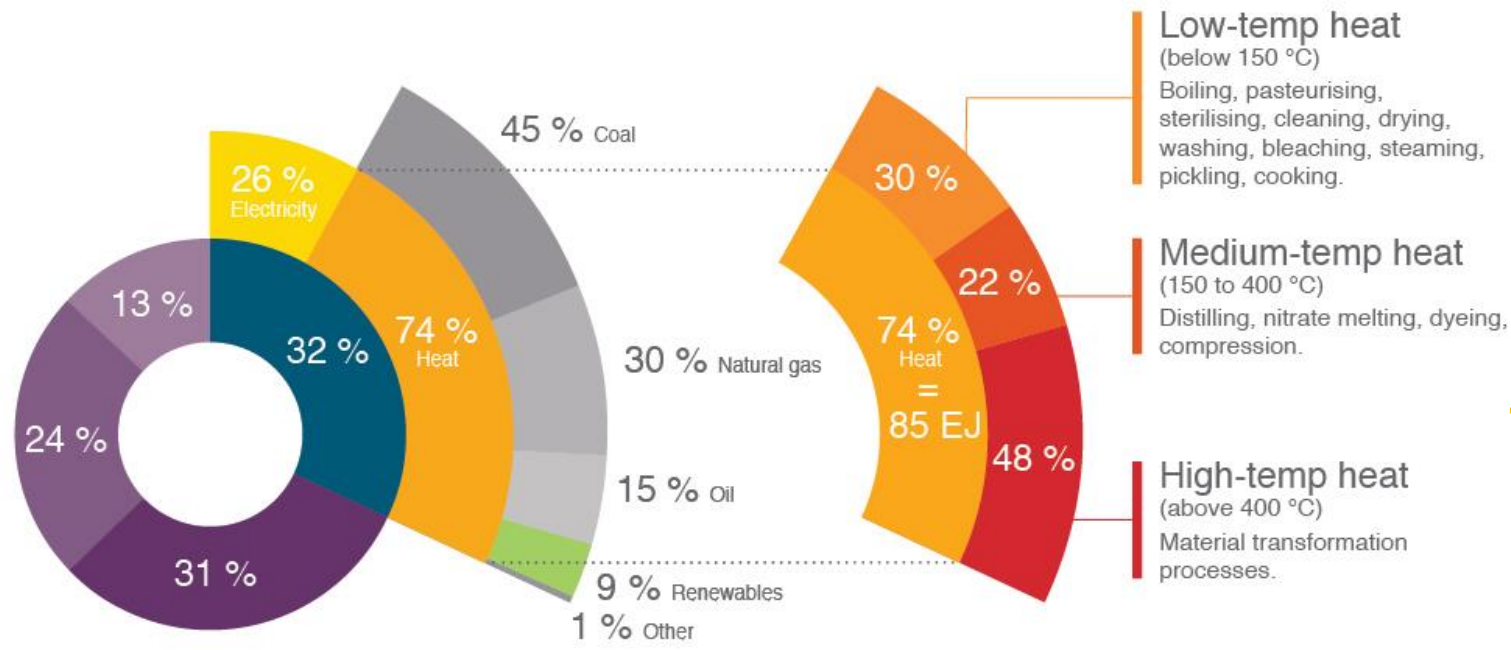




Solar-based decarbonization strategies for industry: market development, innovations and successful business models

**Author: Bärbel Epp, solrico,
www.solrico.com, www.solarthermalworld.org**

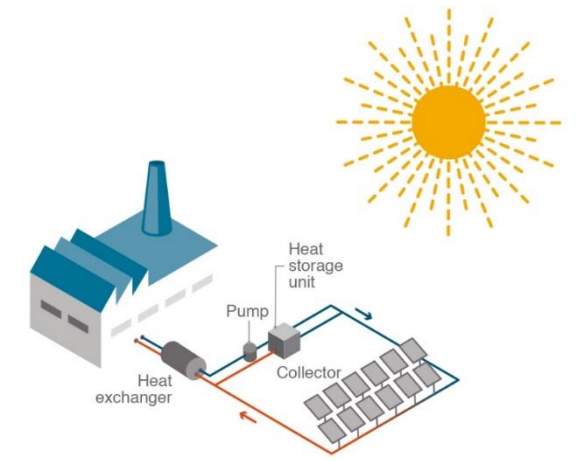
ENORMOUS GLOBAL HEAT DEMAND IN INDUSTRY



■ Industry ■ Transport ■ Residential ■ Other

TOTAL FINAL ENERGY CONSUMPTION 2014: 360 EJ (EXAJOULE); IEA

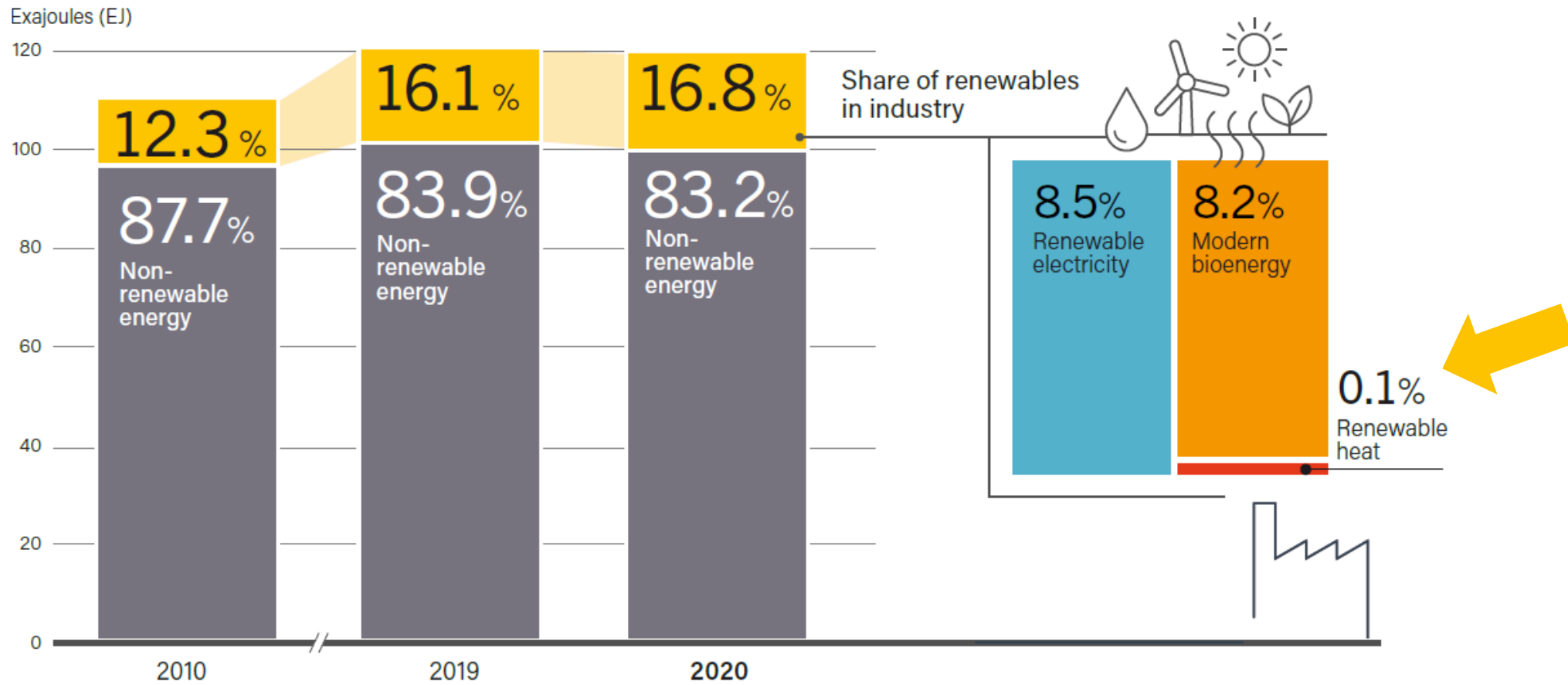
- Low-temp heat** (below 150 °C)
Boiling, pasteurising, sterilising, cleaning, drying, washing, bleaching, steaming, pickling, cooking.
- Medium-temp heat** (150 to 400 °C)
Distilling, nitrate melting, dyeing, compression.
- High-temp heat** (above 400 °C)
Material transformation processes.



