with a payback period of 7 years.

2.2.3 Demand for construction of low carbon cities in Western China

Since the reform and opening in the late 1970s, China has become the fastest growing developing country in the world, and it's also currently the second largest country of energy production and consumption. One of the major challenges of the domestic energy sector is the low proportion of high-quality clean fuel, while coal remains the dominant fuel, accounting for 64% in 2016. Burning coal is a leading cause of toxic air pollution, smog and acid rain, thus resulting in an urgent need to control the pollution and to preserve the ecological system.

Recently, the serious haze phenomenon has appeared in many Chinese cities, where the pollution consists of carbon dioxide and other harmful air pollutants emitted by burning fossil fuels. In Northern regions, severe air pollution occurs during the winter heating season when even more fossil fuel is burned. Once the meteorological condition is adverse, the heavy pollution has more chances to form. When the winter came in 2016, Beijing had already twice issued a red alert for heavy air pollution: during the periods of 8-10 December and 16-21 December. Starting from night of December 16th, Beijing had experienced the most severe haze weather that year. The pollution started to impact not only people's health, but as well had a social and economic impact.

According to the prediction of Chinese Academy of Engineering, the volume of carbon dioxide for the domestic heating can reach 900 million tons by 2020. As illustrated in Figure19, the Western regions have abundant solar energy resources and solar radiation hitting the soil is equivalent to 1700 billion tons of standard coal. Moreover, 2/3 of the total area of China receives more than 2,200 hours of annual sunshine, and total radiation over 2000 MJ/m^2 per year.

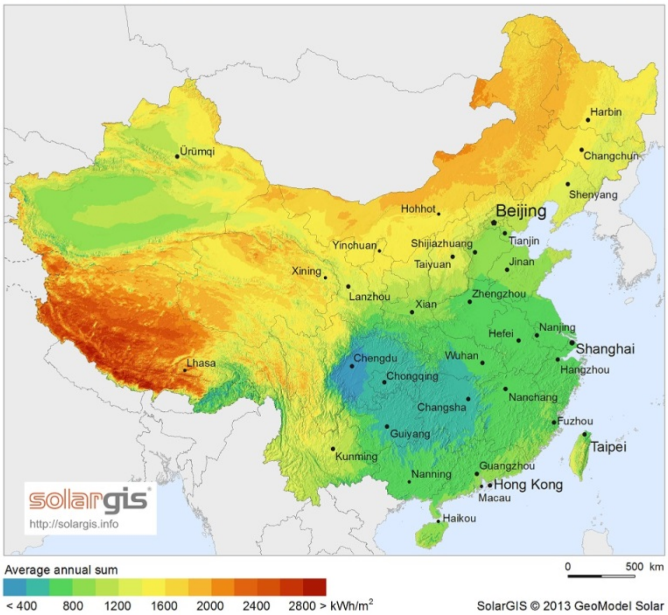

Figure19. Direct Normal Irradiation map of China

The Chinese government has taken active measures in order to ensure energy supply and to achieve sustainable development. *The 13th FYP for energy technology innovation* indicates that green and low-carbon energy ought to be the main direction for energy technology innovation. According to the plan, the main focus should be on large-scale development and utilization of new energy, technology research of large-scale CSP and cogeneration plants, design and production of key components, solar cogeneration energy cascaded utilization and others. It contains the information about the indicators of renewable heating and fuel utilization. Likewise, the plan proposes that in order to achieve 15% and 20% of renewables by 2020 and 2030 respectively, the further promotion of renewable energy development should be done in order to accelerate the transition from fossil energy and improve the competitiveness of renewables. By the year 2020 the renewable energy used for heating and domestic fuel is expected to substitute the use of standard coal with the total amount of 1.5 billion.

In December 2016, President Xi Jinping presided the fourteenth meeting of the Central Financial Leading Group, where the importance of expanded use of clean energy for heating in northern regions, saying that it is closely linked to people's well-being, the reduction of smoggy days, improvement in energy production and consumption, as well as the rural lifestyle revolution. In the process, the private sector will play the major role, and the governments will facilitate the clean energy expansion and help residents to accept the new heating source. The regions could choose gas or electricity based on their situations and increase the proportion of clean energy in the energy consumption mix. In accordance with the goal to promote clean heating, it is important to develop the efficient renewable energy systems and to reduce energy consumption. Thus, the solar energy cogeneration represents an innovative solution that would ensure efficient and clean production of thermal and electrical power.

2.2.4 CSP and Belt and Road initiative

The Belt and Road initiative (BRI) provides a visionary blueprint for global economic development, combining the Silk Road Economic Belt and the 21st-Century Maritime Road (Figure 20). Proposed by President Xi Jinping in 2013, the

Figure 20. Roadmap of 'the Belt and Road'[5]

BRI is the strategic initiative to promote the interconnection of infrastructure, economic integration and development among neighboring countries. The routes cover more than 60 countries and regions from Asia to Europe via Southeast Asia,

[5] https://beltandroad.hktdc.com/en/belt-and-road-basics

South Asia, Central Asia, West Asia and the Middle East. The main Chinese regions involved in BRI are: five northwest provinces or autonomous regions of Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang, and four southwest provinces or municipalities of Chongqing, Sichuan, Yunnan and Guangxi. BRI should be seen not as an entity or a mechanism, but rather as idea or initiative of cooperation and development. Based on the existing bilateral and multilateral mechanisms between China and other countries, BRI aims to promote social and economic development, awareness of a community of shared destiny and fosters regional and international peace and cooperation.

The population in the Belt and Road region is nearly 4.6 billion, accounting for over 60 per cent of the world's total. The economic aggregate of the countries along the BRI is about US$21 trillion, nearly 30 per cent of the world economy. The majority of those countries are the emerging economies and developing countries, eager to attract new investments that could boost their economic development and bring prosperity to the regions. Moreover, BRI brings new opportunities for energy cooperation, as central Asian countries, rich in energy reserves, interested in the Chinese energy market.

The CSP technology corresponds with the BRI strategy of sustainable development and represents an important opportunity for its dissemination. Meanwhile, countries along the BRI have high levels of DNI and need for new and clean energy sources, yet they possess already the necessary capital, human resources to work on CSP development locally. The promotion of cooperation between countries in solar energy sector would boost technology development, achieving mutually beneficial results.

By 2016 the global CSP installed capacity achieved 4,400 MW with 120 operational projects. The projects that are currently in the planning phase or under construction account for 56% in the United States, 24% in Spain and 8% in the Middle East. Since last year, the CSP installed capacity has experienced a rapid growth in countries as Israel, Saudi Arabia, South Africa and others.

Global CSP installed capacity growth rate slowed in 2016, only increasing

76.86MW on the basis of 4940MW of 2015. The total global CSP installed capacity reaches around 5017MW, and the growing rate is only 1.56%. However, with the newly increased installed capacity of emerging markets including Morocco (1 MW), South Africa (50 MW) and China (20.2 MW), USA (2 MW) it is predicted that global CSP installed capacity will have a huge increase in the next years.

Currently, the global energy market undergoes major changes and energy sectors in many countries are facing new challenges. Low oil price severely impacted fossil fuel sector, while also created opportunities for the development of solar and other new energy sources. Additionally, due to the serious environmental problems, governments attach great importance to energy saving, emission reduction, and the promotion of new energy technologies. CSP has various advantages such as: relatively high efficiency; ability to provide grid flexibility; possible cogeneration with other energy sources; contribute to the reduction of power waste and pollution. Therefore, despite the CSP technology is facing many difficulties it will surely achieve rapid development in the future.

While BRI mainly focuses on infrastructure, the energy sector has the potential to transform the unilateral relationship to regional cooperation, and could create unprecedented opportunities for Chinese new energy enterprises to boost the international cooperation.

2.2.5 Industrial upgrade

According to International Energy Agency (IEA), the Levelized Costs of Electricity (LCOE)[6] of CSP is expected to decrease to 6 cents/kWh by 2030. Technological advances of solar collectors will largely contribute to the cost reduction achieving \$50 /m^2, as projected by the U.S. Department of Energy (figure 21).

