Industry-Specific Utilization of Solar Industrial Process Heat (SHIP)

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This chapter is dedicated to Professor Peter J. Derrick who passed away in March 2017 during the writing of this chapter.

Contents

Author Contribution
The first draft was written by SHF. The data in the figures and charts was supplied by SHF. The final draft was reviewed and edited by MAPM and NH.

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Abstract

Solar industrial process heating systems have become very promising for the industrial sectors as replacement of fossil fuel generation sources to supply heat for industrial scale water heating, air drying, cleaning, food processing, metal refining, and various other uses. The potential of solar industrial process heating systems varies depending on the availability of solar resources and the government policy towards process heat utilization. Though solar driven industrial heating systems may reduce the environmental burdens to a great extent, the feasibility of integration due to the system design requirements and capital cost should be considered systematically. This book chapter will discuss some of the processes which are currently using solar industrial process heating systems and outlines about the leading countries who are utilizing solar industrial process heating systems on a large scale.

14.1 Solar Industrial Process Heat (SHIP)

Industrial process heat is generated based on renewables and nonrenewable sources of energy for various uses in the industrial sectors. The process heat generation sources from the renewable resources promote a sustainable operation and reduction of greenhouse-gas emissions. Solar process heat utilized in industrial processes is the best solution for sustainability problems, irrespective of the higher capital costs associated with their implementation. However, many industrial sectors are currently relying on solar process heat for thermal energy generation with or without energy storage systems for off-peak hours. The implementation of these systems principally depends on the capital costs of the industry, availability of solar energy, and the government policy. The process heat generated from solar resources which are used in industrial operations is termed as “solar heat for industrial processes (SHIP).” Process heat is generated using solar power and the combination of suitable solar collector technologies. The design of solar collector technology varies based on the design criteria such as the selection of suitable collector, number or combination of collectors, collector size and area, the position of installation, working fluid, thermal power, storage volume, and the temperature range for a chosen industrial process.

Solar heat for industrial processes (SHIP) is currently growing throughout the world with solar energy potential. According to the SHIP plants database, 303 plants are in operation in conjunction with industrial processes. Mostly these SHIP plants are of relatively small sized, running for low-temperature industrial processes. SHIP plants are on the focus of researchers, industrialists, government, and policy makers to utilize the immense potential of the abundant source of renewable energy while reducing the environmental burdens associated with massive scale consumption of fossil fuels. To achieve the sustainable development goal for 2050, solar heat for industrial processes (SHIP) can play a vital role. Though many SHIP plants are already in operation, enormous potential exists in many industrial sectors and countries which required to be identified and analyzed to take necessary steps towards successful implementation of SHIP plants.

Industrialized and developed countries are already using SHIP plants in their industrial sectors like agriculture, mining, manufacturing of food, meat, tobacco, textile, leather, wood, paper, chemical, pharmaceutical, rubber, computer, machinery, vehicle, furniture, and so on. Countries who are successfully operating the SHIP plants in the abovementioned industrial sectors are Australia, Austria, Peoples Republic of China (China herein), Chile, Germany, Greece, India, Oman, Qatar, Romania, South Africa, Spain, Sweden, Switzerland, Turkey, United Arab Emirate, and the United States of America (USA herein). Researchers also analyzed the country-specific SHIP potential for India, Australia, the United States, Spain, Portugal, Austria, China, Germany, South Africa, Mexico, Turkey, Pakistan, and Chile. In addition, there is an increasing focus on design methodology of SHIP plants based on software simulation and experimental investigation. The design optimization and performance assessment of SHIP plants are also analyzed based on design methodology.

In this article, Sect. 14.2 illustrates the previous literature studies based on country-specific prospects of SHIP plants, their industries, and industrial processes. Section 14.3 will describe the key industrial processes which are utilizing solar process heat, based on their country, industrial sector information, and solar collector specifications. Section 14.4 will discuss the summary of the present condition of the SHIP plants based on collector area, type of collectors, collector's summary based on industry type, and country-specific SHIP installation summary. Section 14.5 gives the concluding remark.

14.2 Existing Studies on SHIP

There are several studies in the form of research papers, review papers, and scientific reports which analyzed the potentiality of SHIP plants based on their location (country), industry, or process/operation. Analyzing the SHIP plants database information about operating SHIP plants in the world, the 12 most influential countries for SHIP are India, Austria, Germany, the USA, Spain, China, South Africa, Mexico, France, and Greece.

In India, the dominant industrial sectors that are utilizing SHIP are agriculture, food, tobacco, textile, wearing apparel, leather, paper, chemical metals, electrical equipment, and transport equipment. With the growing demand for renewable energy resources, solar radiation in India has an average of around 250 clear sunny days which created immense opportunities for using SHIP plants. However, still many industrial sectors lack using solar process heat. According to the existing literature, SHIP plants in India are in the area of food, paper, and dairy industries. Palappanian described an energy network named Planters Energy Network (PEN), that is an nongovernment organization (NGO) for drying processes using solar process heat utilized for drying rubber, leaves, pulses, fish, or grains. These units are operating in conjunction with conventional process heating systems [1]. Sharma et al. conducted several review works based on the potential of SHIP in the paper and dairy industries in India based on the SHIP plants design requirements like process heat, thermal energy, and solar collector design. They conducted a survey based on the location of paper industries in India and their requirements [2–5]. Suresh et al. developed a solar industrial process heating system integration methodology through matching process heating requirements and solar collector technologies. They considered the dominant industries in India while addressing the economic and developmental parameters [6].

In Austria, the dominant industrial sectors are food, beverages, leather, chemical, metals, and furniture. Austria developed and used solar collector systems in the building and industrial processes from the last two decades. However, industrial sectors like paper, electronics, wood, pulp, etc. are still in lack of attention which is also major industrial sectors in Austria. Very few research works or reports are available based on SHIP plants in Austria in the open literature. Kranzl et al. analyzed the overview of prospects of renewable energy in Austria until 2030, especially in the upper region of Austria [7].

For Germany, the economy is ruled by the industrial sectors utilizing SHIP plants like agriculture, food, beverage, textiles, chemicals, and metals. SHIP plants used in Germany are mostly low-temperature process heating systems while few are high-temperature industrial processes. Lauterbach reviewed existing potential studies in the field of solar process heat used in Germany with a focus on their industrial processes. According to their research, there are 11 potential industrial sectors which hold solar process heat integration feasibilities. The temperature range determined by their work in 100–200 degree Celsius (°C) through the comparison among theoretical and technical feasibility studies [8]. Frey analyzed a textile factory which has solar industrial process heating systems installed in it located in Germany and practically analyzed their design parameters, system requirements, and optimized results [9].

In the United States, the vital industrial sectors which are operating in conjunction with SHIP plants are agriculture, food, textiles, and beverages. Many industrial sectors like chemical, metal, mining, and electrical equipment-based industries are still in the lack of attention, where the potential for solar process heating systems integration exists. Kurup et al. conducted several studies based on solar process heating system integration focus in the United States of America. They were focused on five top industrial sectors, while they conducted their research based on food industries and SHIP potential. They worked through analyzing solar resources availability, energy requirements in industrial processes, and temperature range of solar collectors [10, 11].

For Spain, the SHIP plants are operating in conjunction with agriculture, food, textiles, wood, metals, and motor vehicle. However, Spain also has great potential to integrate SHIP plants in the industrial sectors like pharmaceutical, chemical, and automobile industries. Schweiger et al. conducted a review work based on solar process heat integration potential of Spain and Portugal. They studied the recent developments of medium temperature and high-temperature industrial collectors and processes and gave an outline for future trend [12, 13]. Silva et al. studied the SHIP plants installed in the food industries while prime attention is on parabolic-trough solar collectors [14–16].