IRENA

Source: Solar Payback / IRENA 2017

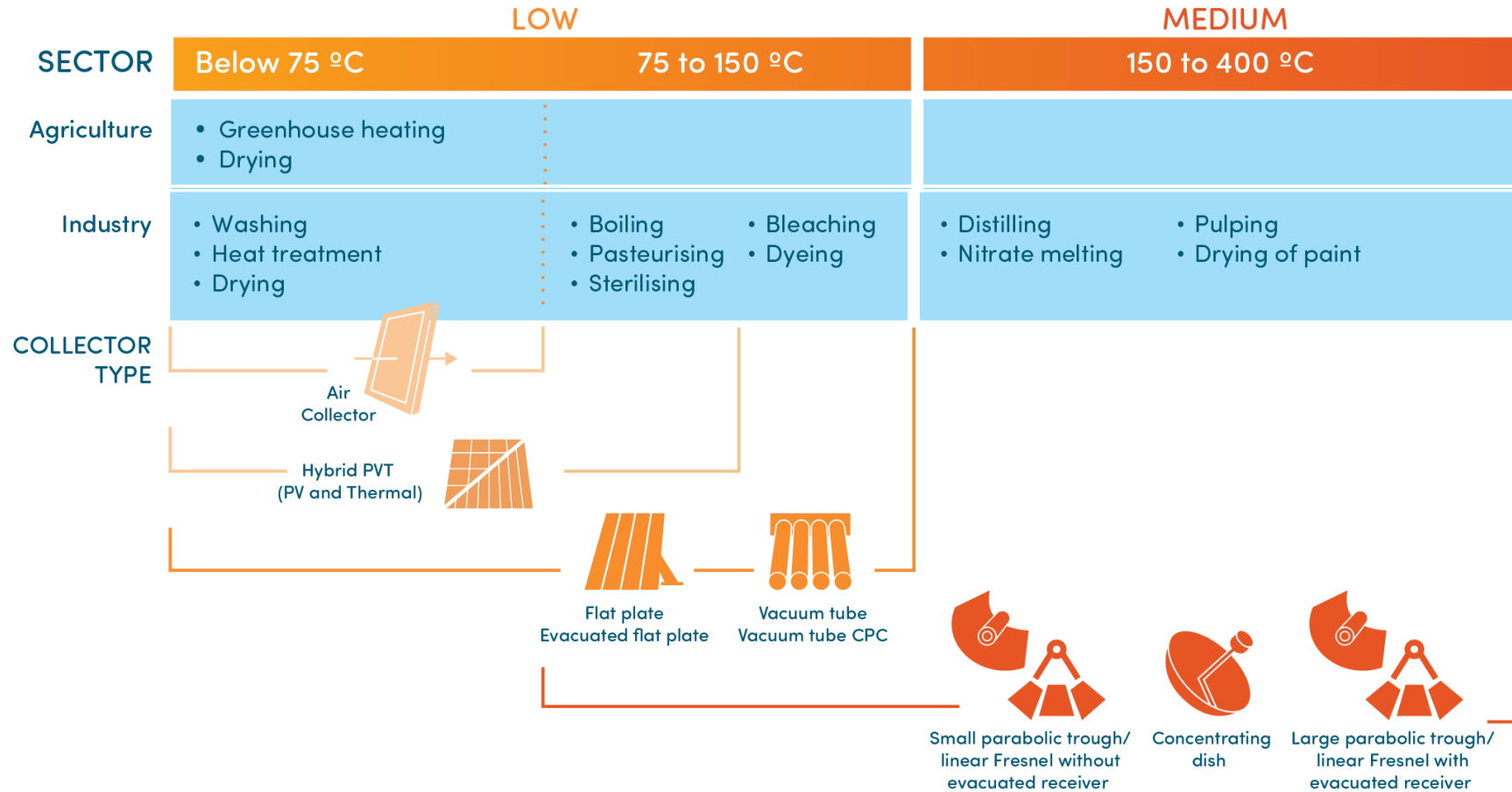
FIGURE 7.
Renewable Share of Total Final Energy Consumption in Industry, 2010, 2019 and 2020



Source: REN21, GSR 2023, Energy Demand

Note: Modern bioenergy includes heat supplied by district energy networks.

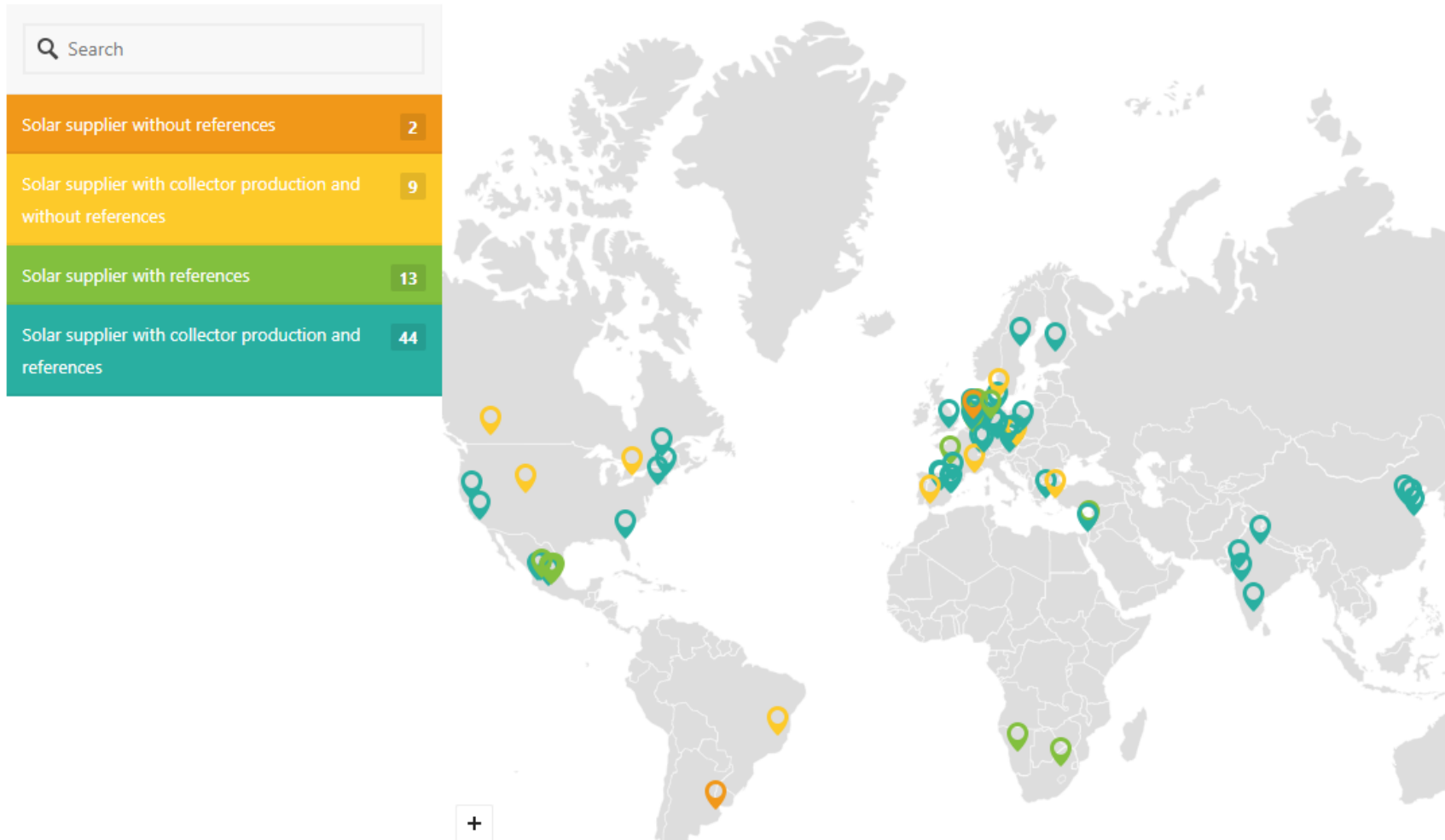
Suitable collector technologies for different temperature levels?