Figure 22 shows the distribution of CSP related patent applications by country. The leaders in patent applications are the United States and Germany, becoming the

[6] Levelized Cost of Electricity (LCOE) is an important tool for the comparison of various generation options, as it demonstrates the per-kilowatt hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle

actual front-runners in related innovative work. Among the Alliance members, the 23 CSP enterprises, both foreign and national, have made the applications for patens (shown in figure 23). Thus, this trend indicates that CSP learning curve in China will be greatly reduced. Moreover, other results indicate that the capital investment are expected to decrease to 10,000 RMB/kW (1,448 USD/kW) by 2025 and LCOE to 0.6 RMB/kWh (0.087 USD/kWh), as illustrated in the figure 24 and 25.

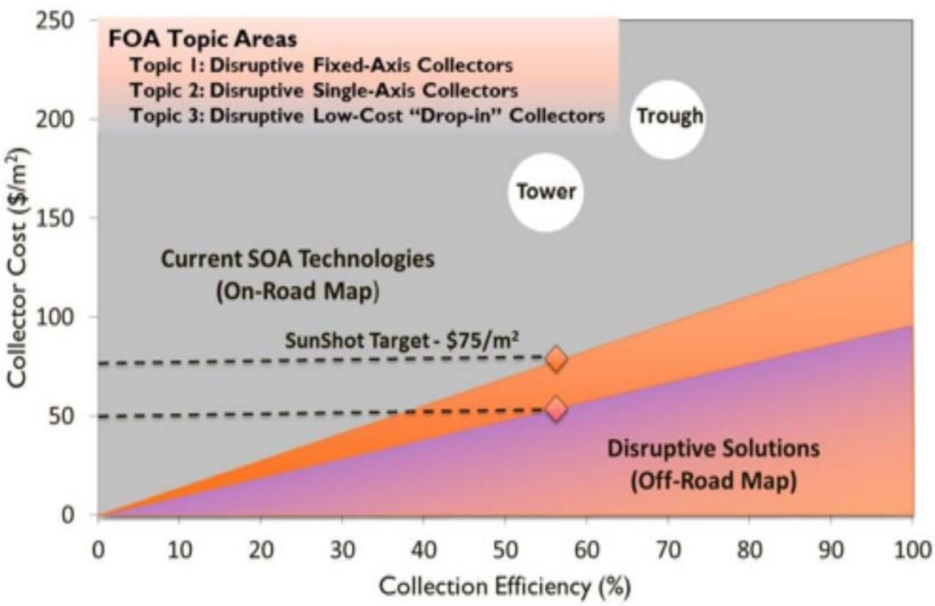

Figure 21. The cost of collectors and efficiency prediction by the U.S. Department of Energy

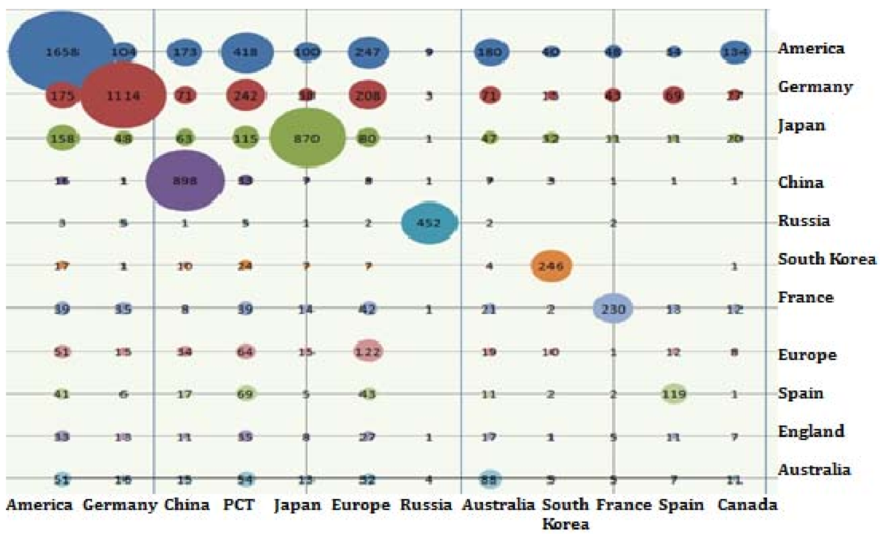

Figure 22. The distribution of CSP related patent applications by country

Figure 23. The research team focusing on the FIT setting for CSP demonstration projects

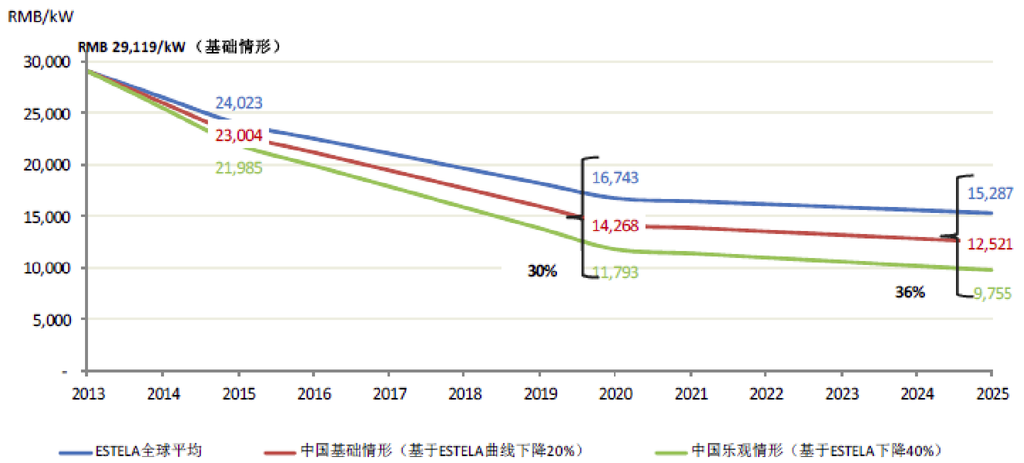

Figure 24. Learning curve of CSP one-time investment in China

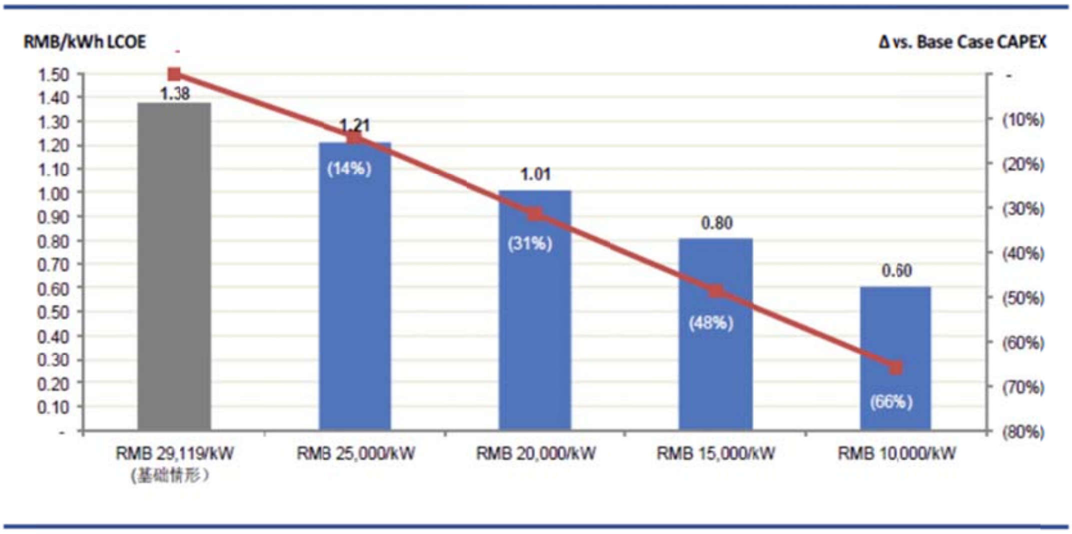

Figure 25. Relationship of CSP price and one-time investment

Besides the traditional system optimization, equipment reliability, and cost and efficiency of equipment, other new CSP technologies, which deserve particular attention, are: system and grid dispatching technology that can meet the electrical load curve of duck type, supercritical steam and carbon dioxide, receivers using solid materials or heavy metal and others. Furthermore, the technology of transforming solar heat into chemical energy and thus obtaining gas or fluid fuel is also noteworthy.