In the Peoples Republic of China, the SHIP operated industrial sectors are agriculture, food, beverage, textiles, chemicals, and leathers. The dominant industries in China are mining, ore processing, and automobiles; so undoubtedly, immense potential still exists for solar process heat integration in these industries: mining, ore processing, and automobiles. Though the SHIP plants in operation are mostly low-temperature and medium-temperature process heating application where mining industries require not only low and medium temperature but also high-temperature process heating systems. Sturm et al. analyzed different types of steam generation systems while focusing on renewable energy integration based on their energy requirements [17]. Liu et al. studied energy consumption in Chinese industrial sectors through an economic input-output analysis based on 29 types of industries [18]. Jia et al. studied SHIP plants installed in P.R. China based on their energy consumption, SHIP integration, and solar collector technologies. They have also analyzed 26 SHIP cases from 10 industrial sectors in China [19].

For South Africa, SHIP driven industrial sectors are mining, food, beverages, machinery, and motor vehicles. However immense potential still exists to integrate solar process heat in automobile and electronic equipment industries which are identified as major industries in South Africa. The existing SHIP plants in South Africa are mostly low-temperature process heat applications, while medium and high-temperature process heating systems are also in operation due to the huge availability of solar resources. There are few research works based on SHIP plants in South Africa. Brent et al. studied concentrating on solar water heating systems to identify the potential for South Africa [20]. Joubert et al. analyzed 89 large-scale solar thermal systems in South Africa based on their industries sectors, economics, and application areas [21]. Uhlig et al. analyzed the potentialities of high-temperature solar process heat applications based on concentrating solar thermal technologies [22].

In Mexico, solar process heat is used mostly in the agriculture and food industries. Mexico has a good number of solar industrial process heating systems in operation while mostly they are low and medium temperature solar thermal systems. Only a few research works exist which analyzed the potentiality of SHIP plants in Mexico. Ramos et al. studied parabolic-trough solar collector technologies to be considered for the textile and food industries of Mexico [23].

In France, the food, beverage, and metal industries are utilizing solar process heat. However, no significant research works or review studies have been reported which have analyzed the potential of SHIP plants located in France.

In Greece, SHIP plants are operating in the industrial sectors like food, beverage, textiles, pharmaceuticals, and leather industries. There are a few studies regarding the SHIP potentiality analysis in respect of Greece. Karagiorgas et al. studied solar thermal systems and compared with conventional thermal systems based on their energy equivalency [24].

14.3 Industrial Processes with SHIP

This subsection will elaborate on the major industrial processes which are already integrated with SHIP plants throughout the world. The subsections are organized based on the industries processes with operating SHIP plants information. The processes are cleaning, drying, pasteurization, general process heating, cooking, cooling processes, surface treatment, and other processes (evaporation, blanching, sterilization, heating of production hall, cooling of production hall, melting, extraction, bleaching, painting, and retaining [25, 26]). Among the 303 SHIP plants information collected in the SHIP plants database, 237 plants are in operating in the abovementioned industrial processes. Rest of the 66 SHIP plants are operating with other process heating conditions which are excluded from this study. Most of the SHIP plants with widely integrated industrial processes are currently under consideration. In these subsections, the tables describe the name of the SHIP plants, industry information, country, solar collector specifications, and installed thermal power requirements. Plants information are placed alphabetically, irrespective of their design specifications and capacity.

14.3.1 Cleaning Process with SHIP

For the industrial cleaning processes, 61 plants are reported to date according to the SHIP plants database information, while the industries are food, beverage, meat, textile, mining, dairy, fish, transport, chemical, and manufacturing. The dominant industrial sector is the food industries where 30 SHIP plants are operating with the solar-driven cleaning process. Countries which are utilizing solar process heat for industrial cleaning operations are Israel, Greece, the United States of America, South Africa, Mexico, France, Germany, India, Austria, Portugal, Canada, Spain, and Saudi Arabia. The leading countries are Austria (9 plants), Germany (6 plants), Greece (5 plants), Mexico (11 plants), South Africa (6 plants), and United States (5 plants). Among these plants, 45 plants are operating with flat-plate solar collector technologies where mostly are low-temperature industrial processes. The other types of solar collectors are parabolic trough collector and evacuated tube collectors. The highest capacity SHIP plant with solar cleaning operation is Prestige Food located in the United States, where the average solar collector area is 7804 m^2, installed thermal power is 5462.8 kWh, and storage volume is 946 m^3. Table 14.1 showed the SHIP plants summary based on solar driven industrial cleaning operations and their key details.

14.3.2 Drying Process with SHIP

For the industrial drying processes, 33 plants are reported to date according to the SHIP plants database information, while the industries are agriculture, textile, furniture, food, transportation, tobacco, mineral, rubber, beverage, paper, and metal. The dominant industrial sector is the food industries where 10 SHIP plants are operating with the solar-driven drying process. Countries which are utilizing solar process heat for industrial cleaning operations are India, the United States, Romania, Mexico, Austria, Germany, Costa Rica, Panama, China, Argentina, Thailand, Indonesia, Canada, Spain, and Portugal. The leading countries are the United States of America (8 plants), Germany (3 plants), Austria (3 plants), Mexico (3 plants), and India (4 plants). Among these plants, 18 plants are operating with air

Table 14.1 Summary of the SHIP operated-industrial cleaning processes [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
1 Of Tov Hatching Farm	Israel	Food	FPC (~65)	313.5	212.4	20
Achaia Clauss S.A.	Greece	Beverage	FPC (45~60)	308.0		15
Adams Farm Slaughterhouse	USA	Meat		297.0	207.9	
Allegro S.A. Children's Cloathing Manufacturer	Greece	Textile	FPC (33~60)	70	49	3.5
Anglo Plat – Brakfontein	South Africa	Mining	FPC	540	378	42
Anglo Plat – Middelpunt	South Africa	Mining	FPC	180	126	14.2
BHP Billiton Wolwekrans Colliery	South Africa	Mining	FPC (~60)	390	273	40
Bonaprime Slaughterhouse	Mexico	Meat	FPC (65~70)	65	45.5	3
Battenkill Valley Creamery	USA	Dairy	FPC	53	37.1	
Bonilait Dairy	France	Dairy	FPC (~80)	1500	1050	30
Bourdouil	France	Beverage	FPC (15~70)	105	52	6
Brauerei Hald (brewery for beverages)	Germany	Beverage	FPC (~60)	25.1	19.6	3
Brown's Brewing Co	USA	Beverage	FPC	53	37.1	4
Carnes La Laguna Slaughterhouse	Mexico	Meat	ETC (65~80)	99	69	6
Carnes Muma	Mexico	Meat	ETC (60~80)	72	50	5
Carnes Selectas DE Mexico SA DE CV	Mexico	Meat	FPC (55~85)	175	122.5	5
Caritas-Werkstätten: Wäscherei	Germany		FPC (20~90)	80	56	5.6
Carnes Selectas de Sonora S.A. de C.V.	Mexico	Meat	PTC (20~70)	89.48	22.2	3

(*continued*)

Table 14.1 (continued)