Source: Solar Payback / Solar Heat Europe

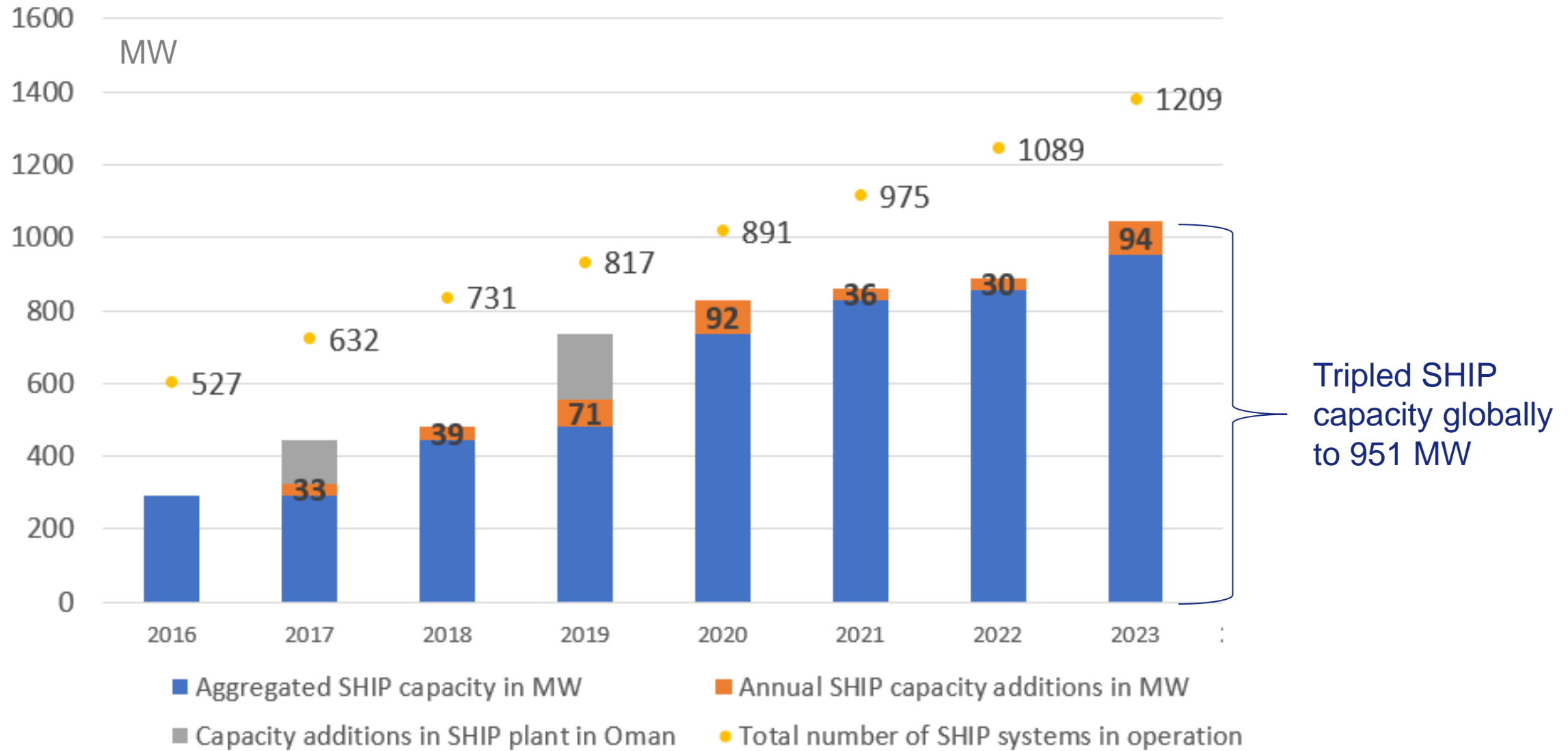
Global SHIP market development 2017-2023

Suppliers of Turnkey Solar Process Heat Systems



SHIP supplier worldmap: <https://www.solar-payback.com/suppliers/>

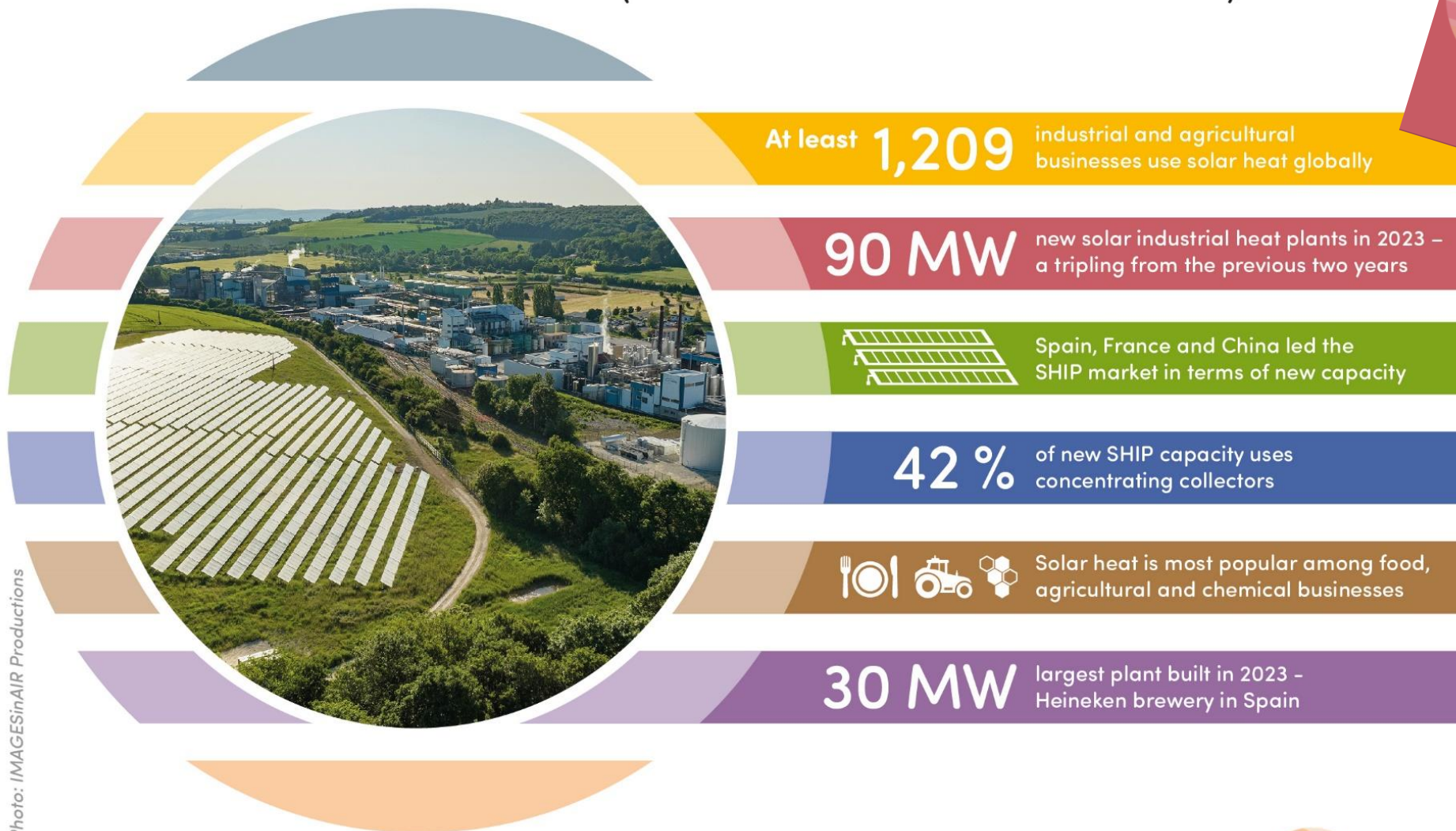
Solar industrial heat market development 2016 to 2023



Source: Annual surveys among SHIP Supplier listed on <https://www.solar-payback.com/suppliers/>

Highlights of SHIP market 2023

(SHIP = Solar Heat for Industrial Processes)