2.3 Challenges

2.3.1 Rapid decrease of PV price

The major challenge for CSP to remain competitive with PV technology is the rapid decrease of PV price. In 2016 NDRC issued the Notice on PV and onshore wind power FIT adjustment (N [2016]2729). 2017 rates for PV would range between 0.65 RMB/kWh ($0.094/kWh) and 0.85 RMB/kWh, depending on region. The FIT policy regarding the PV would be determined as follow: the projects approved after January 1st, 2017 will be included in 2017 scheme, while those approved before the end of 2016, but could not be completed and connected to the grid, will as well receive the FIT of 2017. The specific prices are shown in table 7.

Table 7. PV price policy in China

Area classification based on solar resources	FIT 2016	FIT 2017	Regions
I level	0.8	0.65	Ningxia; Haining in Qinghai; Jiayuguan, Wuwei, Zhangye, Jiuquan, Dunhuang and Jinchang in Gansu; Hami, Tacheng, Altay and Karamay in Xinjiang; Inner Mongonia except for regions including Chifeng, Tongliao, Hinggan League and Hulun Buir.
II level	0.88	0.75	Beijing; Tianjin; Heilongjiang; Jinlin; Liaoning; Sichuan; Yunnan; Chifeng, Tongliao, Hinggan League and Hulun Buir in Inneri Mongonia; Chengde, Zhangjiakou, Tangshan, Qinhuangdao in Hebei; Datong, Suzhou, Xinzhou and Yangquan in Shanxi; Yulin, Yan'an in Shaanxi; Other regions except for those included in I level in Qinghai, Gansu and Xinjiang
III level	0.98	0.85	Other regions except for those included in I and II level
Distributed generation	0.42	0.42	

FIT unit: RMB/kWh, Data source: NDRC

The FIT prices for CSP projects as well were divided into 3 areas based on solar irradiation with average price of 1.15 RMB/kWh. Yet, the LCOE of PV decreases more rapidly than LCOE of CSP that creates an additional obstacle to the CSP development.

2.3.2 Lack of experience in CSP sector

Up to December 31st, 2016, in China there were 4 CSP projects with power production over 200 kW in full-system operation, and another 4 projects were under construction. So far there is no design department in China that able to design the entire CSP plant or put it into operation. Design methods, equipment reliability, and operation methods must be experienced through the practice that current Chinese CSP sector lacks. Thus the owners of the first demonstration projects might give the preference to the foreign, more experienced technical teams to design power plant and project commissioning.

2.3.3 Overcapacity in manufacturing industry

Chinese glass and machinery manufacturing industry has large production capacity, meaning the number of manufacturers specialized in CSP equipment will increase remarkably after thermal power will gain further encouragement by national policies. However, it's inevitable that phenomenon of overcapacity and low quality will emerge in CSP sector together with the price falling. Hence, the structure concerned with safety supervision and inspection of product quality should be in place following the CSP development.

2.3.4 Capacity of human resources

Human resources are central to the CSP industry development. In China there are professionals working with concentrators, heat absorbers, materials, TES, electricity generating equipment, control systems and others. Yet, there is a lack of trained professionals, especially experienced engineers, technicians and operation personnel. The Alliance together with other involved companies and institutions should promote various engineering training programs, developing CSP plant simulators and capacitating the CSP professionals to meet the future demand of the sector.

2.3.5 Unequal competitive opportunities between foreign and Chinese companies

The foreign CSP sector accounts for more than 40 years of its development, building CSP power plants with the total installed capacity of 4,500 MW. Whereas, the Chinese CSP sector has just started less than 10 years ago, that leaves the national companies behind comparing with the foreign counterparts. For over 30 years foreign companies were working on the improvements of key parts of CSP plant, as solar vacuum collectors, trough concentrators, heliostats, as well as design software, design methods and others. The experience acquired by foreign companies through many years creates unequal competitive opportunities between foreign and Chinese companies. This challenge could be illustrated by the example of equipment procurement for 50 MW troughs of CGNPG and 100 MW tower of Guohua Electric where the foreign companies were chosen instead of the national companies.

2.3.6 Insufficient capital investment in research and pilot testing

Due to the early stage of the CSP scientific research and industrial development in China, there is lack of funds destined to technology transfer and pilot testing. The total amount of Research and Development (R&D) fund to CSP sector decreased in 2016 compared with data from 2015, coming mainly from the National Natural Science Fund for the research of solar thermal technology concept.

However, after the list of demonstration projects was published in September, 2016, the funds provided by enterprises to CSP research have increased. Additionally, specialized research centers were established by state-owned enterprises, as State Grid, Huaneng, State Power Investment Corporation, and China Energy Engineering Corporation, etc.

2.3.7 Standards and certification

The National Solar Standards Committee was established in 2016, as well as China Electricity Council established the International Electro-technical Commission (IEC) Standard Working Group. Electric Power Planning & Engineering Institute formulated 16 industry standards and the Alliance added more 12 standards. In March, 2016, the Alliance established product inspection and testing laboratory, signed a cooperation agreement with the certification company, enabling it to start the certification process already in 2017.

2.4 Analysis and forecast of future demand

The 13^{th} FYP for energy has clarified that the total installed capacity of CSP power plants should be no less than 5 GW by 2020. The first CSP demonstration projects are expected to have the annual electricity of 4500 hours. Therefore, by 2020, the annual generating capacity of domestic CSP is expected to reach 22,500 GWh. Additionally, there is a need for multi-energy cogeneration projects, thus the total installed capacity of CSP in China is expected to attain around 5500 MW, while the area for building heating using the CSP cogeneration will reach 9 million m^2.

With the development and maturity of the domestic CSP technology, the export of CSP products estimated to flourish by 2020 reaching the value with capacity to supply the plant of 4000 MW and covering mainly South Africa and North Africa, West Asia, and South America and others. The primary products mostly include vacuum tubes, trough and plane reflector mirrors, heliostat tracking devices and complete machine, and plant equipment inspection devices.

3. The forecast of CSP industry development within the 13th FYP

3.1 Financial Objectives

3.1.1 Gross output value scale of CSP industry

The projected total installed capacity of CSP expects to generate about RMB 80 billion (USD 11.6 billion) of gross income by 2020 or RMB 20 billion (USD 2.9 billion) per year. The export of key equipment and materials would obtain the gross income of RMB 36 billion (USD 5.2 billion). The gross output value of the CSP industry is to be about RMB 120 billion (USD 17.4 billion). Moreover, the annual sales of one or two equipment manufacturing enterprises, probably working with concentrators, could reach about RMB 10 billion (USD 1.45 billion).

3.1.2 Outlook of production costs and capital investment

By 2020, the sales price of heliostats is projected to be 700 RMB/m^2, trough receivers - 2,300 RMB/unit, glass reflector mirrors - 120 RMB/m^2, trough concentrators - 550 RMB/m^2. In addition, the capital investment in CSP plant with TES of 6 hours will decrease by 48% compared with 2010 data, reaching only 20 million RMB/MW (USD 2.9 billion per MW).

3.2 Objectives for CSP equipment production

3.2.1 Gross income of domestic key equipment production

The industry of CSP equipment manufacturing, as solar concentrators, heat absorbing components, as well as EPC developers have unprecedented growth in China. One or two enterprises with an annual gross income of more than RMB 10 billion (USD 1.6 billion) are supposed to appear, and about another 20 with over one billion RMB (USD 0.16 billion). The competition in solar collector's production will grow, as key enterprises of glass industry expected to join the sector. The number of collectors factories will decrease from 6 to 2-3, and the majority of those enterprises will be working with vehicle glass.

In addition, there will be about 30 enterprises that focus on ST molten salt receivers. The domestic chemical equipment factories and boiler factories will be the competitors for this kind of products. Whereas the gross output value of the entire industry is not large, about less than RMB 5 billion during 2017-2020.

3.2.2 Service providers

With the development of demonstration projects, the service providers will gradually emerge. The company will focus primary on plant design, software programming, inspection of equipment, system testing and evaluation, elaboration of standard, simulator development, training programs, equipment maintenance, cleaning of collectors and others. The gross output value of service providers is expected to attain around 100 million RMB (USD 14.5 million) in the next 4 years.

3.2.3 Development of EPC companies

Through practical experience working with the first demonstration projects, three to five large developers are expected to appear in China. By 2020 both state-owed and private EPC enterprises will gain enough experience and funding to enter the international market and becoming global leaders in the field.

