First Summer School

Part A: Line-focus Solar Thermal Technologies

September 20-24, 2021

Lecture 7:

SHIP Applications and Electricity Generation with Line-Focus Collectors

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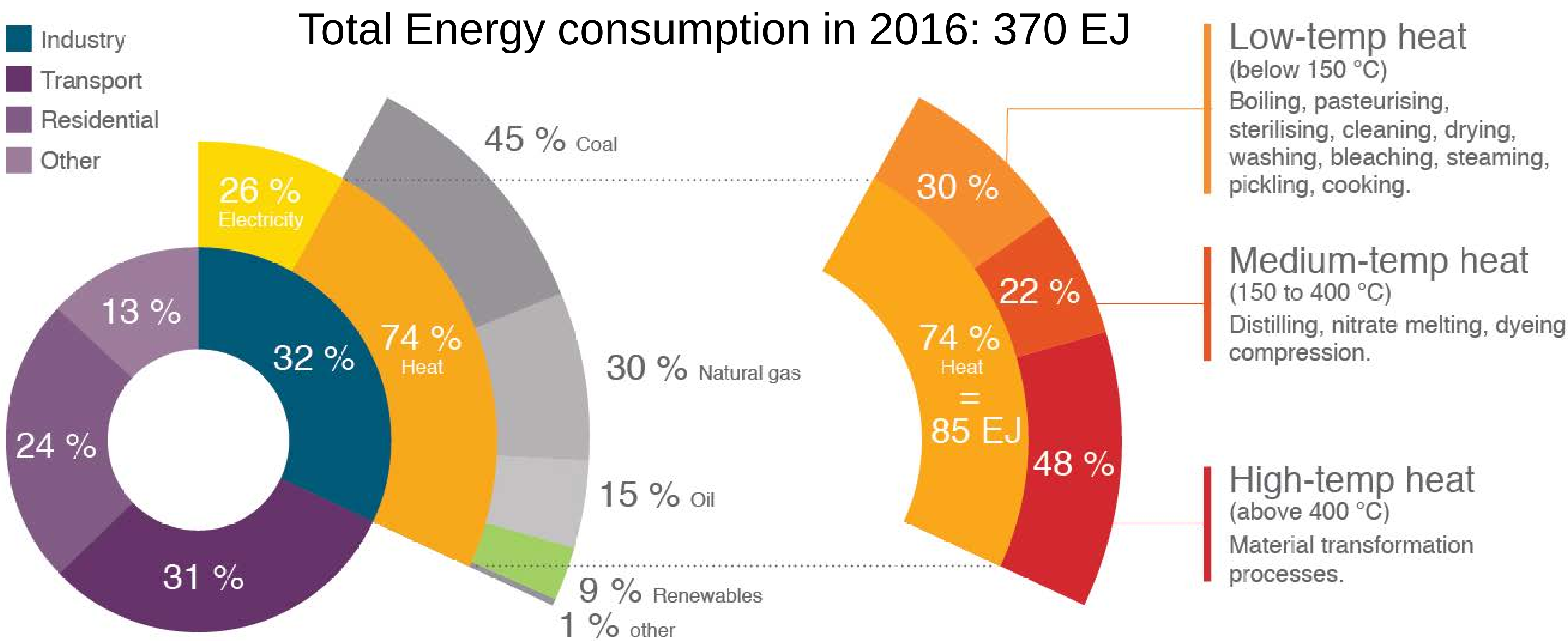
Contents

☛ • Solar Heat for Industrial Processes (SHIP)

• Solar thermal electricity (STE)

Solar heat for industrial processes (SHIP)

Total World energy consumption by sectors in 2017



- ➢Heat represents three quarters of the total energy demand of industries world-wide, and 70% of it is medium to high temperature heat, more easily supplied by concentrating solar thermal systems

Solar heat for industrial processes (SHIP)

A *SHIP Application* consists of a solar field supplying thermal energy to an industrial process that consumes this type of energy. With line-focus collectors these applications can cover a wide temperature range (from 100ºC to about 400ºC)

- Main applications:
  - ✓Steam generation
  - ✓High volumes of hot water production

Solar heat for industrial processes (SHIP)