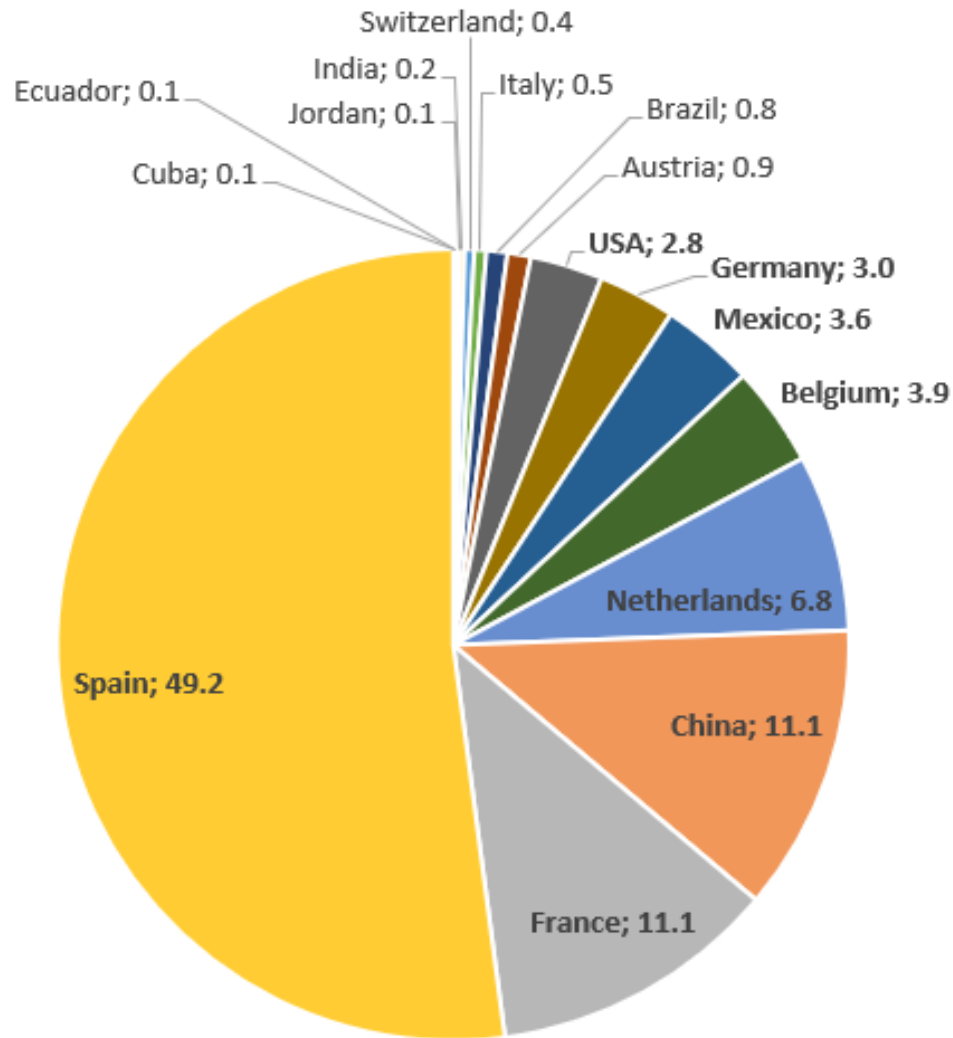


<https://www.iea-shc.org/solar-heat-worldwide>

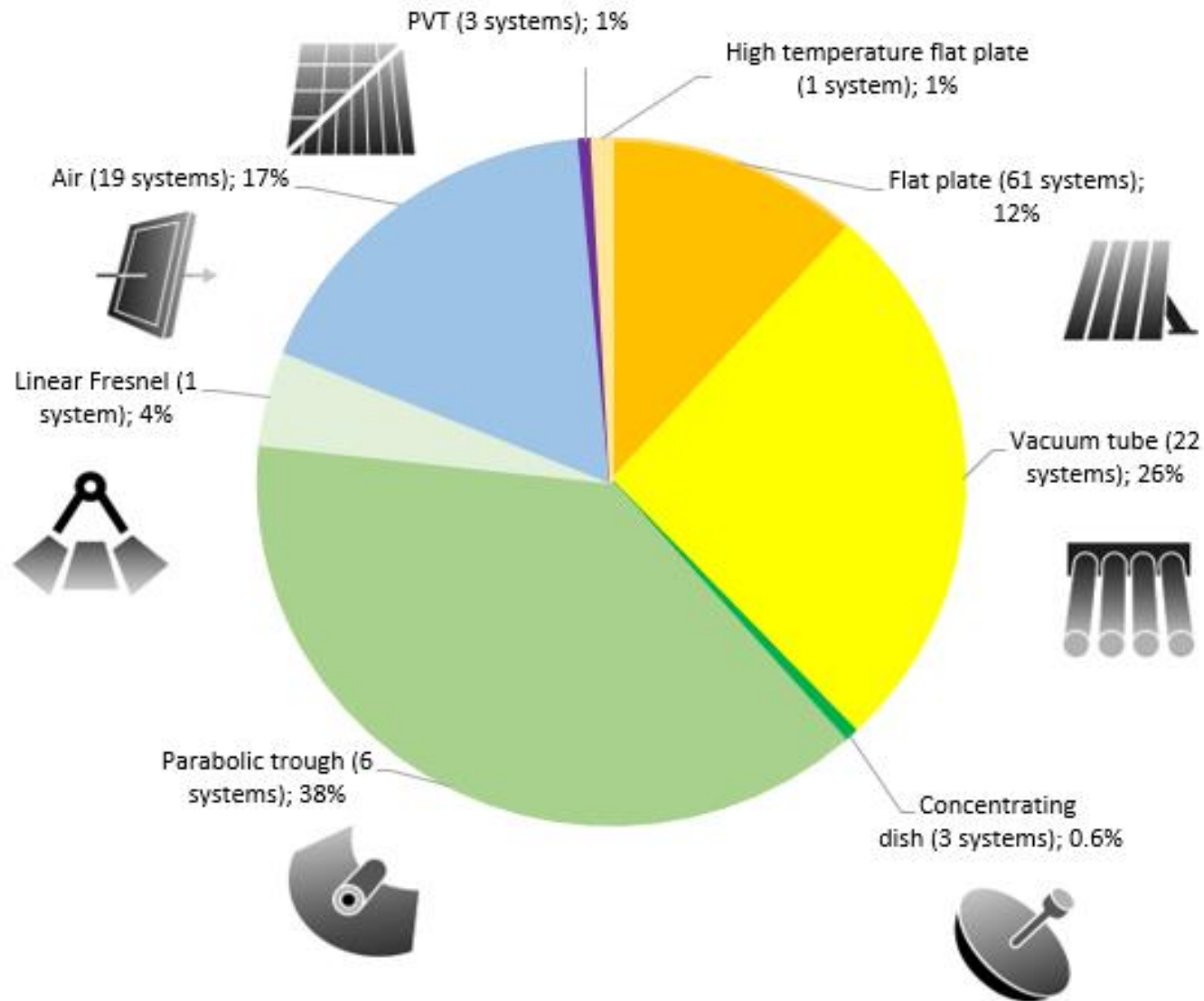
Photo: IMAGESinAIR Productions



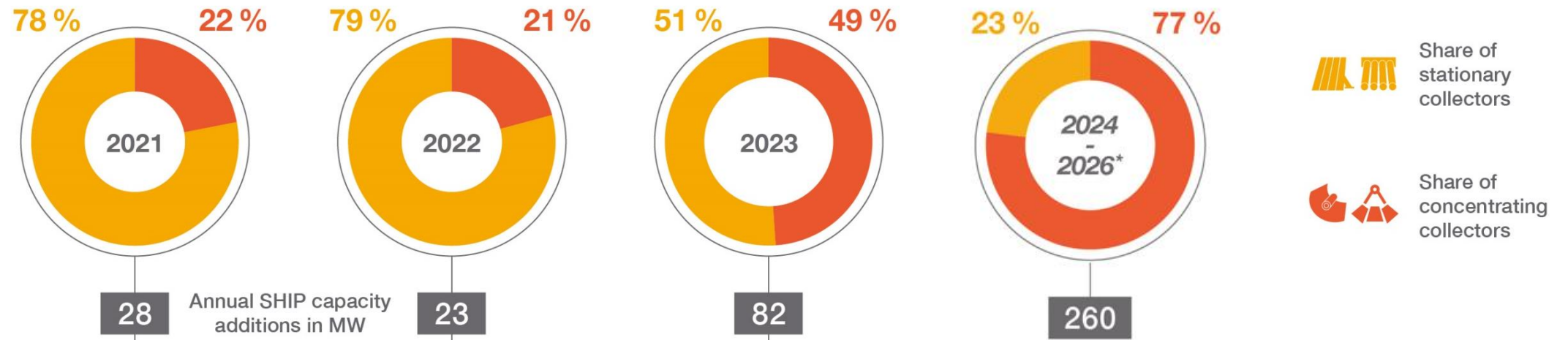
SHIP capacity additions in 2023 in MW per country [Total: 94 MW]



Spain profited from a EUR 108 million EU funding in 2021 called *Thermal Energy Production* which approved 51 solar heat projects totalling 62 MW