3.3 Objectives for technical improvements

By 2020, Chinese companies and institutes expect to achieve several technical improvements: the annual average efficiency of CSP plant will reached 17%; the efficiency of TES system - 90%; the plant annual electricity generating hours at full power - 4500 hours; the reflectance of collector - 93%; the surface tolerance temperature of trough receiver - 600 ℃; the absorption rate of coating on tower receiver - 92%; coating emissivity being 10% at room temperature and 25% at 650; sales price of heliostats will decrease to 750 RMB/m^2 (108.6 USD/m^2); and sale price of trough collectors to 600 RMB/m^2 (86.9 USD/m^2).

3.4 Suggestions on measures to be taken

According to the current technology advancement of the Chinese CSP industry, the following measures are suggested to be taken in the near future:

(1) Boost innovation in engineering technology in the following areas: innovative integration; design capability; the product quality inspection; technology of

concentrators to lower costs; prolong the life of receivers and related components.

(2) Promote scientific research in the following areas: TES materials, specially work with low melting point and high decomposition temperature; reliability technology of molten salt receivers; CSP plant system simulation; new types of self-adaptive receivers that can be support the energy-flux distribution; new concepts of concentrators, reducing cosine loss; heavy metals and chemical fluid; heat transfer fluid of receivers and others.

3.5 Export opportunities

The renewable energy sector becomes more international, enhancing the interconnectedness between countries through global value-chain. Due to the early stage of Chinese CSP sector, the participation of foreign companies is inevitable, contributing to the improvement of domestic engineering technologies.

The exports of Chinese CSP technologies should be gradually boosted. The following products or services could be exported in near future:

1) Basic materials, such as primary glass of reflecting mirrors, glass reflectors, molten salt and others.

2) Equipment, as drives used in heliostats, machines to produce heliostats, tracking system, trough concentrators, trough vacuum tubes and others.

3) The complete sets of equipment, such as solar island, and heat collecting island, etc.

4) EPC services.

5) The complete set of inspection and test equipment to provide verify product's quality.

6) Investments in construction and operation of overseas CSP plants in regions with high electricity price as South America or North Africa.

Moreover, the following goals are suggested to be achieved by Chinese companies in global CSP market by 2020:

1) Engage in EPC work of five to six international projects, with total installed capacity of overseas projects reaching 500 MW;

2) Export heliostats with an area of 2 million m^2;

3) Export trough concentrators of 2 million m^2;

4) Export trough reflector mirrors of 1 million m^2;

5) Export of tracking system of 50 thousand units;

6) Export trough vacuum tubes of 100 thousand units.

4. Guidelines for decisions makers

4.1 Planning for sustainable development of CSP industry

In order to develop the CSP industry in more sustainable way there are following measures suggested to be taken: technical standard system should be improved; overall planning of CSP industry should be designed; the load power characteristics of large-scale CSP should be integrated in systems with high proportion of renewable energy; further integration needed between CSP power plant and the construction of transmission lines. Finally, the long-term planning of equipment manufacturing industry is crucial, taking into consideration the conditions of local resources, available energy sources, industries' capacity and human resources.

4.2 Quality Supervision System

The Institutions related to quality supervision or testing are important for the entire value-chain of CSP sector to ensure its sustainable development, thus further measures has to be taken to strengthen them. Besides, the civil society should be mobilized to demand the efficient use of solar energy that could be transformed into professional supervision together with users' participation in quality management. Thus, the Chinese solar industry would transit from a quantity-driven to a quality-driven market.

The standardization is vital for the expansion of the Chinese CSP sector and the following measures are suggested to be taken: the technical standards should be improved, the market supervision should be strengthened, and related key equipment should pass the mandatory testing and certification process, among other actions. In addition, the comprehensive evaluation mechanism has to be elaborated for enterprises to raise the access threshold based on technical capacity, managerial assessment of proficiency, possibility for market expansion, profitability, credit rating and others indicators.

The backward production capacity should be eliminated by the means of mandatory "survival of the fittest", leaving a larger market share for competitive enterprises. Furthermore, the protection of intellectual property rights should be strengthened to create an attractive environment for independent innovation.

4.3 Building industrial early-warning system

There is a need to establish a CSP technology testing experimental platform with national quality supervision, as well as the independent and public third party assessment. The platform could provide the service of simulation research, on-site testing for solar systems and components, as well as the public-shared information on the research demonstration projects. The platform could share the results of product's certification to public, promoting the CSP technology's development and ensuring the product's quality.

4.4 Government supports

The research suggests that the government needs to take the following measures to accelerate the development of solar thermal industry: integrate solar thermal into the planning of local infrastructure construction; elaborate the price subsidy mechanism, covering the whole solar thermal sector; integrate the index related to renewable energy use into the energy saving and emission reduction evaluation system; elaborate the quota scheme to integrate the solar thermal into the grid system; investigate the adequate mechanism of carbon tax policy establishment, making carbon trading market suitable for Chinese environment; and finally investigate other encouragement and support policies appropriate for solar thermal sector.

4.5 Promotion of technology innovation

The advantages of solar thermal use are innumerable as it's a clean, abundant and free renewable energy sources, yet the difficulties still exist such as high capital cost, intermittency and others. Promotion of technology innovation is a key to solve the various problems, focusing on: functional photothermal conversion materials, which could adapt to different temperatures; heat collecting media; full spectrum absorption methods and devices of high-efficiency heat exchange; TES materials and efficient methods of its use; solar refrigeration cycle and media materials matched with dynamic heat collecting; solar heat supply methods of multi-energy complementary systems. Thus, technical breakthrough is the key to achieve low cost and large-scale application of solar thermal energy.

4.6 Implementation of solar-based system

Here are proposed the measures to be taken to implement the complementary systems in which solar is the major energy source: technology research enhancement, standards and specifications for large-scale CSP power plant grid-connected access technology should be formulated; weather forecast technique should be studied; TES technologies and multi-energy cogeneration should also be researched to enhance grid-connected capacity of system where solar-based source side could be complementary with load side.

The integration between the four aspects of CSP development, as scale, local load consumption capacity, power regulation capacity and grid bearing capacity should be planned; the planning of renewable and new sources of energy, together with supporting grid options should be arranged and optimized, especially for the northwest areas with abundant wind and solar resources. In addition, the electricity price mechanism should be pushed to form, and dispatching modes should be reformed, thus to promote the realization of energy-saving economic dispatching and renewable energy priority access to the grid.

4.7 International cooperation

Cooperation with several international and national organizations, such as the United Nations, IEA, International Electrotechnical Commission, Institute of Electrical and Electronic Engineers and others, should be strengthened to jointly organize international conferences and forums. Moreover, academic and professional exchanges need to be promoted by directing the adequate funds to support the joint work and international mobility.

There are other measures that CSP sector together with government could take into consideration:

- Collect and analyze the information on global solar energy resource, as the total amount, geographical distribution, conditions of utilization, exploitation status;

- Integrate to one platform the results of existing studies, survey and other sources from international institutions and various countries;
- Establish communication channels between the international organizations, governments, enterprises, and society;
- Analyze development trends of CSP sector and power supply/demand in the world, targeting countries where China can achieve large-scale CSP development combined with planning objectives of the selected countries;
- Participate in the formulation of relevant international rules, offer advices and suggestions to relevant international organizations and government agencies and finally establish the communication mechanism between the involved parties.

4.8 Enabling larger roles for Alliances and Associations

There are several organizations that actively promote the development of solar thermal energy on international and national levels, such as IEA, International Renewable Energy Agency (IRENA), China National Solar Thermal Energy Alliance, and China Renewable Energy Association and others. Relying on the experience of these organizations the development of solar thermal technology can be promoted in a global dimension through the international exchange and joint cooperation. Moreover, it's important to attribute a larger role for the Alliances and Associations, enabling the advocacy for sector's challenges.

4.9 Fiscal incentives

The fiscal incentives are crucial for CSP enterprises to increase spending on research and development (R&D), largely because R&D and innovation are considered key to productivity. As an example, R&D tax incentives or R&D subsidies could be integrated at the early stages of companies' development.[7]

[7] For more information, please check the OECD report on tax incentives for R&D.

5. Rising the awareness through educational process

The role of education in solar energy development can’t be underestimated. Every child should learn about the importance of sustainable development and renewable energy sources. Thus, the course on renewable energy, especially solar thermal power use, could be included in the educational system, starting from primary and secondary schools in China. The integration of solar energy into the curriculum of colleges and universities should be prioritized to not only raise the awareness within the general public, but as well to form the future professionals. Besides, mass media sources represent an important tool in educational process and should be encouraged to spread the benefits of solar thermal energy and raise awareness about the topic.