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Centro Lechero Cooperativo de los Altos SCL	Mexico	Dairy	PTC (19~92)	422	94.5	9.5
Chalmar Beef Pty (Ltd)	South Africa	Food	FPC	121.2	39	
Clean Park	Germany		FPC (20~90)	24	16.8	0.85
Dausa Milk	India	Dairy	FPC (75~85)	110	77	5
Edmund Merl - Gourmet Foods	Germany	Food	FPC (20~60)	568	397.6	30
Eisvogel Hubert Bernegger	Austria	Fish	FPC	44	30.8	2.5
Gangl Fruit Juices	Austria	Beverage	FPC (95~105)	60	42	21.9
Golan Winery	Israel	Food	FPC(~85)	244	246	30
Hammerer	Austria		FPC (20~60)	180	126	6
Harita Seatings Systems Limited	India	Transport	ETC (55~60)	754.8	360	
Izra'el's Kitchen	Israel		FPC (~85)	120	123	5
Kibbutz Urim	Israel		FPC (~80)	40.6	30.5	5
Knorr Best Foods S.A.	Portugal	Food	FPC (40~45)	440	308	10
L'Oreal Pune	India	Chemical	FPC (~55)	640	448	32
Laiterie Chagnon SHIP	Canada	Dairy	PTC Montesano – Canary Islands	82	46	
MAPAG	Austria	Chemical	FPC (~60)	42	29.4	2.5
Metbrauerei Neuwirth	Austria	Beverage	FPC (50~95)	20	14	0.85
Mevgal S.A.	Greece	Food	Multiple	1	0.7	10

Moguntia Spice Making	Austria	Food	FPC	220	154	20
Montesano – Canary Islands	Spain	Food	FPC (40~60)	290	203	23
Montesano – Jerez de los Caballero	Spain	Meat	FPC (40~45)	252	176.4	30
Mother Dairy	India	Dairy	Multiple (70~90)	1520	1064	
Mr. Wash Mannheim	Germany	Transportation	ETC	197	137.9	
Nestle Waters	Saudi Arabia	Beverage	FPC	515	460.5	15
New York City Subway Washing Plant	USA	Transportation	ETC	164	85	
Northam Platinum's Booysendal Mine	South Africa	Mining	FPC (~60)	192	134.4	30
Procarne Slaughterhouse "A"	Mexico	Meat	FPC (65~75)	110	77	6
Procarne Slaughterhouse "B"	Mexico	Meat	ETC (65~80)	96	67	5
Parkings Service S.A.	Spain	Other	FPC (20~80)	510	357	40
Peitler Vineyard	Austria	Beverage	FPC	100.8	70.56	4
Plektemboriki Kritis S.A.	Greece	Food	FPC (40~90)	50	35	2
Prestage Foods	**USA**	**Food**	**FPC (60~)**	**7804**	**5462.8**	**946**
Rainbow Industries	India	Other		25	17.6	
Santa Anita Dairy	Mexico	Dairy	ETC (60~70)	68	47	3.5
Sukarne Slaughterhouse	Mexico	Meat	ETC (70~80)	195	136	10
Sukarne Slaughterhouse – Mexicali	Mexico	Meat	FPC	100	70	5
Siddharth Surgicals	India	Textile	PTC (~110)	263	184.1	

(continued)

Table 14.1 (continued)

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Sona Koyo	India	Manufacturing	ETC	560	210	
Stadtreinigung Dresden GmbH	Germany	Other	FPC	151	105.7	10
Sunwash Gratwein	Austria	Other	FPC (20~90)	43	30.1	3
Sunwash Köflach	Austria	Other	FPC (20~90)	43	30.1	3
Tyras S.A.	Greece	Food	FPC (20~80)	1040	728	50
Xstrata Elands Mine	South Africa	Mining	ETC (~60)	504	352.8	60

collector technologies where mostly are low-temperature industrial processes. The other types of solar collectors are a flat-plate collector and evacuated-tube collectors. The highest capacity SHIP plant with solar drying operation is Habau-concrete component production located in Austria, where the average solar collector area is 1500 m^2, installed thermal power is 1050 kWh, and storage volume is 80 m^3. Another similar one is Parc Solaire Alain Lemaire located in Canada, where the average solar collector area is 1490 m^2 and installed thermal power is 800 kWh. Table 14.2 showed the SHIP plants summary based on solar driven industrial drying operations and their key details.

14.3.3 Pasteurization with SHIP

For the industrial pasteurization processes, 16 plants are reported to date according to the SHIP plants database information, while the industries are dairy, beverage, and manufacturing industries. The dominant industrial sector is the dairy industries where 11 SHIP plants are operating with solar-driven pasteurization process. Countries which are utilizing solar process heat for industrial pasteurization operations are India, Mexico, Morocco, Czech Republic, and Austria. The leading countries are Mexico (9 plants) and India (4 plants). Among these plants, ten plants are operating with parabolic-trough solar collector technologies where mostly are low-temperature industrial processes. The other types of solar collectors are flat-plate collector and multiple collectors. The highest capacity SHIP plant with solar pasteurization operation is Solar Pasteurization (Lechera Guadalajara Sello Rojo) located in Mexico, where the average solar collector area is 1641.25 m^2, installed thermal power is 240 kWh, and storage volume is 50 m^3. Another similar one is Nestle Dairy Plant Lagos De Moreno located in Mexico, where the average solar collector area is 1327.59 m^2 and installed thermal power is 137 kWh, the storage volume is 5 m^3. Milma dairy located in India have installed collector area of about 1440 m^2 and installed thermal power is 1008 kWh, the storage volume is 60 m^3. Table 14.3 showed the SHIP plants summary based on solar driven industrial pasteurization operations and their key details.

14.3.4 General Process Heating with SHIP

For the general process heating operations, 56 plants are reported to date according to the SHIP plants database information, while the industries are metal, manufacturing, dairy, food, chemical, agriculture, pharmaceutical, beverage, transport, mining, animal, textile, vegetable, etc. The dominant industrial sector is the food industries where 23 SHIP plants are operating with solar-driven general process heating operations. Countries which are utilizing solar process heat for general process heating Germany, Mexico, Greece, Spain, Ukraine, Chile, Egypt, Switzerland, India, Netherlands, Jordan, and Portugal. The leading countries are Mexico (30 plants), Spain (4 plants), and India (5 plants). These plants are operating with parabolic-trough solar collector technologies or flat-plate solar collector technologies, where most are low-temperature industrial

Table 14.2 Summary of the SHIP-operated industrial drying processes [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
AMR Dal mill	India	Agriculture	Air collector (65~75)	230	161	
Acme McCrary	USA	Textile	FPC	743	520.1	1
Aroma Plant Romania	Romania	Agriculture	Air collector	80	56	1
CIATEQ	Mexico	Professional	FPC (60~90)	80	56	4
Carpentry Hamminger	Austria	Furniture	FPC (~60)	88	61.6	14
Carriers & Sons	USA	Food	Air collector (~43)	300	210	1
Cologne Transit Authority (Kölner VKB)	Germany	Transportation	ETC	237	165.9	25.2
Coopeldos	Costa Rica	Food	Air collector (40~45)	860	602	1
Duran Coffee	Panama	Food	Air collector (40~45)	900	630	1
FengLi Fruit Drying	China	Food	Air collector (50~70)	55.7	38.99	1
Grammer Solar Argentinia	Argentina	Tobacco	Air collector	737	515.9	1
Habau - Concrete Component Production	Austria	Mineral	FPC (16~25)	1500	1050	80
Hofigal S.A.	Romania	Agriculture	Air collector	60	42	1
Inter Rubber Latex Co. Ltd.	Thailand	Rubber	Air collector	80	56	1
Kaveri Agri-Care Pvt. Ltd.	India	Food	Air collector (~105)	414	289.8	1
Keyawa Orchards	USA	Food	Air collector (~43)	864	604.8	1
Kreher's Poultry Farms	USA	Food	Air collector (~43)	50.4	35.28	1
Krimmer	Germany	Agriculture	FPC (~35)	150	105	42