Industry	Process (es)	Temperature (ºC)	Medium
Food processing, beverages production, milk processing	Cooking, pasteurization, sterilization, tempering drying, heat treatment…	40 - 150	Steam, water, air
Textile	Blanching-dying, Drying, Pressing, Fixing, printing	40 - 180	Water, steam
Pulp and paper	Bleaching, de-linking, drying, pulp preparation…	60 - 200	Water, pressurized water, steam, air
Chemical and pharmaceutical	Distillation, evaporation, drying…	100 - 170	Water, steam, air
Leather products, rubber, plastic and glass manufacturing	Pre-tanning, drying and finishing, preheating, preparation, distillation, lamination…	50 - 200	Water, air, steam
…	…	…	…

Solar heat for industrial processes (SHIP)

Low-temperature heat production (T~100ºC)

Line-focus collectors versus Flat-plate collectors

- Advantages of line-focus tracking collectors
  - Smaller and cheaper thermal energy storage systems
  - Lower thermal losses→ higher efficiency
  - Smaller solar field surface for a required power level
  - No risk of reaching dangerous stagnation temperatures→ stow position (off-focus)

Solar heat for industrial processes (SHIP)

Low-temperature heat production (T~100ºC)

Line-focus collectors versus Flat-plate collectors

- Disadvantages of line-focus tracking collectors
  - ✓ Solar tracking system → higher installation and maintenance costs
  - ✓ Cleaning operations: higher maintenance costs
  - ✓ Geographically limited, because
    - Only direct solar radiation is used
    - Operation may be interrupted at high wind speeds

Solar heat for industrial processes (SHIP)

Refrigeration and Cooling

- This application requires a heat source in the medium temperature range (80ºC -180ºC) → Solar energy supply with PTCs or LFR
- Refrigeration and cooling needs are more important in those countries with a high level of solar radiation
- Refrigeration requirements in the food processing industry and conservation of pharmaceutical products in developing countries is a very interesting market niche for solar energy
- Energy demand for air conditioning in most industrialized countries has been increasing
  - More cooling is needed during periods of high solar radiation
  - Disturbance in the transport and distribution grid due to overload

Solar heat for industrial processes (SHIP)

Solar Refrigeration and Cooling versus Conventional Systems

- Advantages:
  - Solar radiation availability and cooling requirements usually coincide seasonally and geographically
  - Solar air-conditioning and refrigeration facilities can also be easily combined with space heating and hot-water applications
- Disadvantages:
  - High costs associated with these systems
  - Clear market supremacy of conventional compression chillers
  - Shortage of small heat pump equipment
  - Lack of practical experience and acquaintance among architects, builders and planners with their design, control and operation

Solar heat for industrial processes (SHIP)

The main drawbacks of SHIP applications are:

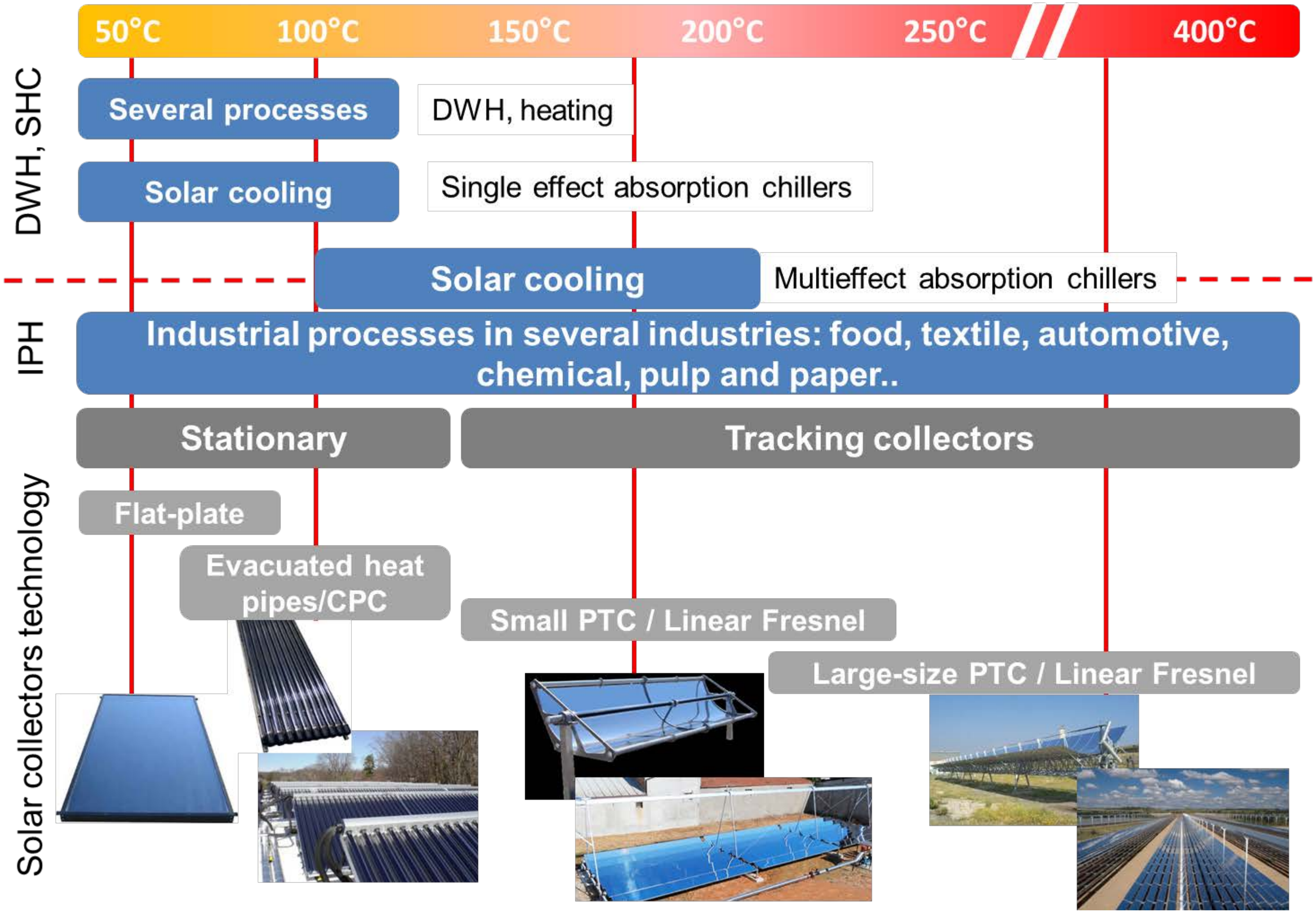
- Land availability and cost in industrial areas
- Lack of collector designs suitable for roof mounting
- Non-constant energy source (solar radiation)
- Financial issues: payback periods must be <5 years
- Skilled manpower requirement for O&M

Solar heat for industrial processes (SHIP)

➢ Specifications for line-focus tracking collectors designed for SIPH:

- Flexibility (valid for a wide range of nominal power)
- Small size
- Light weight
- Durability
- High “efficiency/cost ratio”
- Easy installation and operation
- Minimal maintenance

Commercial collectors for SHIP

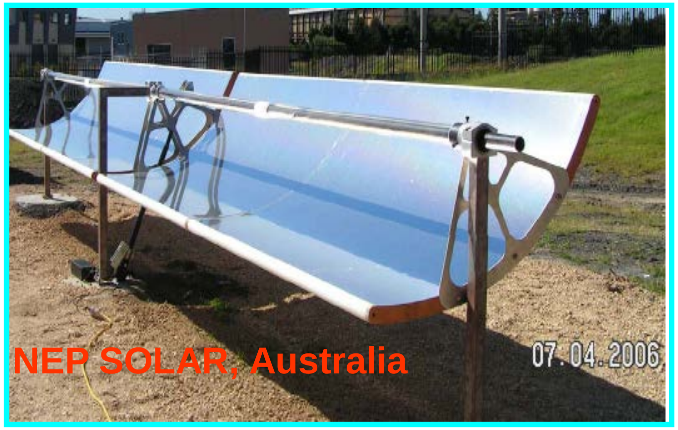


Examples of PTCs for SHIP

Currently marketed

LUCIDA Solar, Turkey

SOLITEM, Turkey



NEP SOLAR, Australia

SHIP: Commercial projects

For more information about SHIP applications (technology, suppliers, commercial projects,..) see:

https://www.solar-payback.com/

SHIP projects built by Inventive Power (Mexico)

Data base of collectors for SHIP


STAGE-STE

stage-ste.eu/keydocuments/solarthermalcollectors.php

STAGE-STE EUROPEAN ENERGY RESEARCH ALLIANCE

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Medium Temperature Solar Collectors Database

Within the work package 11 "Line-focusing STE technologies" of the project STAGE-STE a **solar collectors' database** has been created. This database currently contains information of about 75 different models of solar collector and is configured to be updated online.