First megatrend: concentrating collectors are on the rise



Source: solrico, July 2024

Annual industry surveys
between 2016 and 2024
without projects in China



Photo: XuCheng Energy

Client:	Tourism resort Water World
Site:	Handan, China
Project developer:	Inner Mongolia XuCheng Energy, China
Collector type:	parabolic trough collectors
Collector field:	114,000 m ² / 80 MW
Solar heat temp.:	up to 180 °C
Commissioning:	June 2024
Application:	Ice and snowmaking and space/pool heating
Business model:	turnkey delivery contract

1.5 GW SHIP system in Oman in the planning phase



Client:	Ma'aden Group, Saudi Arabia
Project developer:	GlassPointm USA
Collector type:	GlassPoint Enclosed Trough
Collector field:	1.5 GW _{th}
Application:	Steam production for aluminum refinery
First Steam:	2026
Business model:	Heat delivery contract

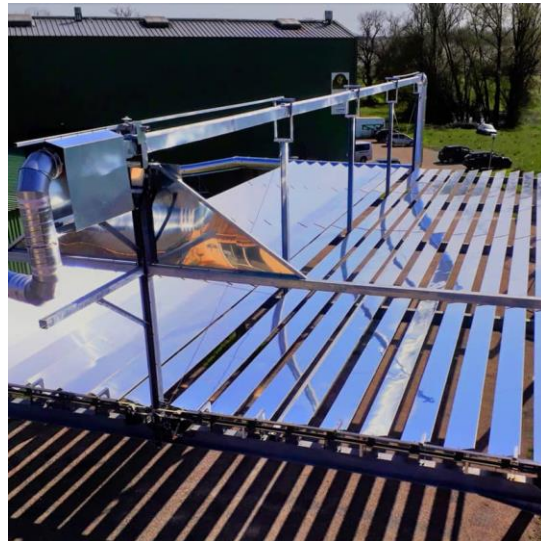
Photo: Glasspoint



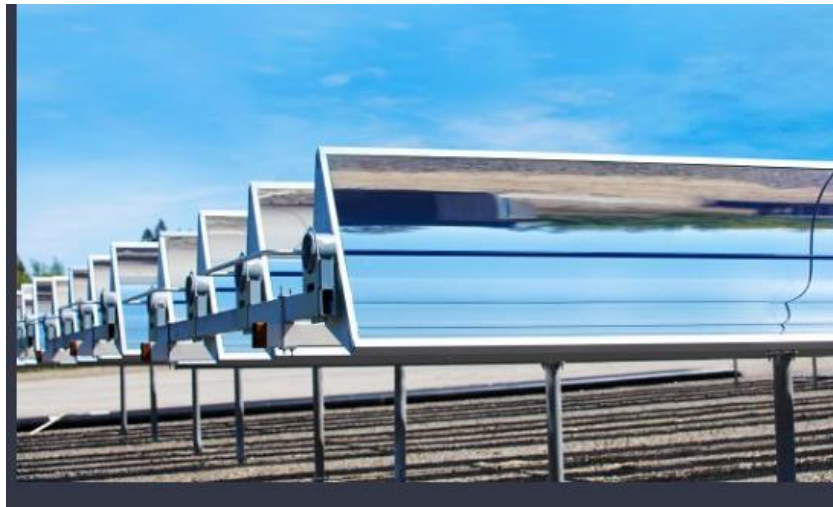
Solarsteam, Canada



Heliovis, Austria



Idhelio, France



Phoenix Solar Thermal, Canada (production line from Absolicon, Sweden)

New providers of concentrating collector technologies

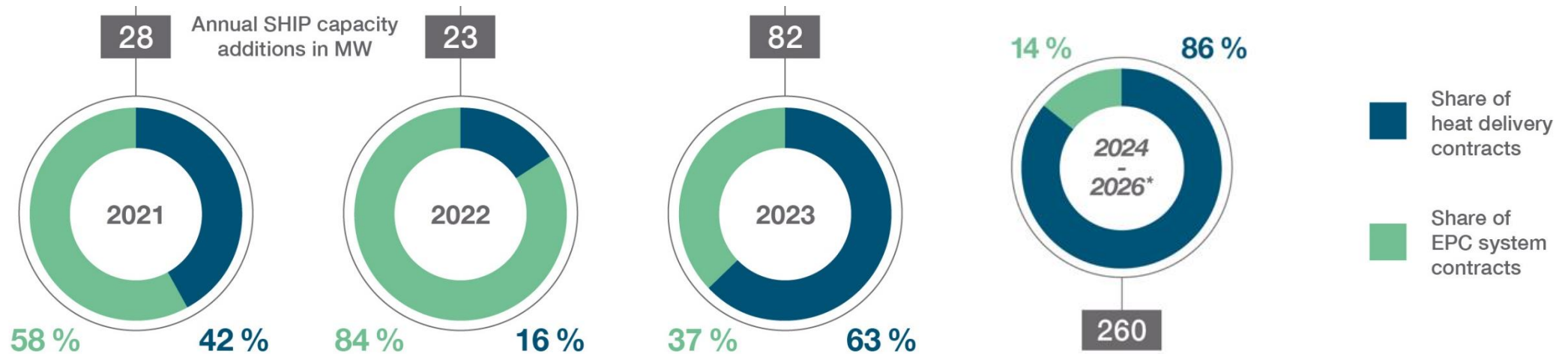


Client: Oil & Gas producer
Site: Qarat al Milh, Oman
Project developer: Heliovis (Austria)
Collector type: parabolic trough collectors in an inflatable tube
Collector field: 1,683 m² / 0.9 MW
Commissioning: Beginning 2024

Photos: Heliovis

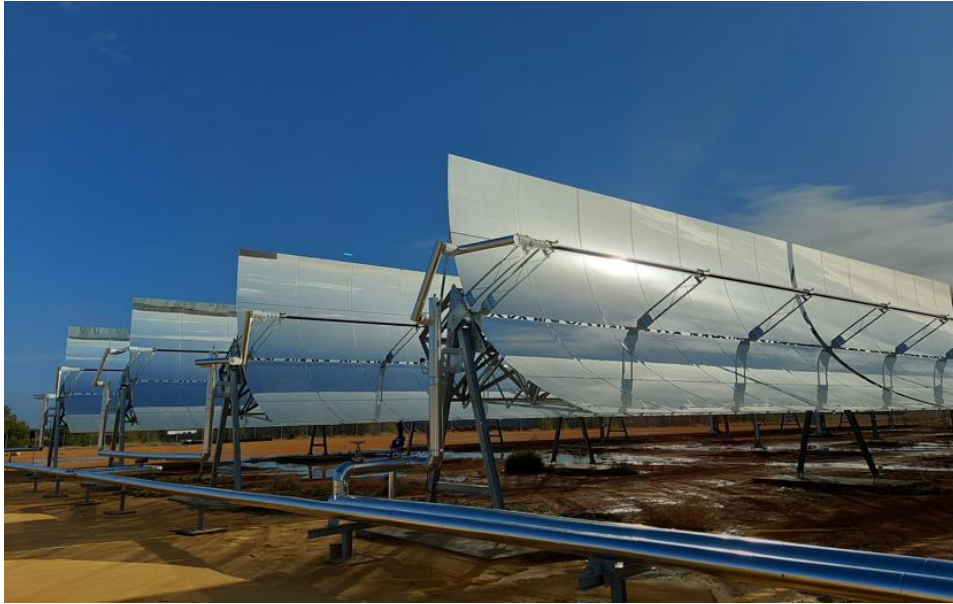


Second megatrend: heat delivery contracts dominate the future SHIP market



Source: solrico, July 2024

Annual industry surveys
between 2016 and 2024
without projects in China



Client: Heineken (brewery)
Site: Sevilla, Spain
Project developer: Engie / Solarlite (Spain / Germany)
Collector type: parabolic trough collectors
Collector field: 43,414 m² / 30 MW
Solar heat temp.: up to 210 °C
Commissioning: September 2023
Business model: Heat purchase agreement with Engie (20 years)



Client: Lactalis (dairy)
Site: Verdun, France
Project developer: New Heat (France)
Collector type: Flat plate collectors
Collector field: 15,000 m² / 10.5 MW
Solar heat temp.: 80 °C
Commissioning: March 2023
Business model: Special Purpose Vehicle as ESCO