(*continued*)

Table 14.2 (continued)

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Lackiererei Vogel	Germany	Repair	ETC	43	30.1	3
Leitl Beton GmbH	Austria	Mineral	FPC	315	220.5	36
Malabar Tea Drying	Indonesia	Food	Air collector (~35)	600	420	1
Neumarkter Lammsbräu	Germany	Beverage	Air collector (~60)	72.5	50.75	1
PSG Hospital Laundry	India	Human health	PTC (~150)	50	35	
Parc Solaire Alain Lemaire	**Canada**	**Paper**	**PTC (120~140)**	**1490**	**800**	
Pincasa	Spain	Metal	Various ETC (~180)	180	26	
Rockland County	USA	Waste	Air collector	743	520.1	1
Silampos, S. A.	Portugal	Metal	PTC (50~160)	450	67	
Surprise Ship for sewage sludge drying	USA	Waste	PTC (90~100)	151	98	
Sonoma County Herb Exchange	USA	Agriculture	Air collector	10	7	1
Sunsweet Dryers	USA	Food	Air collector	110	77	1
Ultramarine Pigments	India	Chemical	Other (~140)	570	399	
Zacatecas Termosolar Drying Plant – Air Collectors	Mexico	Agriculture	Air collector (55~120)	120	84	
Zacatecas Termosolar Drying Plant – Flate Plate	Mexico	Agriculture	FPC (70~85)	125	87	12

Table 14.3 Summary of the SHIP-operated industrial pasteurization processes [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
B.G. Chitale	India	Dairy	Various	320	224	
Bevco, S. de R.L. de C.V.	Mexico	Beverage	PTC (20~90)	33.43	15.05	2.5
COPAG (rooftop)	Morocco	Dairy	PTC (80~90)	110	61	
Casa Cuervo S. A de C.V.	Mexico	Beverage	PTC (30~90)	577.13	123.55	9.6
Cider house Hostetin	Czech Republic	Beverage	FPC	36	25.2	9
Durango Dairy Company (Productos Lácteos COVBARS)	Mexico	Dairy	PTC (80~90)	265.68	46.2	7
HP Dairy State	India	Dairy	FPC	120	84	6
Indian Institute of Horticulture	India	Manufacturing	Various	42	29.4	
Krispl Fruit Juice	Austria	Manufacturing	FPC (~80)	112	78.4	20
Lácteos Mojica	Mexico	Dairy	PTC (20~95)	132	59.88	4.5
Milma dairy	India	Dairy	FPC	1440	1008	60
Nestle Dairy Plant Chapa De Corzo	Mexico	Dairy	PTC (~90)	460	126	5
Nestle Dairy Plant Lagos De Moreno	Mexico	Dairy	PTC (~90)	1327.59	137	5
Quesera Lacteos Ticoy, S.A. de C.V	Mexico	Dairy	PTC (~90)	250	42	6
Quesos La Doñita	Mexico	Dairy	PTC	66	22.2	1.5
Solar Pasteurization (Lechera Guadalajara Sello Rojo)	**Mexico**	**Dairy**	**PTC (~85)**	**1641.25**	**240**	**50**

processes. The other types of solar collectors are an unglazed collector or air collectors. The highest capacity SHIP plant with general process heating operation is Codelco Gabriela Mistral located in Chile, where the average solar collector area is 39,300 m^2, installed thermal power is 27,510 kWh, and storage volume is 4300 m^3. Table 14.4

Table 14.4 Summary of the SHIP operated general process heating operations [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Alanod Solar	Germany	Metal	PTC (~143)	108	75.6	
Alimentos y Productos para Ganado Lechero	Mexico	Manufacturing	PTC (~60)	1031.25	179.85	24.4
Alpino S.A.	Greece	Dairy	FPC (20~70)	740	518	25
Autolavados Carte S.A.	Spain	Other	FPC (40~70)	138	96.6	12
Barcel	Mexico	Food	FPC (60~70)	172	120	12
BASF Mexico	Mexico	Chemical	FPC (60~70)	30	21	1.5
Bermejillo Chapin	Mexico	Agriculture	FPC (60~75)	200	140	9
Biotecnología Mexicana de Microalgas S.A. de C.V.	Mexico	Pharmaceutical	PTC (55~75)	110	31.67	10
Brewery Radoy	Ukraine	Beverage	FPC	216	151.2	15
COFICAB	Mexico	Transport	FPC (60~90)	25	17.5	2
Codelco Gabriela Mistral	**Chile**	**Mining**	**FPC**	**39,300**	**27,510**	**4300**
El NASR Pharamaceutical	Egypt	Pharmaceutical	PTC	1900	1330	
Emmi Dairy Saignelégier	Switzerland	Dairy	PTC	627	360	15
Frito Lay	USA	Food	PTC	5068	3547.6	1
Futtermittel Fixkraft	Austria	Animal	FPC	324	226.8	6
Gamesa-Quaker Pepsico Mexico	Mexico	Food	FPC (60~70)	64	45	4
Gatorade Mexico	Mexico	Beverage	FPC (60~70)	56	39	3
General Electric Queretaro	Mexico	Manufacturing	FPC (60~90)	24	16.8	2
Glaxo Smithkline Mexico	Mexico	Pharmaceutical	FPC (70~80)	360	252	25
Grupo BIMBO	Mexico	Food	FPC (60~80)	232	162	15
Guetermann Polygal	Mexico	Textile	FPC (55~85)	450	315	20
Gatorade	USA	Beverage	FPC (~35)	4221	2954.7	114
Grammer Solar Vietnam	Vietnam	Textile	Air collector	480	336	1
IER UNAM	Mexico		FPC (70~95)	75	52.5	
ITEC Culiacan	Mexico		FPC (75~110)	60	42	
India Tobacco Division	India	Tobacco	Various	900	220	

(*continued*)

Table 14.4 (continued)