Table 8. Professional media platforms specialized in solar thermal energy

Educational institutions in China	**Mass media sources**
Primary and Secondary Schools*	China National Solar Thermal Energy Alliance: http://www.nafste.org/
Colleges and Universities	CSPPLAZA: http://www.cspplaza.com
Renewable Energy Research Institutes	➢ Smart Energy: http://www.secn.net/ ➢ Beijixing Electric Website: http://www.bjx.com.cn/ ➢ Energy Observation: http://www.chinaero.com.cn/ ➢ Solar Industry Information: http://www.cstif.com/ ➢ Electricity Big Data: http://www.epcnn.com/ ➢ China Recycling Economy Association renewable energy Specialized Committee: http://www.creia.net/ ➢ China National Renewable Energy Innovation Alliance: http://www.chnreia.org/ ➢ China New Energy Website: http://www.newenergy.org.cn ➢ New Energy and Renewable Energy Website: http://www.crein.org.cn/ ➢ Solar Kepu Website: http://kepu.himin.com/ ➢ China Renewable Energy Information Website: http://www.cnrec.info/

* Official Popular Science Platform - Beijing Solar Thermal Utilization Popular Science Base (Supporting Institution：IEE, CAS)

6. Development of Chinese solar heating sector

6.1 Technological overview and challenges

6.1.1 Chinese solar heating industry

1) Technology status

The research on Solar Thermal System (STS) in China has started since the 7th FYP period (1996-1990). STS converts solar radiation into heat, using a heat transfer fluid, which can be air, water or a specially designed fluid. The hot fluid can be used directly for hot water needs or space heating/cooling needs, or a heat exchanger can be used to transfer the thermal energy to the final application.[8] Regarding the heating process, STS can be mainly classified into passive thermal heating and active thermal heating. The passive heating can provide, through design elements, the heating without use of mechanical and electrical devices. However, in some relatively cold areas it's impossible to rely only on passive heating, than the active heating is used, using the Heat Transfer Fluid (HTF).

The most common HTF used for active solar space heating are hot water and air. Both technologies have different characteristics, illustrated in table 9. Using air as HTF provides many advantages, as antifreeze, overheating prevention system, and low maintenance cost. Yet, it has also certain disadvantages as the poor heat transfer properties of air, resulting in difficulty to achieve higher collecting efficiency. Another disadvantage is the need for handling large volume of air due to its low density.

The biggest challenge for air solar space heating is the absence of heat storage equipment, resulting in large indoor temperature fluctuations. It makes more difficult to use the system in urban residential buildings, but more suitable for public buildings mainly for daytime use and rural residential buildings that have lower requirements for indoor thermal environment.

Comparing with air-based system, solar water-based space heating has larger

[8] http://www.solarthermalworld.org/sites/gstec/files/news/file/2015-02-27/irena-solar-heating-and-cooling-2015.pdf

scale in China. Basically, water is used as a heat-transfer fluid to carry heat through solar collectors and a heat exchanger to the storage tanks, as shown in the figure 26.

Table 9. Comparison between solar air and water thermal heating systems

No.	Performance Indicators	Water	Air
1	Price of system (RMB/m^2)	1600	500
2	Efficiency	50% (Colleting Efficiency) 45% (System Efficiency)	45% (Colleting Efficiency) 37% (System Efficiency)
3	Anti-freeze (winter period)	-The collector(s) and piping (collector loop),has to be drained, when there's a chance the temperature might drop below the liquid's freezing point. -Use an antifreeze solution as the heat-transfer fluid	No antifreeze problem exists.
4	Overheating (summer period)	Surfaces of collectors could be covered , but it's difficult to control the boiling temperature of water tank	Air vent can be opened in summer to form a chimney, creating a ventilation process.
5	System maintenance	Periodic maintenance is required, as check pipelines, water treatment to avoid pipe blockage, control cabinet maintenance, collector's replacement, etc.	Less often maintenance is required, such as cleaning filter screens at air vent every year, and replacing aging vent plugs.
6	Room temperature fluctuation	There is a small room temperature fluctuation	Without replenishing heat at night, there will be a large room temperature fluctuation between day and night.
7	Guarantee	Mature technology with product's quality that could be guaranteed	Emerging technology; product quality has great impacts on heating efficiency.

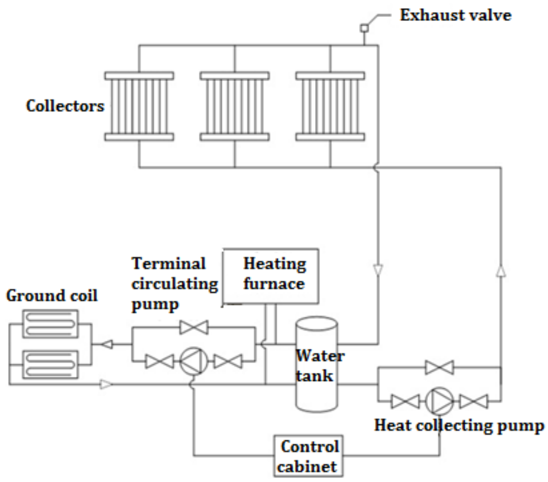

Figure 26. Operation principle of solar water thermal heating system

The heat is stored in the water tank and released as required, while when temperature in the water tank is lower than the demand of heat supply, the auxiliary system, such as heat pump, electric boiler, fuel gas and others, could help to maintain the fixed temperature in tank.

2) Industry development

Solar water heaters became popular in China, successfully solving the problem of domestic hot water supply in urban and rural areas. According to the data from *Solar Heat Worldwide* 2014 (2016 Edition) made by SHC (Solar Heating & Cooling Program of International Energy Agency), by the end of 2014, an installed capacity of 410.2 GWth, corresponding to a total of 586 million square meters of collector area was in operation worldwide. The major share, 68 %, was contributed by domestic hot water applications for single-family houses (Figure 27), while China became an outstanding leader in this sector.

However, with the overcapacity of domestic market, the production of solar water heaters has declined significantly, as illustrated in table 10. The development of solar space heating could resolve both problems: boost again the decreasing industry and contribute to the emissions reduction produced by conventional space heating systems.

Table 10. Chinese market of solar collectors

Year	Produced collector's area (10,000 m^2)	Annual heat production MWth	Annual growth * (%)	Total volume** (10,000 m^2)	Annual heat production MWth	Annual growth (%)***
1998	350	2450	--	1500	10500	--
2001	820	5740	28.1	3200	22400	23.1
2005	1500	10500	11.1	7500	52500	21.0
2010	4900	34300	16.7	22170	155190	23.8
2011	5760	40320	17.6	27110	189770	22.3
2012	6200	43400	7.6	32310	226170	19.2
2013	6360	44520	2.6	37470	262290	16.0
2014	5240	36680	-17.6	41360	289520	10.4
2015	4350	30450	-17.0	44210	309470	6.9

* The annual growth corresponds to the column of produced collector's area
**Total volume means the area of produced, installed and stored collectors.
***The annual growth corresponds to the column of total volume
Source: data from report of the 13th FYP for solar thermal utilization.