Heat purchase agreements are a business model to overcome the barriers

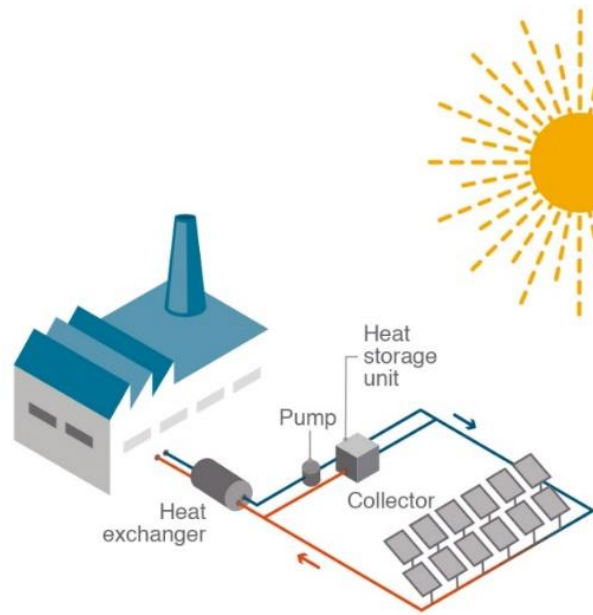


Client: Heineken (brewery)
Site: Valencia, Spain
Project developer: Solatom (Spain)
Collector type: Linear Fresnel collector
Collector field: 6,000 m² / 3 MW
Solar heat temp.: 220 C°
Commissioning: September 2023
Business model: Heat purchase agreement with CSIN (Spain)



Client: Ball Corp (packaging)
Site: California (USA)
Project developer: SOLID Solar Energy Systems (Austria)
Collector type: Flat plate collectors
Collector field: 4,000 m² / 2.8 MW
Solar heat temp.: 70 °C
Commissioning: May 2023
Business model: Heat purchase agreement with Tigi Solar (Israel)

Opportunities and challenges



Proven and mature technology

Growing number of very committed project developers with improved business models

Locally manufactured components (short transportation routes)

Integrated thermal storages

Increasing interest of multinational cooperations

Attractive installation area requirements (three times less area than PV for the same amount of energy)

Low demand for critical materials

“Although the SHIP market has demonstrated a high growth potential, the sales cycle for industrial clients has not shortened as we had expected.”

“Customers are cautious because the energy market situation cannot be assessed. Gas prices dropped while interest rates increased.”

“Although we had many leads in various countries, we did not close any projects during 2023.”



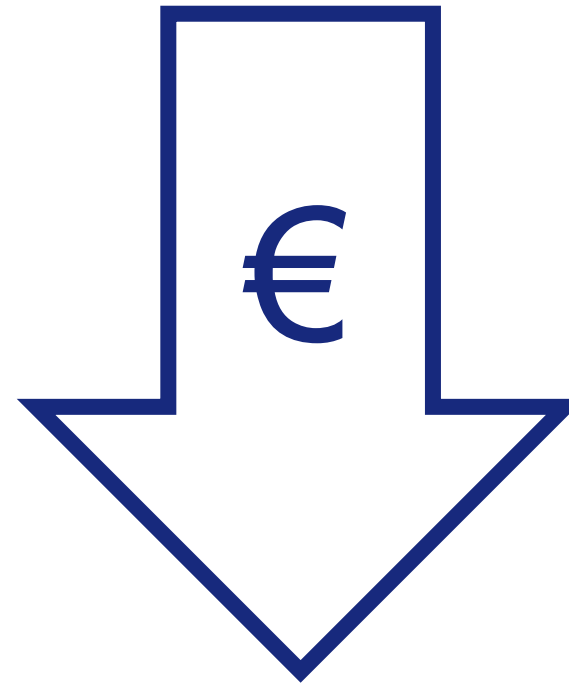
- Difficult to close contracts
- Long project development times
- High dependency on energy prices

- But demand and requests are increasing

Public awareness	Raise awareness on the role of SHIP in CO2 free, reliable heat supply at projectable cost, independent on energy markets and with high local content. Continuous information on companies, industry associations and politics.	SHIP Industry, R&D, industrial engineering companies
Solutions for hybrid heat systems	Develop detailed design guidelines. SHC TCP work can be the basis for formalizing official design guidelines.	SHIP Industry, R&D
Cutting costs	Use learning rate and scaling effects for large projects (Think BIG). Provide continuous support for applied R&D to further cost reductions.	Solar companies and R&D, politics incl. funding agencies



**First main need:
Bring down costs**



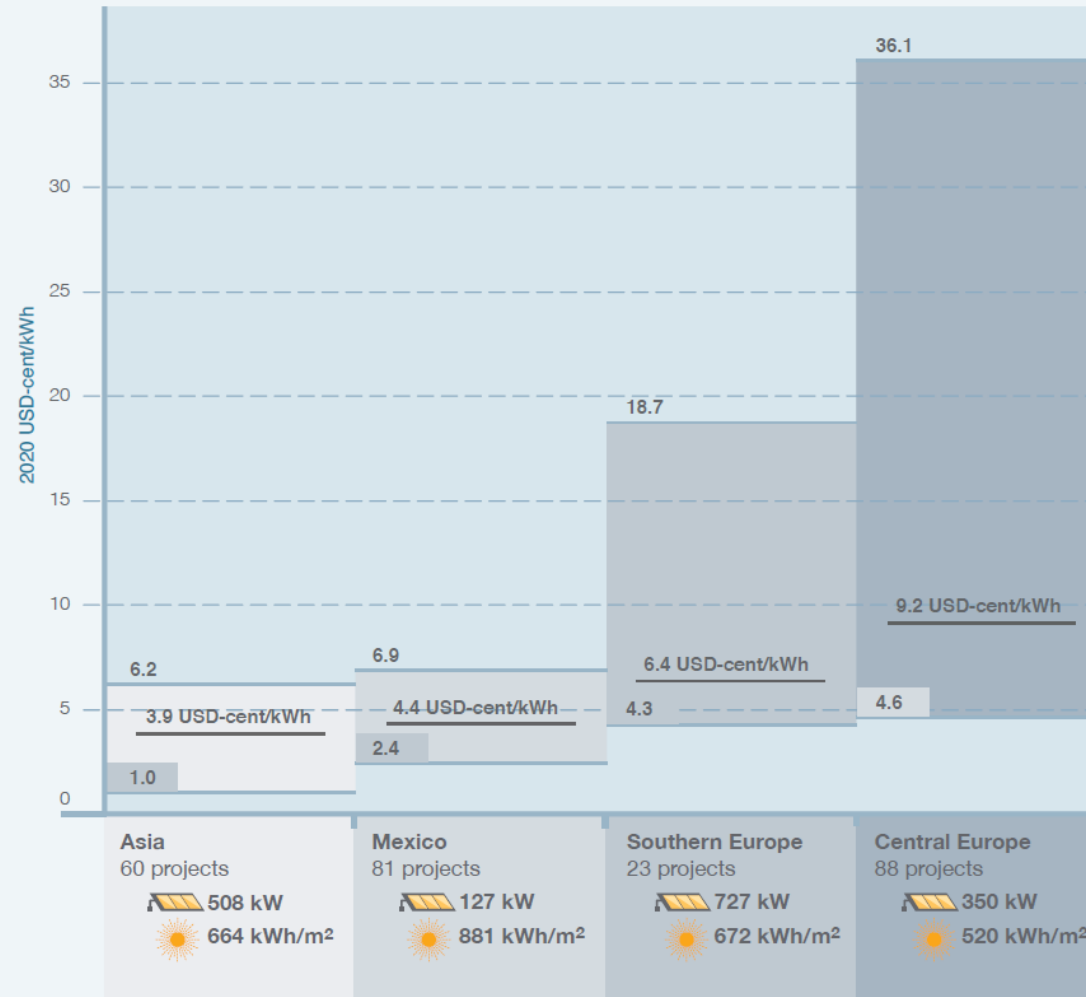
Asia and Mexico are the markets with the lowest industrial solar heat costs

How to read this chart:

- The grey bands show the 5th and 95th percentiles of LCOH by project for a region / country. Projects with various collector technologies are included all commissioned in the period 2010 to 2020. The LCOH is calculated with a standardised WACC of 5 % and 25 years lifetime.
- The bold line represents the weighted-average installed costs for that country/region.
- Average collector field size
- Average annual solar yield



Weighted-average LCOH of SHIP plants in different regions



Note: Costs are in USD-cent/kWh 2020 value. Conversion into EUR-cent/kWh by 0.876 exchange rate value 2020

34 EUR/MWh in China, 38 EUR/MWh in Mexico and 80 MWh in Central Europe



MEXICO

Country with the highest number of SHIP plants installed

- 119 plants (21 MW_{th}) by the end of 2023
- Average size: 184 m²



The system supports not just the electrowinning process, but also the production of hot water for the copper cathode rinsing.