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Industria Alimnetaria Alcoyana	Spain	Food	FPC (40~130)	151	105.7	12
KOF Mixcoac	Mexico	Beverage	FPC (50~70)	125	87.5	10
KOF Tlanepantla	Mexico	Beverage	FPC (50~75)	45	31.5	2.5
Körner KvK	Austria	Metal	FPC (~80)	86	60.2	10
L'oreal Mexico	Mexico	Pharmaceutical	FPC (55~75)	154	107	8
Lavin Industries	Mexico	Pharmaceutical	FPC (60~75)	525	367	20
Liomont Laboratories	Mexico	Pharmaceutical	FPC (60~80)	75	52.5	4
Laguna	Germany		FPC (20~90)	57	39.9	3.3
Lesa Dairy	Switzerland	Dairy	PTC	115	67	0.01
Marinela CDMX	Mexico	Food	FPC (60~70)	164	114	9
Mexlub	Mexico	Chemical	FPC (60~75)	50	35	3
Minera El Rob Peñoles	Mexico	Mining	FPC (60~80)	330	231	15
Matatlan Dairy	Mexico	Dairy	PTC	64	46.2	2.5
Metadero Montesierra	Spain	Food	FPC (50~60)	79	55.3	5
Nestle Chiapas	Mexico	Food	FPC (~90)	650	455	25
Nestle. Toluca	Mexico	Food	Unglazed (~37)	3700	2590	500
Peñoles Totolapan I	Mexico	Mining	FPC (60~70)	60	42	3
Peñoles Totolapan II	Mexico	Mining	FPC (65~75)	160	112	8
Peñoles Totolapan III	Mexico	Mining	FPC (65~85)	45	31.5	3
Panchmahal Dairy	India	Dairy	FPC	472	330.4	20
Perfetti van Melle	Netherlands	Dairy	FPC	2400	1680	95
RAM Pharma	Jordan	Pharmaceutical	Fresnel (160~165)	550	222	2
SANA Internacional	Mexico	Food	FPC (55~75)	240	168	7.5
Salem District Cooperative Milk Producers Union	India	Dairy	Various (~95)	338	236.6	
Simoa S.A.	Portugal	Food	FPC (~30)	670	469	
Stapleton-Spence Fruit Packing Co.	USA	Vegetable	Unglazed	2637	1845.9	50
Synthokem Labs	India	Pharmaceutical	ETC	288	201.6	10
TE-PE S.A.	Spain	Food	FPC (40~130)	260	182	20

(*continued*)

Table 14.4 (continued)

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Tapi Foods	India	Vegetable	Various	93	65.1	
Unison	Mexico	Education	Various (50~70)	254	177.8	

showed the SHIP plants summary based on solar driven industrial pasteurization operations and their key details.

14.3.5 Cooking with SHIP

For the solar cooking operations, 13 plants are reported to date according to the SHIP plants database information, while the industries are food, meat, manufacturing, and vegetables. The dominant industrial sector is the food industries where 7 SHIP plants are operating with solar-driven cooking operations. Countries which are utilizing solar process heat for industrial cooking are Mexico, India, Austria, and Spain. The leading country is Mexico (10 plants). These plants are operating with parabolic-trough solar collector technologies or flat-plate solar collector technologies, where most are low-temperature industrial processes. The other types of solar collectors are a combination of different type of solar collectors. The highest capacity SHIP plant for solar cooking operation is Procesadora de Alimentos Integrales-Paisa located in Mexico, where the average solar collector area is 577.13 m^2, installed thermal power is 116.12 kWh, and storage volume is 3 m^3. Table 14.5 showed the SHIP plants summary based on solar driven cooking operations and their key details.

14.3.6 Cooling Processes with SHIP

F0or the solar cooling operations, 12 plants are reported to date according to the SHIP plants database information, while the industries are food, construction, beverage, manufacturing, and so on. The dominant industrial sector is the manufacturing industries where three SHIP plants are operating with solar-driven cooling operations. Countries which are utilizing solar are United Arab Emerits (UAE), South Africa, Germany, Tunisia, and Spain. The leading country is UAE (2 plants) and Germany (2 plants). These plants are operating with Fresnel collector technologies, where most are low-temperature industrial processes. The other types of solar collectors are a parabolic-trough collector, flat-plate collector, or a combination of different type of solar collectors. The highest

Table 14.5 Summary of the SHIP operated solar cooking operations [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Agriculture University Tamil Nadu	India	Food	Various	250	175	
Barcel S.A DE C.V.	Mexico	Food	PTC (35~164)	529.2	77.9	0.15
Conservas del Norte S.A de C.V.	Mexico	Food	PTC (25~95)	660	104.81	9
Fleischwaren Berger	Austria	Meat	FPC (30~95)	1067	746.9	60
Grupo Mirasol de Occidente SA de CV	Mexico	Meat	PTC (21~95)	396	64.83	5
Grupo Mosa la Luz SA de CV	Mexico	Food	PTC (55~110)	693	92.61	9.6
IMATEC Tortilla Dough Factory	Mexico	Manufacturing	FPC (65~85)	125	87.5	5
INDUSTRIA MAIZ	Mexico	Food	FPC (65~80)	72	50.4	3.5
INDUSTRIAS CRICOTL	Mexico	Food	FPC (55~85)	72	50	3
Nutrición Marina	Mexico	Manufacturing	PTC	310	97.2	7.5
Papes Safor S.L.	Spain	Vegetable	PTC (200~250)	175	134	
Procesadora de Alimentos Integrales – PAISA	**Mexico**	**Manufacturing**	**PTC (~95)**	**577.13**	**116.02**	**3**
San Pablo Villa Tortilla Dough Factory	Mexico	Food	FPC (70~85)	70	49	5

capacity SHIP plant for solar cooling operation is the Fédération Internationale de Football Association (FIFA, Soccer) World Cup Solar Cooled Demonstration Stadium located in Qatar, where the average solar collector area is 2000 m^2, installed thermal power is 790 kWh, and storage volume is 40 m^3. Table 14.6 showed the SHIP plants summary based on solar driven cooling operations and their key details.

Table 14.6 Summary of the SHIP operated solar cooling operations [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Bergamo	Italy	Manufacturing	Fresnel	183	74	
Canels S.A. de C.V.	Mexico	Food	PTC (25~80)	577.13	118	2
FIFA world cup solar cooled demonstration stadium	**Qatar**	**Construction**	**Fresnel (7~15)**	**2000**	**790**	**40**
GICB Wine Cellars	France	Beverage	ETC (70~90)	216.2	151	1
Gerhard Rauch Ges.mbH	Austria	Metal Manufacturing	FPC	264	184.8	12
Masdar City Solar Field	UAE	Other	Other (180~165)	44	21	16
Masdar Demonstration Project	UAE	Other	Fresnel	185	74	
Solar cooling for the data center	South Africa	Information	Fresnel (6~32)	678	272	42
Solar cooling for stainless steel pipe industry	Germany	Metal Manufacturing	Fresnel (7~12)	678	272	
Solar refrigeration in the food industry	Germany		Fresnel (−5~ − 10)	123	49	
University of Sevilla	Spain	Education	Fresnel (7~15)	493	198	
Winery Grombalia	Tunisia	Beverage	Fresnel (−10~7)	132	49.5	1

14.3.7 Surface Treatment with SHIP

For the solar driven surface treatment operations, 11 plants are reported to date according to the SHIP plants database information, while the industries are a computer, vehicle, machinery, metal, and manufacturing. The dominant industrial sector is the metal-based industries where five SHIP plants are operating with solar-driven surface treatment operations. Countries which are utilizing solar process heat for industrial cooling are Sweden, Spain, Austria, Germany, Mexico, India, and Switzerland. The leading country is Mexico (2 plants), Spain (2 plants), and India (2 plants). These plants are operating with flat-plate collector technologies, where most are low-temperature industrial processes. The other types of solar collectors are

Table 14.7 Summary of the SHIP operated solar driven surface treatment operations [27]

Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Bomans Lackering	Sweden	Computer	PTC (~160)	100	40	
FASA Valladolid	Spain	Vehicle	FPC (~50)	243.6	170.52	15
Hoval Marchtrenk	Austria	Machinery	FPC	202	141.4	6
Hustert Galvanic	Germany	Metal	ETC (~80)	221	154.7	
Industrias MOSO	Mexico	Manufacturing	FPC (60~80)	110	77	5
Industrias Verona Galvanoplasty	Mexico	Metal	FPC (70~85)	64	44	3.5
Julius Blum	Austria	Metal	ETC (85~60)	460	322	8
Kangaroo India Limited	India	Metal	FPC	506	354.2	65
Nissan Avila	**Spain**	**Vehicle**	**FPC**	**530**	**370**	**40**
SKF Technologies Mysore	India	Metal	PTC	400	72	95
Zehnder Group AG	Switzerland	Machinery	ETC	395.2	276.64	

a parabolic-trough collector or evacuated-tube solar collectors. The highest capacity SHIP plant for solar driven surface treatment operation is Nissan Avila located in Spain, where the average solar collector area is 530 m^2, installed thermal power is 370 kWh, and storage volume is 40 m^3. Table 14.7 showed the SHIP plants summary based on solar operated surface treatment processes and their key details.