This work is being done in the framework of the European project STAGE-STE. The gathered information is also used inside the Task 49 of the International Energy Agency (IEA). The Task 49 is the working group for Solar Heat Integration in Industrial Process (SHIP) of the Solar Heating and Cooling program (SHC) by the IEA (http://task49.iea-shc.org/).

Possible uses of the collectors included in the database are mainly solar process heat but also solar cooling, desalination, electricity generation using Organic Rankine cycle (ORC), pumping irrigation water, water heating for high consumptions, etc.

Existing collectors are based on different technologies (parabolic-trough collectors, linear Fresnel collectors, parabolic dishes, ultra-high vacuum flat plate collectors, fixed mirror solar concentrator, etc...), different designs, concepts, sizes and materials, etc. This database is intended to be a reference in the medium temperature solar thermal collectors market.

(click on the image to enlarge)

(click on the image to enlarge)

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(click on the image to enlarge)

Solar collectors database - Reference documents and forms

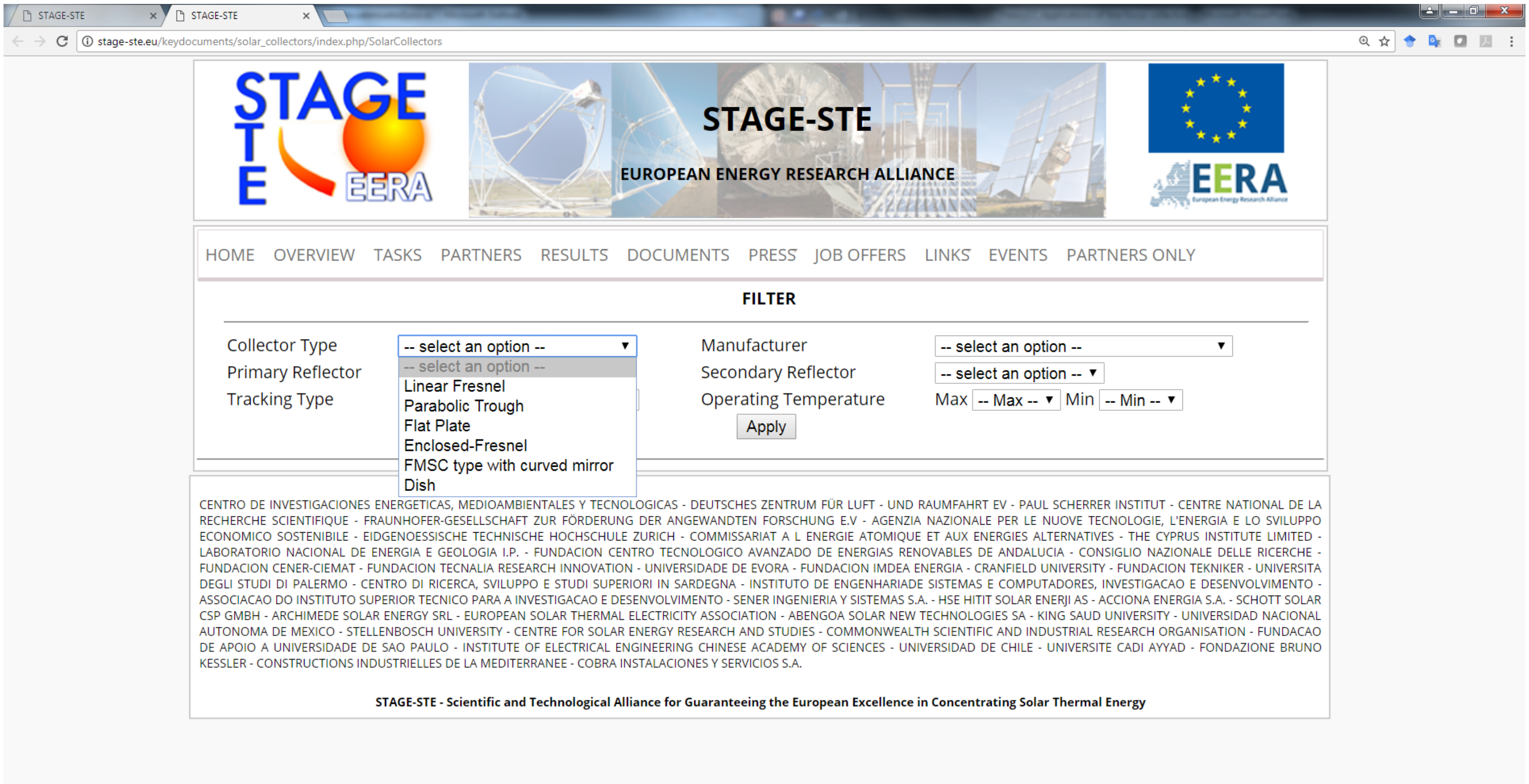
- Solar thermal collectors for medium temperature applications: a comprehensive review and updated database
- Description of the information available in the database.
- Solar collectors database.
- Submit information of a new collector
- For more information on the solar collectors database, please contact collectors@stage-ste.eu