Photo: Módulo Solar

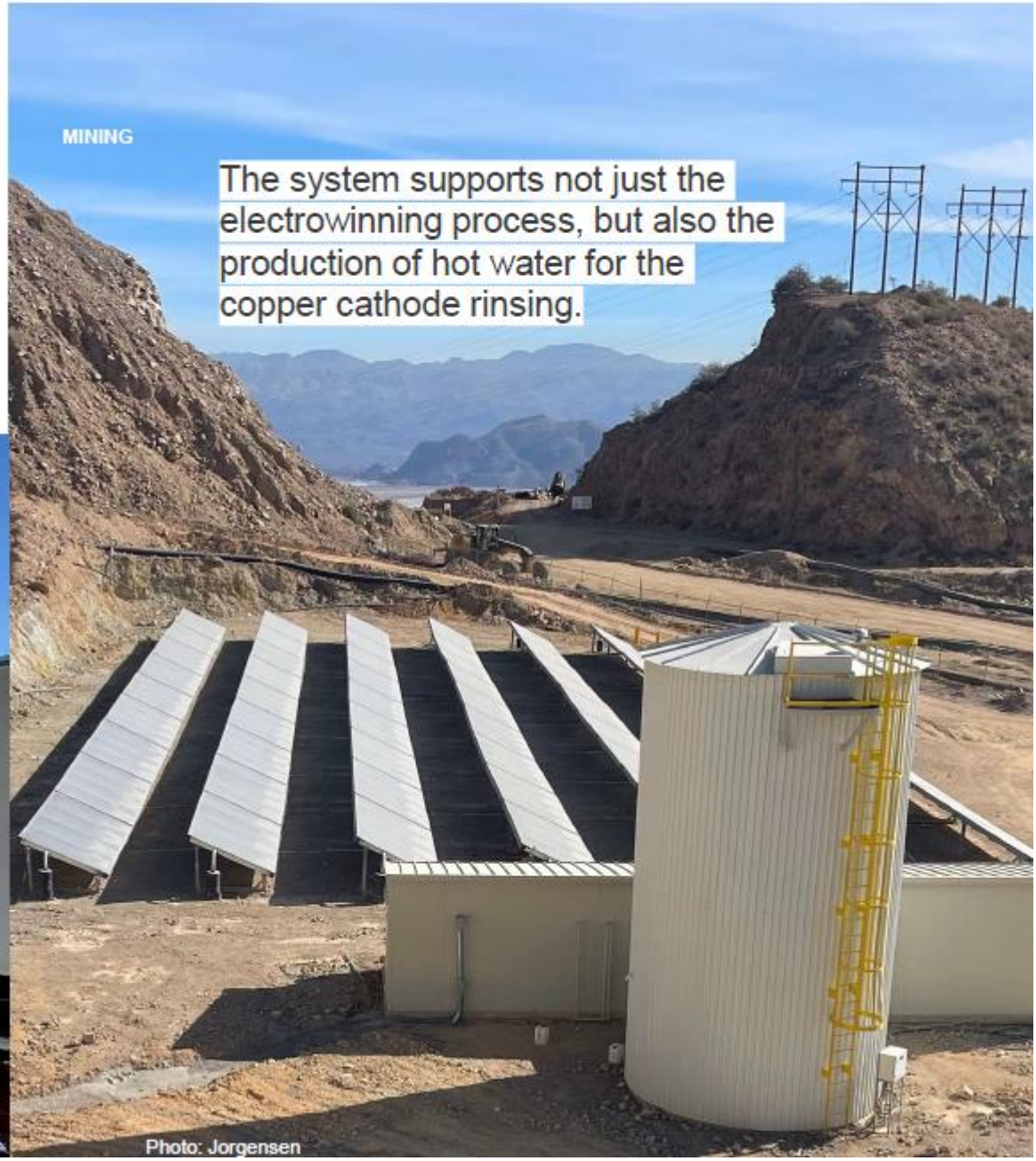


Photo: Jorgensen

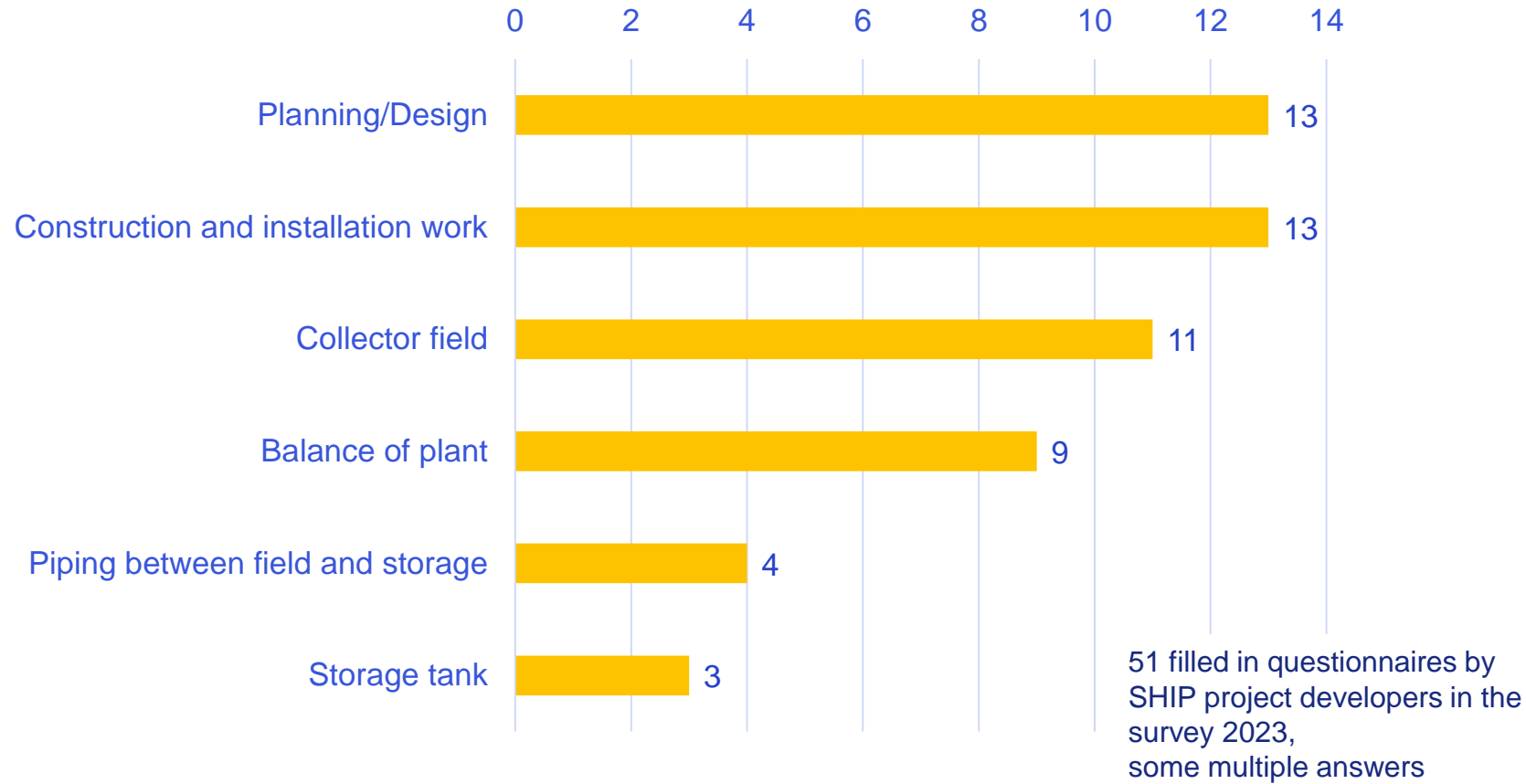
Two new SHIP plants in the state of Sonora, Mexico's mining region



Client: Hanka (ammonium nitrate producer)
Site: Sonora, Mexico
Project developer: Inventive Power (Mexico)
Collector type: parabolic trough collectors
Collector field: 1,300 m² / 0.6 MW
Solar heat temp.: 160 °C
Commissioning: April 2023
Business model: Turnkey installation include steel tanks with 24 m³