14.3.8 Other Processes with SHIP

The other type of industrial processes which have few plants already in operation is evaporation, blanching, sterilization, heating, and cooling of production hall, melting, extraction, bleaching, painting, and retaining. In the case of the solar-operated evaporation process, the industries are a beverage, water supply, and chemical industries which are in Mexico, the United States, and China. For the evaporation process, heat is supplied through parabolic-trough solar collector technologies. The highest capacity SHIP plant integrated with evaporation process is the Solar steam boiler for Procter & Gamble (Tianjin) located in China with the installed collector area 4600 m^2 and installed thermal power is

1050 kWh. For the blanching process, the only SHIP plant is operating at Malaysia named Poultry Processing Malaysia PPNJ which is a meat factory with installed collector area 181.35 $m^{2,}$ installed thermal power is 163.2 kWh, and storage volume is 8 m^3. Solar process heat is used for the sterilization process in two plants located in Switzerland and China for food and dairy industries built on the parabolic-trough collector and evacuated-tube collector. The largest one is Cremo SA in Switzerland with installed collector area 581 $m^{2,}$ installed thermal power is 330 kWh. Among the three operating SHIP plants for heating of production hall, the largest one is Lhasa vegetable greenhouse located in China with installed collector area 2150 m^2 and installed thermal power 440 kWh. For the cooling of production hall, two SHIP plants are in operation from which the larger one is Sarantis S.A. located in Greece with installed collector area 2700 m^2, installed thermal power 1890 kWh, and storage volume is 66 m^3. For the solar melting operation, the only SHIP plant is in Switzerland named Colar Yverdon-Les-Bains, with installed collector area 197 m^2, installed thermal power 96 kWh, and storage volume is 90 m^3. For the extraction process, there are five SHIP plants in metal, food, and mining industries of which Hellenic copper mine in Cyprus is the highest capacity SHIP plant using solar driven extraction process. The installed collector area is 760 m^2, installed thermal power 532 kWh, and storage volume is 100 m^3. In case of the bleaching operation, there are five operating SHIP plants in apparel and textile industries located in India, P.R. China, Greece, and Vietnam of which the largest one is on China named Daly textile with installed collector area 13,000 m^2, installed thermal power 9000 kWh, and storage volume is 900 m^3.

Similarly, five SHIP plants are operating with solar driven painting operation of chemical, vehicle, textile, and machinery industries located in South Africa, Spain, Germany, and India. The largest one is Wheels India with installed collector area 1365 m^2 and installed thermal power 955.5 kWh. For the retaining operation, eight SHIP plants are operating in the leather industries of Thailand, Austria, P.R. China, India, Kenya, Vietnam, and Greece. The largest one is Atutthaya tannery located in Thailand with installed collector area 1890 m^2, installed thermal power 1323 kWh, and storage volume 80 m^3. Table 14.8 showed the SHIP plants summary based on different types of solar-operating processes and their key details.

14.4 SHIP Plants in the World

According to the SHIP plants database, there are 12 countries which have many successfully installed and operated solar-driven industrial process heating plants for different types of industrial operations. So far, 303 SHIP plants have been reported throughout the world. The country-wise scenario for the highest number of installed SHIP plant statistics is presented below to identify the leading countries in this field. Table 14.9 describes the country-based statistics for installed and operating SHIP plants information. According to the results presented in Table 14.9.

Table 14.8 Summary of the SHIP operated different types of processes [27]

Operation	Plant name	Country	Industry	Collector technology (temperature range)	Installed collector area (gross), m^2	Installed thermal power (actual), kWth	Storage volume, m^3
Evaporation	Casa Armando Guillermo Prieto S.A de C.V.	Mexico	Beverage	PTC (21~90)	816.75	136.79	9.9
	Destilería 501 S.A de C.V	Mexico	Beverage	PTC (19~99)	610	94.6	8
	Panoche County Desalination	USA	Water supply	PTC	690	480	
	Solar steam boiler for Procter & Gamble (Tianjin)	**China**	**Chemical**	**PTC (~130)**	**4600**	**1050**	
Blanching	**Poultry Processing Malaysia PPNJ**	**Malaysia**	**Meat**	**ETC (70~75)**	**181.35**	**163.2**	**8**
Sterilization	Cremo SA	Switzerland	Dairy	PTC (~150)	581	330	
	Meihao Food Processing	**China**	**Food**	**ETC (~80)**	**395**	**276.5**	
Heating of production hall	Buenavista Greenhouse	Mexico	Agriculture	PTC	112	36	2.5
	Lhasa vegetable greenhouse	**China**	**Food**	**ETC**	**2150**	**400**	
	Telekom Rottweil	Germany	Information	ETC	503	352.1	20
Cooling of the production hall	Honeywell Technology Solutions	India	Manufacturing	PTC	821	574.7	
	Sarantis S.A.	**Greece**	**Pharmaceutical**	**FPC (7~45)**	**2700**	**1890**	**66**
Melting	**Colas Yverdon-les-Bains**	**Switzerland**	**Construction**	**Various (50~90)**	**197**	**96**	**90**

Extraction	Gillich Galavanic	Austria	Metal	ETC	9	6.3	1.5
	Hellenic Copper Mines	**Cyprus**	**Mining**	**FPC (20~50)**	**760**	**532**	**100**
	Kwality Walls Ice Cream	India	Food	FPC	120	84	11
	Minera Constanza	Chile	Mining	FPC	440	308	
Bleaching	Chelsea Jeans	India	Apparel	FPC	943	660.1	60
	Daly Textile	**China**	**Textile**	**FPC (20~60)**	**13,000**	**9000**	**900**
	Kastrinogiannis S.A.	Greece	Textile	FPC (40~90)	174	121.1	10
	Saitex Jeans	Vietnam	Apparel	ETC	705	493.5	20
	Sharman Shawls	India	Textile	FPC (100~)	360	252	8
Painting	BMW Manufacturing	South Africa	Vehicle	ETC (~90)	200	140	24.2
	Harlequin	Spain	Textile	FPC	47.15	33	5
	Penzkofer Autolackiererei	Germany	Chemical	Air collector	20.1	14.07	1
	Solar Process Heat for Car Paintshop	Germany	Vehicle	Fresnel (~220)	185	66	
	Wheels India	**India**	**Machinery**	**ETC (~75)**	**1365**	**955.5**	
Retanning	**Ayutthaya tannery**	**Thailand**	**Leather**	**ETC (~80)**	**1890**	**1323**	**80**
	Gerberei Kölblinger	Austria	Leather	FPC	77	53.9	40
	Heshan Bestway Leather	China	Leather	ETC (~70)	630	441	60
	Leo Leather	India	Leather	FPC	300	210	15
	Nairobi tannery	Kenya	Leather	ETC	580	406	
	Sadesa Leather	Thailand	Leather	ETC (~80)	540	378	35
	Saigon Tantec	Vietnam	Leather	ETC (~70)	1000	700	70
	Tripou – Katsouris Leather Treatment Factory	Greece	Leather	FPC (48~84)	300	210	15