STATISTICS (Updated on November 25, 2015)

ES 18:27 18/10/2017

[Link to solar collectors database](https://stage-ste.psa.es/keydocuments/solarthermalcollectors.php): https://stage-ste.psa.es/keydocuments/solarthermalcollectors.php

Data base of collectors for SHIP



Link to solar collectors database: https://stage-ste.psa.es/keydocuments/solarthermalcollectors.php

Data base of collectors for SHIP

ar_collectors/index.php/SolarCollectors/show?c=cdVZ0SianWXU9cCd+73dkwfC4WSLufjztifuAWzyoQ4=2

EERA

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FILTER

Collector Type	-- select an option --	Manufacturer	-- select an option --
Primary Reflector	-- select an option --	Secondary Reflector	-- select an option --
Tracking Type	-- select an option --	Operating Temperature	Max -- Max -- Min -- Min --

Apply

Name	PolyThrough 1800 NEP Solar	Manufacturer
Location	Zürich (Switzerland)	Collector Main Features
Website	http://www.nep-solar.com/	Geometrical Features
		Certification
		Optical and thermal characterization parameters
		Operating conditions

Download Information

CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS - DEUTSCHES ZENTRUM FÜR LUFT - UND RAUMFAHRT EV - PAUL SCHERRER INSTITUT - CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE - FRAUNHOFER-GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG E.V - AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE - EIDGENOESSISCHE TECHNISCHE HOCHSCHULE ZURICH - COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES - THE CYPRUS INSTITUTE LIMITED - LABORATORIO NACIONAL DE ENERGIA E GEOLOGIA I.P. - FUNDACION CENTRO TECNOLOGICO AVANZADO DE ENERGIAS RENOVABLES DE ANDALUCIA - CONSIGLIO NAZIONALE DELLE RICERCHE - FUNDACION CENER-CIEMAT - FUNDACION TECNALIA RESEARCH INNOVATION - UNIVERSIDADE DE EVORA - FUNDACION IMDEA ENERGIA - CRANFIELD UNIVERSITY - FUNDACION TEKNIKER - UNIVERSITA DEGLI STUDI DI PALERMO - CENTRO DI RICERCA, SVILUPPO E STUDI SUPERIORI IN SARDEGNA - INSTITUTO DE ENGENHARIADE SISTEMAS E COMPUTADORES, INVESTIGACAO E DESENVOLVIMENTO - ASSOCIACAO DO INSTITUTO SUPERIOR TECNICO PARA A INVESTIGACAO E DESENVOLVIMENTO - SENER INGENIERIA Y SISTEMAS S.A. - HSE HITIT SOLAR ENERJI AS - ACCIONA ENERGIA S.A. - SCHOTT SOLAR CSP GMBH - ARCHIMEDE SOLAR ENERGY SRL - EUROPEAN SOLAR THERMAL ELECTRICITY ASSOCIATION - ABENGOA SOLAR NEW TECHNOLOGIES SA - KING SAUD UNIVERSITY - UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO - STELLENBOSCH UNIVERSITY - CENTRE FOR SOLAR ENERGY RESEARCH AND STUDIES - COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANISATION - FUNDACAO DE APOIO A UNIVERSIDADE DE SAO PAULO - INSTITUTE OF ELECTRICAL ENGINEERING CHINESE ACADEMY OF SCIENCES - UNIVERSIDAD DE CHILE - UNIVERSITE CADI AYYAD - FONDAZIONE BRUNO KESSLER - CONSTRUCTIONS INDUSTRIELLES DE LA MEDITERRANEE - COBRA INSTALACIONES Y SERVICIOS S.A.