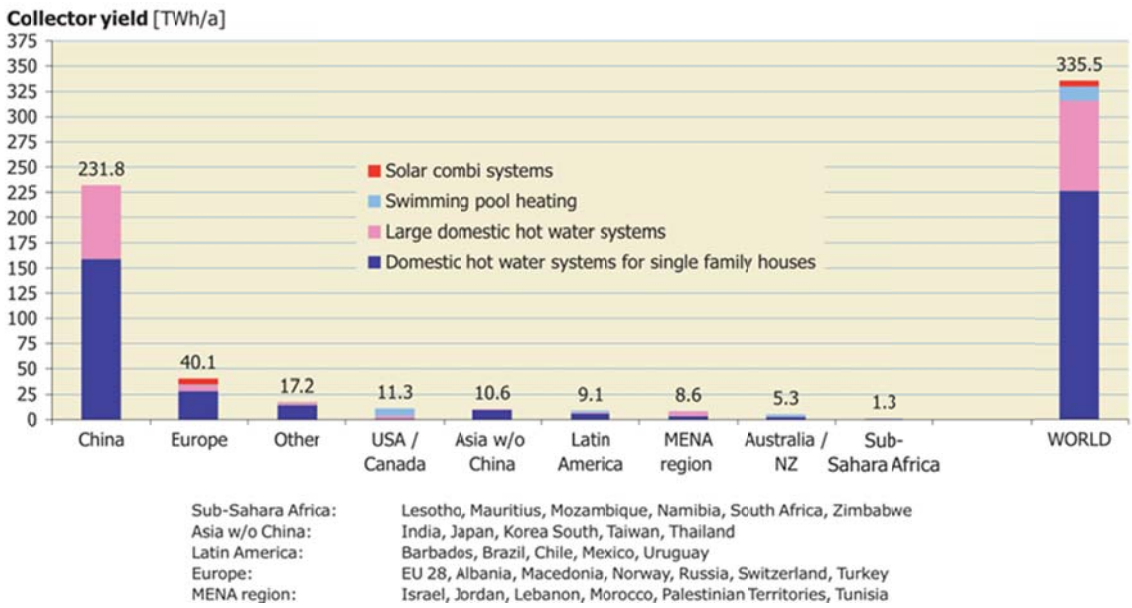

Figure 27. Annual collector yield of unglazed and glazed water collectors in operation in 201

Source: Solar Heat Worldwide 2014 (2016 Edition) made by SHC (Solar Heating & Cooling

Program of International Energy Agency),

Currently, the Chinese solar thermal heating industry has not yet achieved large-scale industrial production, while the demonstration projects are mainly installed at individual buildings. During 2008-2014 the solar water thermal heating systems achieved its fastest growth mainly in Beijing area covering about 500 thousand m^2 by 2013, according to the incomplete statistic. Those buildings mainly located in suburban areas around Beijing, such as district of Pinggu, Mentougou, Fangshan, Miyun, Changping, etc., among which Pinggu district takes the maximum application share. Only Pinggu district accounts for more than 1000 households, which already use solar heating, with a total building area of over 350 thousand m^2, that includes the villages of Jiangjunguan, Bolitai, Guajiayu, Nanzhai, Taipingzhuang, Jingyu, Zhangjiatai, Dadonggou, Damiaoyu, Dongsidaoling, Xiangyang, etc. However, after the changes in electricity policy in 2014 and subsidizing the anthracite and coal, the economic advantage of solar thermal heating system became less prominent, and the number of demonstration projects has decreased significantly.

3) Challenges of solar thermal heating

The heat output of solar thermal heating system influenced by various factors both subjective and objective, including area of solar collectors, location, construction materials, structures, number of residents, lifestyles, and others. Even in the same building, the heat output may change depending on season. Based on field measured data, the ratio of solar collecting area to building area varies within 1/8-1/6, while the solar fraction[9] of the system during the whole heating season is around 20-35%. Moreover, only by using solar thermal heating and without any use of auxiliary facilities, the room temperature in the early and late period of the heating season can be over 16 ℃ and in the coldest months of winter, the average temperature of room is about 10-12 ℃, increasing the temperature in the room by 10 ℃. Thus, solar water thermal heating contributes to energy saving and emission reduction, yet it faces many challenges to large-scale application listed below:

[9] Solar Fraction = Total Solar Energy Delivered to Tank (kWh) / Total Energy Delivered to Tank (kWh). Source: NREL

(1) **Difficulty to solve the problem of thermal imbalance between summer and winter.** The solar fraction in the heating season is 20-35%, while in the non-heating season when solar hot water is merely used, the overheating of system will be rather serious since energy consumption of hot water would account for only 1/10 of the building heating load, which causes the release of excess heat, surpassing the finite TES capacity of the system. Overheating causes problems such as component aging, tube's cracking among others, on more frequent bases that reduce the life of the system and increase the need for system maintenance, eventually resulting in a poor user experience.

(2) **Complexity of the system.** The system has numerous components and its control is so complex that ordinary users have difficulty to operate it. For instance, the auxiliary heat source must be launched by user when the sun radiation is insufficient. Yet, the process of switching between two sets of systems could be challenging without a special training.

(3) Limited TES capacity. The thermal heating system is usually used only during the winter, while the TES capacity is so limited that it's hard to achieve a high proportion of solar fraction. According to the field data, the fraction of solar heating is around 20-35%, limiting the energy saving and emission reduction, which to some extent hinders its large-scale application.

(4) **Long payback time.** The economic analysis of the demonstration projects shows that the price of heat, taking into consideration the initial investment depreciation and operating expenses, is about 0.4-0.6 RMB/kWh_{th} (0.05-0.08 USD/ kWh_{th}) which has no advantage over other alternatives.

Consequently, the thermal imbalance between winter and summer is one of the fundamental problems toward large-scale application, linked with long payback period and maintenance need. **Therefore, only by innovating technological advances in the seasonal heat storage, the system could provide effective, reliable and competitive product that would reduce the maintenance and payback, achieving large-scale utilization of solar thermal heating in the future.**

Table 11. Economic analysis of various types of STS

No.	Items		Low-temperature STS					Concentrated solar collecting system	Air collectors + Air source heat pump
			Biomass Furnace	**Electric Furnace**	**Ground Source Heat Pump**	**Water Source Heat Pump**	**Air Source Heat Pump**		
1	Operating cost (excluding depreciation)	Annual auxiliary heat source energy consumption	17.7 kg/m^2	73.1 kWh/m^2	27.7 kWh/m^2	32.7 kWh/m^2	29.0 kWh/m^2	30.6 kWh/m^2	29.0 kWh/m^2
2		Energy cost	1.5 RMB/kg	0.5 RMB/kWh	0.5 RMB/kWh	0.5 RMB/kWh	0.5 RMB/kWh	0.5 RMB/kWh	0.5 RMB/kWh
3		Annual operating cost (RMB/m^2)	27.5	36.6	13.9	16.4	14.6	15.3	14.6
4	Operation during heating season (150 m^2), RMB/year		4125	5490	2085	2460	2190	2295	2190
5	Capital cost * (RMB/m^2)		410	380	570	600	560	672	458
6	Depreciation cost of system (RMB/m^2)		20.5	19.0	28.5	30.0	28.0	22.4	22.9
7	Heat price per building area (with system depreciation and operation expenses), RMB/m^2		47.5	55.6	41.9	46.4	42.6	37.7	37.5
8	Heat price per power produced (with system depreciation and operation expenses), RMB/kWh$_{th}$		0.47	0.55	0.42	0.46	0.42	0.37	0.37

*Approximate values

6.1.2 Future development of solar space heating

Large solar district heating systems

The large Solar District Heating (SDH), based on medium-temperature solar collectors and seasonal heat storage, is an important direction for development of solar heating in the future. In this section the future trends of the sector's development are presented:

(1) Medium-temperature thermal collector would meet the requirement of heating with various temperature grades.

At present, the supply and return water temperature of the primary heating network in the residential sector is about 95/70°C and 80/65°C, while the supplied steam temperature reaches 130/70°C. The requirement for exact heat grade can be met by using the efficient medium-temperature thermal collectors, which is also another important application area for concentrated solar medium-temperature collectors in the future.

(2) Seasonal heat storage technology of large capacity will enable the four-season use of solar energy.

In non-heating seasons, the collected solar energy can be stored in large-capacity seasonal TES units and when needed could be transferred to heat supply networks. Thus, the system could be run during four seasons, which significantly increases its work hours and reduces the payback period. According to the application experience in Nordic countries, the heat price achieved 0.2-0.3 RMB/kWh_{th} (0.02-0.04 USD/ kWh_{th}) in 2016, becoming competitive with other renewable energy sources. In addition, the use of system during four seasons prevents its components from aging, eliminating the problem of overheating and therefore, increasing the life span. Furthermore, the application of large-capacity seasonal heat storage technology enables to achieve 100% of solar fraction for STS.

(3) The SDH equipped with intelligent control system and professional maintenance team, will eliminate the problem of difficult maintenance for distributed system.

As was mentioned above, one of the challenges solar space heating encounters is the complicated maintenance for ordinary users. The promotion of SDH would eliminate this problem, as the centralized system could be fully managed by the professionals, operating with the intelligent control system, storage and supply of produced heat. Moreover SDH requires a limited number of professional, reducing the cost for end users. For instance, the application of SDH with heat collecting area of 70 thousand m^2 and TES of 220 thousand m^3 in Nordic countries showed that only 5 professionals are needed to carry out its maintenance.