Table 14.9 Country-based analysis of SHIP plants [27]

Country name	Number of SHIP plants	Industrial sectors using SHIP
Mexico	**80**	Agriculture, mining, food, tobacco, textile, wearing apparel, leather, paper, chemical, metals, electrical equipment, transport equipment
India	46	Agriculture, food, tobacco, textile, wearing apparel, leather, paper, chemical, metals, electrical equipment, transport equipment
Austria	27	Food, beverages, leather, chemicals, metals, furniture
Germany	26	Agriculture, food, beverages, textiles, chemicals, metals
United States	19	Agriculture, food, beverages, textiles,
Spain	16	Agriculture, food, textiles, wood, metals, motor vehicle
China	12	Agriculture, food, beverages, textiles, chemicals, leather
South Africa	10	Mining, food, beverages, machinery, motor vehicles
Greece	10	Food, beverages, textiles, Pharmaceuticals, leather
Switzerland	6	Construction, dairy, machinery
France	4	Food and beverages, metals
Israel	4	Food, accommodation, and others

According to the analysis results presented in Tables 14.1, 14.2, 14.3, 14.4, 14.5, 14.6, 14.7, and 14.8, SHIP plants vary among them based on process temperature requirements, installed gross area, number of systems, installed capacity, and size categories. Fig. 14.1 describes the brief relationship among these parameters in terms of installed SHIP plants by March 2018 [28]. According to the results presented here, SHIP plants with gross solar collector size above 30,000 m^2 is 125 MWth valued 250,000 m^2 while for SHIP plants of solar collector size from 1000 to 30,000 m^2 is 54 MWth valued 100,000 m^2. Hence, SHIP plants with gross solar collector size from 500 to 1000 m^2 are 16 MWth valued around 250,000 m^2. SHIP plants with gross solar collector size above from 100 to 500 m^2 is 17 MWth valued 50,000 m^2. SHIP plants with gross solar collector size below 100 m^2 are 2 MWth valued below 50,000 m^2. The installed capacity is largest for the first category of collectors with gross size above 30,000 m^2.

Figure 14.2 describes the installed collector area, number of systems, and installed capacity of the SHIP plants based on the type of solar collectors or their combinations. The chart represents seven types of solar collectors: flat-plate collector, parabolic-trough collector, evacuated-tube collector, other or various collector, air collector, unglazed collector, and Fresnel collector. According to the SHIP plants database information and International Energy Agency (IEA) Solar heating & Cooling Programme (SHC) Task 49, there are around 124 plants with the flat-plate collector of installed collector area around 100,000 m^2, and installed capacity 71 MWth. Forty-nine SHIP plants with parabolic-trough collector with installed collector area around 250,000 m^2 and installed capacity 111 MWth. Forty-six SHIP plants are operating with evacuated-tube collector with installed collector

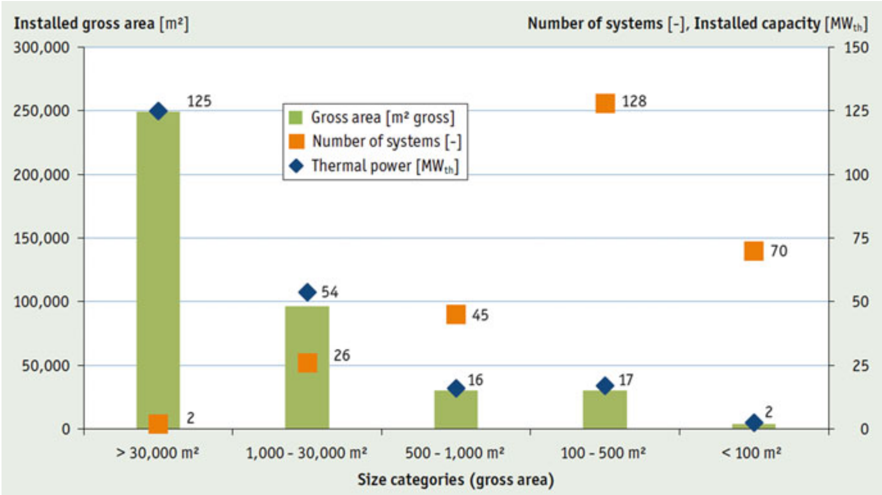

Fig. 14.1 Global SHIP plants in operation based on capacity and collector area [28]

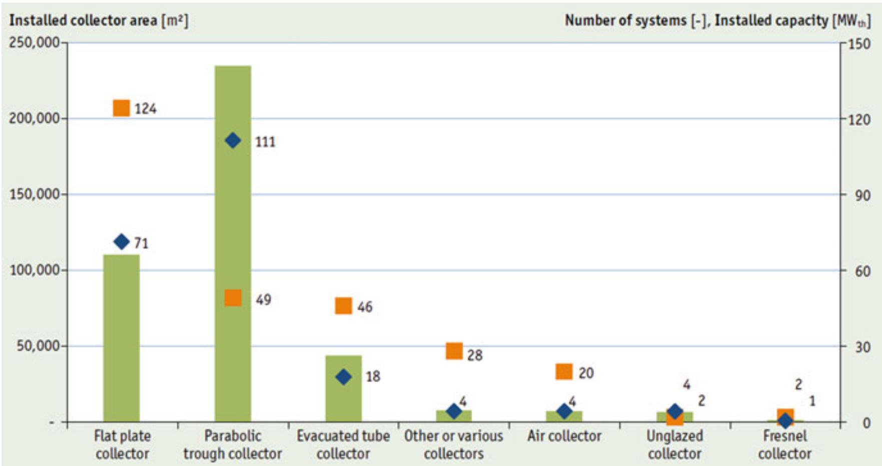

Fig. 14.2 Global SHIP plants in operation based on collector type [28]

area around 50,000 m^2 and installed capacity 18 MW^{th}. Twenty-eight SHIP plants have a combination of different type collectors while installing collector area is around 10,000 m^2 with installed capacity 4 MW^{th}. Similarly, 20 SHIP plants have air collectors with installed collector area around 10,000 m^2 and installed capacity 4 MW^{th}. For the unglazed and Fresnel collectors, these statistics are very low.