STAGE-STE - Scientific and Technological Alliance for Guaranteeing the European Excellence in Concentrating Solar Thermal Energy

PolyThrough 1800

Collector type	Parabolic Trough

Manufacturer	
Name	NEP Solar
Location	Zürich (Switzerland)
Website	http://www.nep-solar.com/

Collector main features	
Technology	Parabolic Trough
Primary reflector	Aluminum
Secondary reflector	No secondary
Receiver cover	Borosilicate glass without AR coating
Tracking type	1-axis tracking
Receiver atmosphere	Air

Geometrical features	
Collector width [m]	1,845
Collector length [m]	20,9
Collector height [m]	1,75
Concentration factor	17,27

Certification	
Applied standard	EN 12975
Testing laboratory	N/A
Certification scheme	Solar Keymark
Status	Pending

Optical and thermal characterization parameters	
Zero loss coefficient (optical efficiency)	0,689
Heat loss coefficient, a1 [W/(m2.K)]	0,36
Temp.dep.heat loss coeff., a2 [W/(m2.K2)]	0,0011

Operating conditions	
Max. operating temperature [°C]	230
Max. operating pressure [bar]	N/A
Heat transfer media	Pressurized Water (w/ or w/out glycol), Thermal oil
Suitable applications	Process heat, solar cooling, polygeneration

Date: October 18, 2017

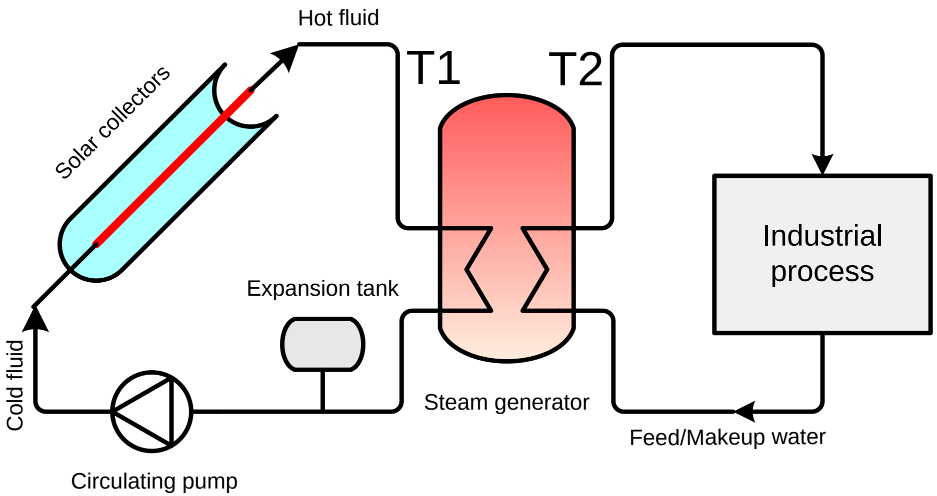
Automatic report generated from http://stage-ste.eu/keydocuments/solarthermalcollectors.php
Activity perfomed within WP11"Linear Focusing STE Technologies" of the STAGE-STE Project (EU Grant Agreement 609.837)

SHIP: Options for Steam Generation

Unfired boiler or Heat Transfer Fluid (HTF) technology

- Two separated loops
- A heat transfer fluid loop, which delivers hot fluid from the solar collectors to an unfired boiler or steam generator and recirculates the fluid to the collectors through a circulating pump
- In steam generator the hot fluid delivers the heat required to convert feed water in the secondary loop into saturated or superheated steam at the pressure and temperature required by the process
- The temperature of the hot fluid from the solar field must be at least 10-20ºC higher than that of the steam to be produced for the process