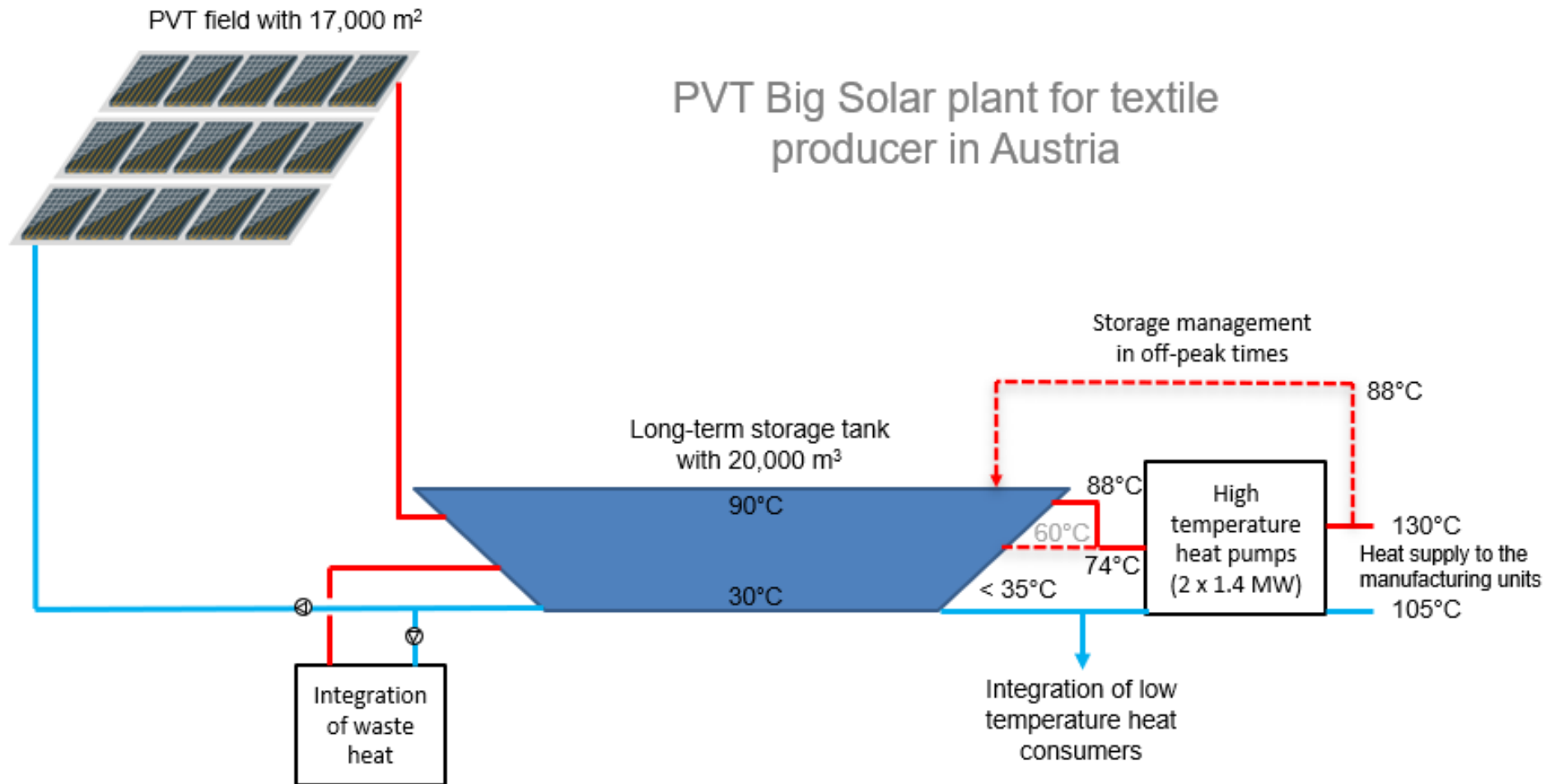
Client: Grupo Mexico (copper mine)
Site: Sonora, Mexico
Project developer: Flemming Jorgensen (Mexico)
Collector type: flat plate collectors
Collector field: 910 m² / 0.8 MW
Solar heat temp.: 65 to 95 °C
Commissioning: December 2023
Business model: Turnkey installation with European technology

Cost reductions are most likely to be achieved for which of the following parts of CAPEX in short term?



Second main need:

Offering hybrid solutions reaching high renewable heat shares (solar heat, waste heat recovery, storages, heat pumps, PV etc.)



Source: AEE INTEC
Feasibility studies in German available here:
<https://www.klimafonds.gv.at/report/solare-grossanlagen-machbarkeitsstudien/>

Concentrating collectors with high-temperature heat storage



Photo: Avery Dennison

Client:	Avery Dennison (Chemical industry)
Site:	Turnhout, Belgium
Project developer:	Azteq, Belgium
Collector type:	Parabolic trough collectors
Collector field:	5,539 m ² / 3.9 MW
Solar heat temp.:	up to 380 C°
Business model:	Heat purchase agreement
Storage tank:	ThermalBattery (5 MWh)
Storage provider:	Energynest, Norway
Storage type:	Solid-state storage with concrete tubes
Operation mode:	Heat-to-heat (Thermal oil) Charging at 380 °C / discharging at 310 °C
Solar share:	around 20 %

Overview of high-temperature heat storage solution providers



Company name	Headquarters	Level of commercialisation
Brenmiller Energy	Israel	Four commercial plants in operation in Italy, Brazil, USA and Israel (27 MWh)
Kyoto Group	Norway	Commercial demonstrator in operation in Denmark (18 MWh)
Eco-Tech Ceram	France	Three commercial plants in operation in France (total 9.3 MWh)
Energynest	Norway	Two commercial projects in Belgium (5 MWh) and Norway (4 MWh)
Rondo Energy	USA	First commercial project in operation in USA (2 MWh)
Polar Night Energy	Finland	First commercial plant in operation in Finland (8 MWh)
Build to zero	Spain	First commercial project under construction
Storworks Power	USA	Demonstrator in operation
Carbon-Clean Technology	Germany	Demonstrator in operation (1 MWh)
Malta Group	USA	Demonstrator in operation in the USA
1414 Degrees	Australia	Demonstrator of SiBrick in operation in Australia (1 MWh)
Kraftanlagen GmbH	Germany	Two demonstration plants in Germany (2 MWh and 20 MWh)
Alumina Energy	USA	First demonstrator in operation in the USA (450 kWh)
Antora Energy	USA	First demonstrator in operation in USA
MGA Thermal	Australia	First Demonstrator (5 MWh) under construction
Exergy3	Great Britain	First demonstrator in Scotland under construction (36 MWh)
Magaldi Green Energy	Italy	First demonstrator under construction
247Solar Inc	USA	Demonstrator under construction in USA (3.6 MWh)
Element16	USA	First demonstrator under construction in USA (1.5 MWh)
E2S Power	Switzerland	Pilot plant in operation in India (0.25 MWh)
Storasol / enolcon	Germany	Pilot plants in operation
Kraftblock	Germany	Pilot plants in operation (70 to 150 MWh)
Lumenion GmbH	Germany	Pilot project in operation in Germany (2.4 MWh). First demonstrator under construction in Germany (20 MWh)
Heliac	Denmark	Pilot plant operated for 24 weeks in Denmark (0.5 MWh)
Sunamp	Great Britain	Pilot projects realised

11 companies offer their products exclusively to industrial customers. 90 % target industrial heat off-takers as one of their customer groups.

It is a fairly young industry with the large majority of the companies founded in the last 15 years. Only two established companies in plant engineering are on the list (light orange)

Three companies plan to offer heat-as-a-service contracts: Rondo (USA), Kaaj Energy (Canada) and Exergy3 (Great Britain).

USA (10 companies) and Europe (16 companies) are technology hubs.

<https://shorturl.at/mQqFL>

- ▶ News articles about the most recent SHIP Supplier Surveys: <https://solarthermalworld.org/modulus/>
- ▶ Check out the SHIP Supplier World map: <http://www.solar-payback.com/suppliers/>
- ▶ Use photos of SHIP plants for your presentations: https://www.solar-payback.com/gallery/gallone_en.php
- ▶ Find the all the results of the survey among medium/high temperature storage tank solution providers: <https://shorturl.at/mQqFL>
- ▶ Consult Solar Heat Worldwide edition 2024 with global, regional and national data about solar heat markets: <https://www.iea-shc.org/solar-heat-worldwide>
- ▶ Check out the technology position paper about SHIP published by IEA SHC Task 64: <https://www.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task64-Technology-Position-Paper-SHIP-2024-01.pdf>
- ▶ And further questions and comments to: Bärbel Epp: epp@solrico.com