Figure 14.3 describes the SHIP plants design specifications based on their respective industrial sector. The diagram is subdivided into ten segments based

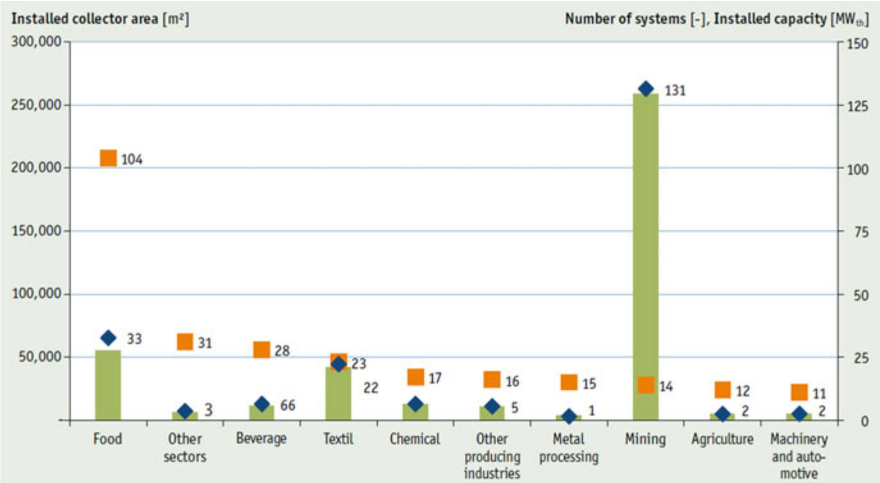

Fig. 14.3 Global SHIP plants in operation based on industrial area [28]

on the industrial sector: food, other sectors, beverage, textile, chemical, other producing industries, metal processing, mining, agriculture, machinery, and automotive. The food industry has 104 systems with installed collector area above 50,000 m^2 and installed capacity 33 MW^{th}. The other sectors have 31 systems with installed collector area above 10,000 m^2 and installed capacity 3 MW^{th}. The beverage industry has 28 systems with installed collector area above 20,000 m^2 and installed capacity 66 MW^{th}. The textile industry has 23 systems with installed collector area above 40,000 m^2 and installed capacity 22 MW^{th}. The chemical sector has 17 systems with installed collector area above 20,000 m^2. The other producing sectors have 16 systems with installed collector area above 15,000 m^2 and installed capacity 5 MW^{th}. The metal processing sectors have 15 systems with installed collector area above 5000 m^2 and installed capacity 1 MW^{th}. The mining sectors have 14 systems with installed collector area around 250,000 m^2 and installed capacity 131 MW^{th}. The agriculture industry has 12 systems with installed collector area around 5000 m^2 and installed capacity 2 MW^{th}. Similarly, the machinery and automotive industry have installed capacity 2 MW^{th}. and installed collector area 5000 m^2 while the number of the system is 11.

Figure 14.4 describes the installed gross collector area, number of systems, and installed capacity of the SHIP plants installed in the world based on their country-specific locations. The chart represents 17 countries which use solar process heat for industrial use. According to the results presented here, the leading SHIP operated countries are Mexico, India, Austria, Germany, the USA, Spain, China, Greece, South Africa, and Chile. Only the SHIP plants with the gross area above 1000 m^2 and installed capacity above 0.7 is considered here for analysis.

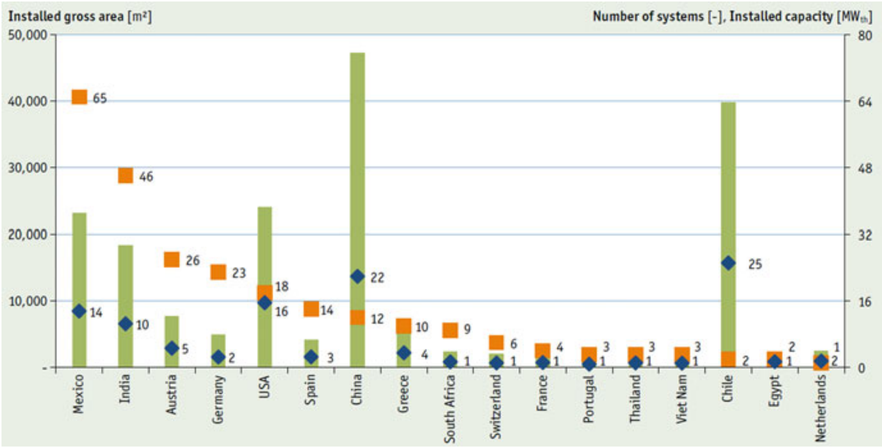

Fig. 14.4 Global SHIP plants in operation based on the country [28]

In Mexico, the number of SHIP plants is 65, installed area around 23,000 m^2, and installed capacity 14 MW^{th}. In the case of India, the number of SHIP plants is 46, installed area around 19,000 m^2, and installed capacity 10 MW^{th}. In Austria, the number of SHIP plants is 26, installed area around 8000 m^2, and installed capacity 5 MW^{th}. In Germany, the number of SHIP plants is 23, installed area around 5000 m^2, and installed capacity 2 MW^{th}. In the USA, the number of SHIP plants is 18, installed area around 25,000 m^2, and installed capacity 16 MW^{th}. In Spain, the number of SHIP plants is 14, installed area around 5000 m^2, and installed capacity 3 MW^{th}.

In China, the number of SHIP plants is 22, installed area around 48,000 m^2, and installed capacity 12 MW^{th}. In Greece, the number of SHIP plants is 10, installed area around 8000 m^2, and installed capacity 4 MW^{th}. In South Africa, the number of SHIP plants is 9, installed area around 3000 m^2, and installed capacity 1 MW^{th}. In Chile, the number of SHIP plants is 25, installed area around 40,000 m^2, and installed capacity 2 MW^{th}.

Table 14.10 describes the solar collector-related information and a carbon dioxide (CO_2) reduction of the leading countries with operating SHIP plants in the current world in their order of installed SHIP plants in operation. The parameters presented here are total collector area in m^2, total capacity in MW^{th}, collector yield in GWh/a, and CO_2 reduction in t_{CO2e}/a. According to the statistics presented here, China has the largest installed solar collector area of 413,600,000 m^2, total capacity 289,520 MW_{th}, collector yield 231,838 GWh/a, and CO_2 reduction 80,435,787 tones of carbon dioxide equilivalence per annum [t_{CO2e}/a]. The second position goes to United States with installed solar collector area of 24,279,331 m^2, total capacity 16,996 $MW^{th.}$, collector yield 10,925 GWh/a, and CO_2 reduction 3,790,555 t_{CO2e}/a. Next comes Germany with installed solar collector area of 18,256,700 m^2, total

Table 14.10 SHIP plant design parameters in the leading countries

Country name	Total collector area [m^2] [28]	Total capacity [MW_{th}] [28]	Collector yield [GWh/a] [28]	CO_2 reduction [t_{CO2e}/a] [28]
Mexico	2,817,077	1972	1612	559,127
India	7,451,900	5216	6435	2,232,502
Austria	5,161,798	3613	2087	724,070
Germany	18,256,700	12,780	7434	2,579,104
United States	24,279,331	16,996	10,925	3,790,555
Spain	3,450,433	2415	2409	835,901
China	413,600,000	289,520	231,838	80,435,787
South Africa	1,650,050	1155	1178	408,709
Greece	4,286,300	3000	2986	1,035,865
Switzerland	1,484,640	1039	586	203,423

capacity 12,780 $MW^{th.}$, collector yield 7434 GWh/a, and CO_2 reduction 2,579,104 t_{CO2e}/a. At next consequentially comes India, Austria, Greece, Spain, Mexico, South Africa, and Switzerland. Though, according to these statistics, the position of Mexico is far lags China, United States, India, and Germany, Mexico is the leading country in the world with the largest number of installed SHIP plants in operation

14.5 Conclusion

This book chapter studies the present condition of the installed SHIP plants based on their industrial processes under consideration, country-based location, and solar collector specifications. This chapter also studied the present condition of solar collector installation in the leading SHIP-operated countries and their CO_2 reduction scenario. Furthermore, this chapter presented the industrial sectors with the potentiality of SHIP integration in the leading countries. Further research should be carried out in those countries where SHIP integration in the industrial processes has not been started yet. In addition, identification of the low-temperature processes is required to extend the scope of SHIP integration in the world.

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Acronyms

FPC	Flat-plate collector
PTC	Parabolic-trough collector
ETC	Evacuated-tube collector
SHIP	Solar heat for industrial processes

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