2. Development of SDH

The SDH can be generally classified into two categories:

1) Industrial waste heat recovery technology that uses district thermal supply system for peak load regulation and mainly based on CSP cogeneration;
2) Large-scale SDH based on heat and power production, using the combination of solar and other renewable energy sources, with solar fraction of more than 50%.

Due to the limitation of seasonal heat storage technology and lack of related business guidance mechanism, in China there is no yet large scale SDH system that would be nationally designed, using the nationally produced key components and equipment. However, it's important to notice that since the 12th FYP (2012–17), Chinese government and relevant enterprises have made some attempts to carry out the demonstration projects of SDH. This recent emergence of interest in SDH expected to foster the advances in key technologies and lead the future large-scale application.

6.2 Projects of SDH in China

6.2.1 Demonstration project of large-scale solar energy and industrial waste cogeneration thermal plant for urban district heating

Location: Chifeng city in Inner Mongolia Autonomous Region

Owner: Tsinghua University, Chifeng Heran Energy Saving Science and Technology Co., Ltd

Umbrella program: the National Science & Technology Pillar Program during the 12th FYP Period

Construction time: August 26th, 2015—August 28th, 2016

Project's description:

The demonstration project of 20MW industrial waste heat recovery system was installed in a copper smelting plant in Chifeng, Mongolia to provide heat with the total amount of 500,000 GJ for the district heat supply network covering the building area of 1 million m^2 in Chifeng city.

As illustrated in figure 28, the industrial waste heat recovery system is located in the waste heat plant room in the north region of the copper plant, while the Borehole-duct TES (BTES) and solar system were located on a hill in the south, about 1,300 meters away and height difference of 60 meters from the industrial waste heat plant room. The total area of demonstration project is about 10 thousand m^2, BTES units covered 50 thousand m^3.

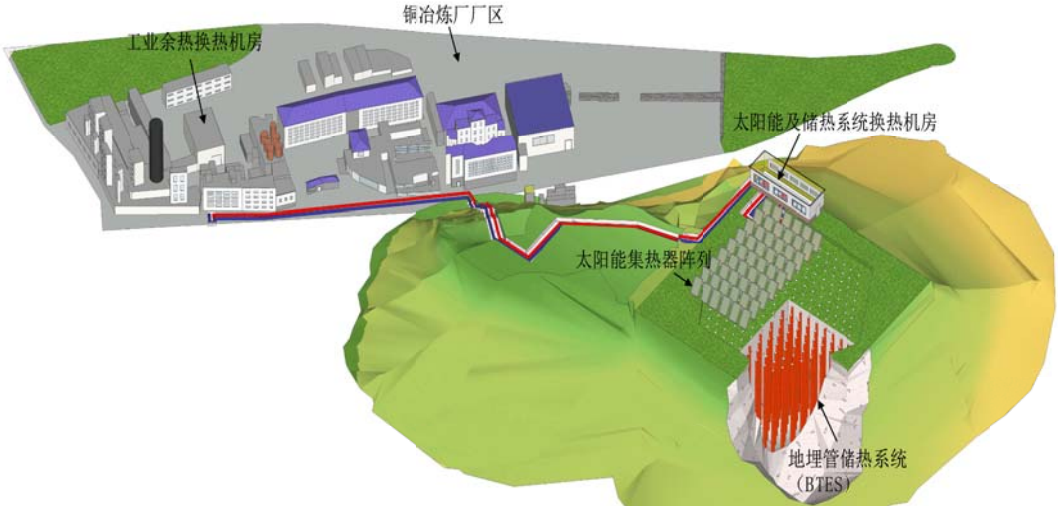

Figure28. Scheme of the project's site in Chifeng city

The demonstration system consists of solar energy subsystems, industrial waste heat, and underground heat storage. The operation cycle is divided into the heat storage period starting from April 16th to October 14th; and generation period corresponding to the local heating season from October 15th to April 15th.

During two different periods, the system operates in two different ways. During the period of heat storage, the running mode of the system is shown in figure 29. The circulating pump P1 of heat storage launched with flow rate of 30 m^3/h, and the HTF is heated in the industrial waste heat recovery subsystem to 80°C. Then, HTF flows through the solar subsystem, with the temperature continuously rising to 85 °C, to the underground TES subsystem and exchanges heat with the cycle fluid in borehole-duct heat exchangers. During the heat-exchange process, the HTF release heat to the soil underground, with its temperature reducing to 50 °C, and then return to the industrial waste heat recovery subsystem to get more industrial waste heat, and so the cycle repeats.

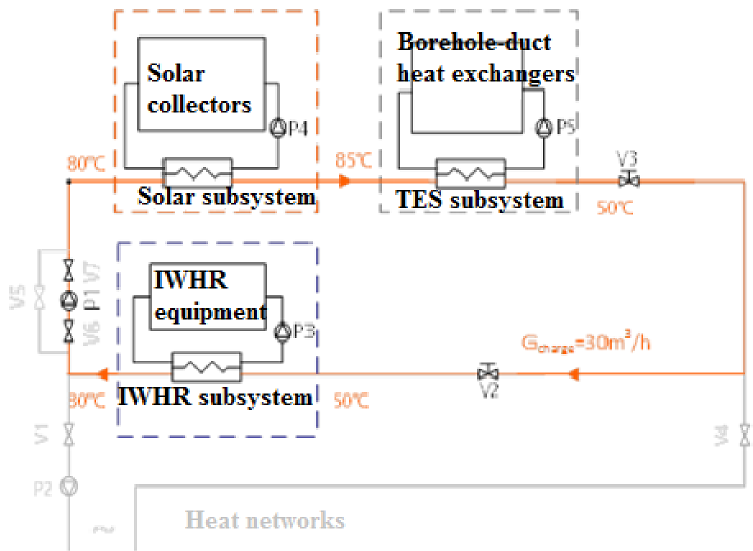

Figure 29. Scheme of heat storage in SDH project in Chifeng

While during the period of heat extraction, the running mode of the system is shown in figure 30.

When the circulating pump P2 of heat generation is started, the flow direction between the solar subsystem and TES subsystem is switched. Part of the low-temperature water returned from heat supply networks, firstly flows through the TES subsystem, with a flow rate of 30 m^3/h, to extract heat stored in the underground, and then flows through the solar subsystem reaching about 45 °C, which is shown as the blue line in figure 30. While another part of the separated heat fluid flows into the industrial waste heat recovery subsystem to recover the industrial waste heat, with a flow rate of 270 m^3/h and temperature increasing to around 65 °C, which is shown as the red line in figure 30. Later two parts of the fluid are mixed and they flow into the heat networks to supply heat. The returned low-temperature water in the heat networks is obtained from each heat supply station by integrating absorption heat pumps in the terminal.

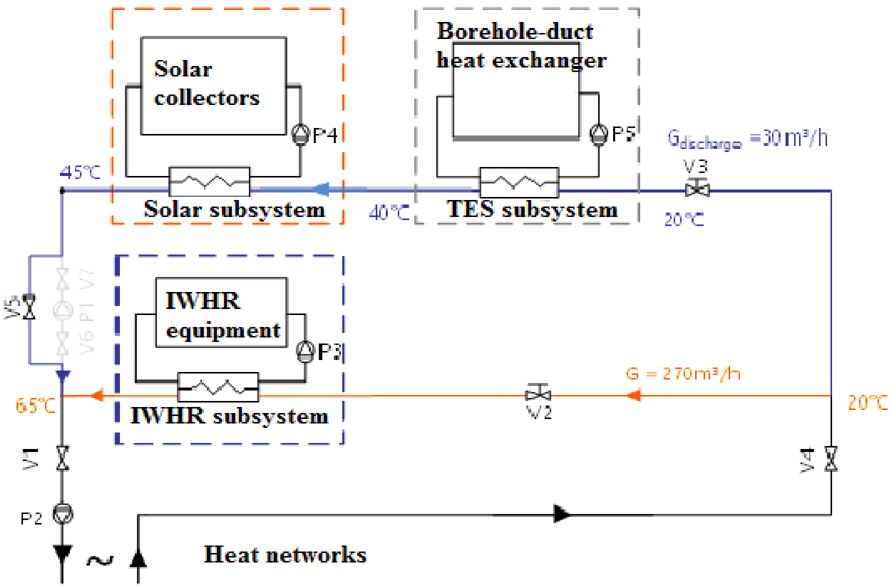

Figure 30. Scheme of heat extraction in SDH project in Chifeng

Main design and operating parameters:

Table 12. Main parameters of the project

Parameter	Unit	Value
Collector area	m^2	1002
Efficiency curve of collector	-	η=0.497-1.483T_i^*
Thermal conductivity of soil	W/(m·k)	0.852

Initial temperature of soil	°C	10

Operating Parameters under typical conditions:

In the heat storage period:

- Temperature of water flowing from the industrial waste heat recovery system: 70°C(day) / 80°C (night)
- Temperature of water flowing from the solar heat collecting system: 85°C (the highest) / 75°C (on average)
- Inlet water temperature of the TES system: 75°C (on average)
- Outlet water temperature of the TES system: 55℃ (on average)
- Circulating flow rate of heat exchange: 30m^3/h
- Pressure of circulation lines: 0.65 MPa (heat station of industrial waste heat) / 0.10MPa（heat station of TES）
- Power of heat exchange circulating pump: 18.5 kW
- Power of heat storage circulating pump: 18.5 kW
- Circulating pump power of U-tube collector array: 12 kW
- Circulating pump power of CPC collector array: 5 kW

In the heat extraction period:

- Inlet water temperature of the TES system: 25°C (on average)
- Outlet water temperature of the TES system: 45℃ (on average)
- Temperature of water out from the solar heat collecting system: 60°C (the highest) / 50°C (on average)
- Circulating flow rate of heat exchange: 30m^3/h
- Pressure of circulation lines: 0.65 MPa (heat station of industrial waste heat) / 0.10MPa（heat station of TES）
- Power of heat exchange circulating pump: 18.5 kW
- Power of heat storage circulating pump: 18.5 kW
- Circulating pump power of U-tube collector array: 12 kW
- Circulating pump power of CPC collector array: 5 kW

6.2.2 Demonstration project of seasonal heat storage for SDH system in Hebei University of Economics and Business

Location: 7 Xuefu Road Northbound, Shijiazhuang, Hebei province

Proprietors: Hebei University of Economics and Business

Construction Units: Beijing Sijimuge Solar Energy Technology Group Co., Ltd., Hebei Daxiang Investment Co., Ltd.

Construction Time: October, 2012—November, 2013

Description:

The general design idea was based on mechanical circulation and constant outlet temperature. The aim of system is to ensure water supply, security and stability of the thermal power supply, as well as to maximize the energy saving. The whole system is comprised by solar collectors, bath heat supply water tanks, seasonal TES water tanks, auxiliary heat sources, control cabinets, related water pumps, pipes, valves and others (Figure 31).

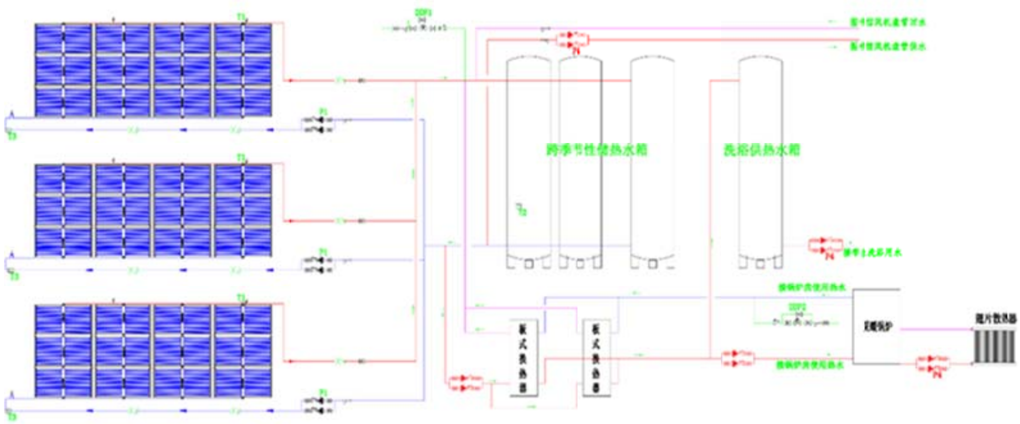

Figure 31. Operation principle diagram of seasonal TES for SDH project in Hebei

1) Water in the seasonal TES tank is cyclically heated by the solar thermal collectors system until its temperature increases to reach a relatively high set value. And the cyclic heating will be repeated when the water temperature in the seasonal

TES tank declines to a certain value. The processes of the seasonal TES tank heating cycle among other processes are all regulated by butterfly valves.

2) Water in the heat supply tank is replenished through tap water pressure, prior to which the tap water is indirectly heated by flowing through the plate heat exchanger and extracting heat form the seasonal TES tank. The water in the seasonal TES tank will be transferred into the pool boiler heating system to be later reheated and used when the temperature reaches a set value.

3) Heat supply cycle of finned radiators: firstly, the heating circulating water is heated by high-temperature water in the seasonal TES tank flowing through the plate heat exchanger. Yet, if the temperature of water in the seasonal TES tank doesn't reach the requirement value of heat exchanger, the water will be directly circulated with the heating terminals. In case the temperature of water in the seasonal TES tank falls below the direct heating temperature requirements again, water would be cyclically heated by the boiler and heating terminals, for which the manual operation is required.

4) Heat supply cycle for fan coils in a library: the hot water in the seasonal TES tank is directly circulated with the terminals of fan coils. When the water temperature falls below the direct heating temperature again, it will be cyclically heated by the boiler and heating terminals, for which manual operation is required.

5) The anti-freezing and temperature difference circulations are operated using the automatic control functions, while other functions, as water replenishment, control of heat supply and heating system, require manual operation.

2. Operation principles:

1) Heat collectors:

When the temperature difference between collector (T1) and the seasonal TES water tank (T2) is no less than 7°C, the temperature difference circulating pump P1 is started, while when the difference is no more than 3°C, than P1 pump is stoped.

2) Anti-freezing: when temperature of the collector (T3) is lower than the set

value of 5℃, the circulating pump P1 is started, while when T3 is higher than the set value of 10℃, P1 pump is stoped.

6.2.3 Main parameters

1) Basic information of the project

(1) Heat collecting area: 11.6 thousand m^2 (total area)

(2) TES capacity: water in the TES tank of over 20 thousand tons

(3) Heat supply area: 80160 m^2 (14 dormitory buildings) + 3000 m^2 (Library)

(4) Capacity of auxiliary heat source: 2 units of steam boilers

2) Operation parameters

(1) Heat collecting temperature: 45-85°C

(2) TES temperature: 50-85°C

(3) Heat networks temperature: 55-60°C

(4) Flow rate and pressure: 200 ton/h，0.4MPA

3) Water consumption: 32 liters per capita (45°C), with a bath proportion of 25%, thus the total hot water consumption per day is 121 tons. The corresponding hot water load is 15.2 GJ/day and the annual heat load is 4180 GJ if calculated with an annual bath time of 275 days.

4) Fuel consumption: 12,622,294 kWh/year

Current operational status:

1) Testing method introduction: the project is tested and inspected according to GB 50495-2009 Technical Specifications for Solar Heating Engineering .

2) Testing time and period:

Testing points include the measurement of local radiation, ambient temperature, ambient humidity, indoor temperature of heat supply, inlet water temperature, flow rate of domestic water supply, in and out water flows of each building, pipelines of sub cycle, pipelines of major cycle, four interfaces of plate heat exchanger, water level points of three different heights in water tank, supply/return water pipe network and others. The testing system can be installed with energy meters which can measure temperature, average hourly heat and total heat. The heat storage statistics in different seasons can be carried out by the above measured data.

The development of SDH is an important direction for the large scale application of solar thermal energy in the future. The necessary prerequisite for its further development is the innovative advances in the efficient solar thermal collectors for medium temperature applications and large-capacity seasonal TES technology. Currently compared with Denmark and other Nordic countries, the development of SDH in China is still in its early stage and the additional progress is needed in technical systems and key technologies. In addition, the heat price and capital investments are still higher, comparing with systems based on conventional coal and other energy sources. Thus, the scale expansion and sustainable development of SDH depends on joint efforts of government, enterprises and research institutions to establish and execute a long-term incentive policy.