T1 >T2



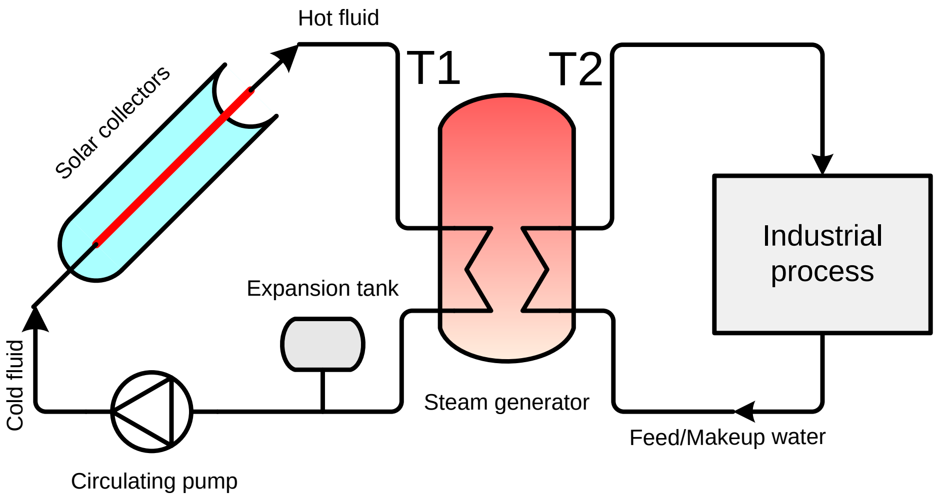
HTF based SHIP system

SHIP: Options for Steam Generation

Unfired boiler or Heat Transfer Fluid (HTF) technology

- The working fluid commonly used in the solar field for this indirect concept is thermal oil
- A nitrogen system is provided over the organic fluid to prevent oxidation a fire hazards
- An storage tank may be implemented to increase the number of operating hours
- An expansion tank is required at the solar field side to absorb the thermal expansion of the oil

T1 >T2

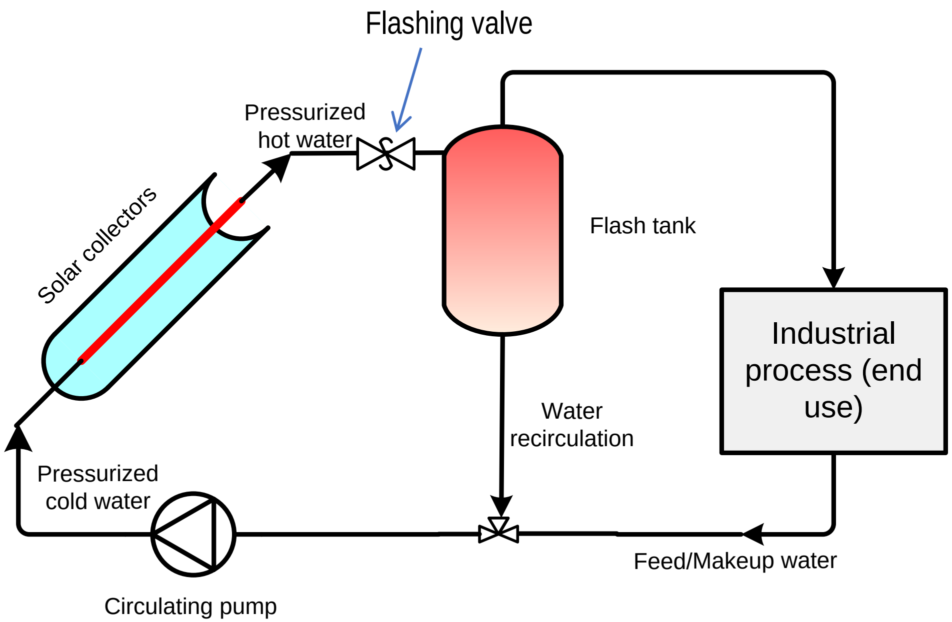


HTF based SHIP system

SHIP: Options for Steam Generation

Flash boiler

- Water from the flash boiler is pressurized and circulated through the solar field
- The water is pressurized and maintained at the required pressure by a circulating pump to prevent boiling within the collectors or piping
- When the pressurized heated water from the collector field enters the boiler flash chamber, due to the change in pressure in the vessel, a part of it is converted into saturated steam.

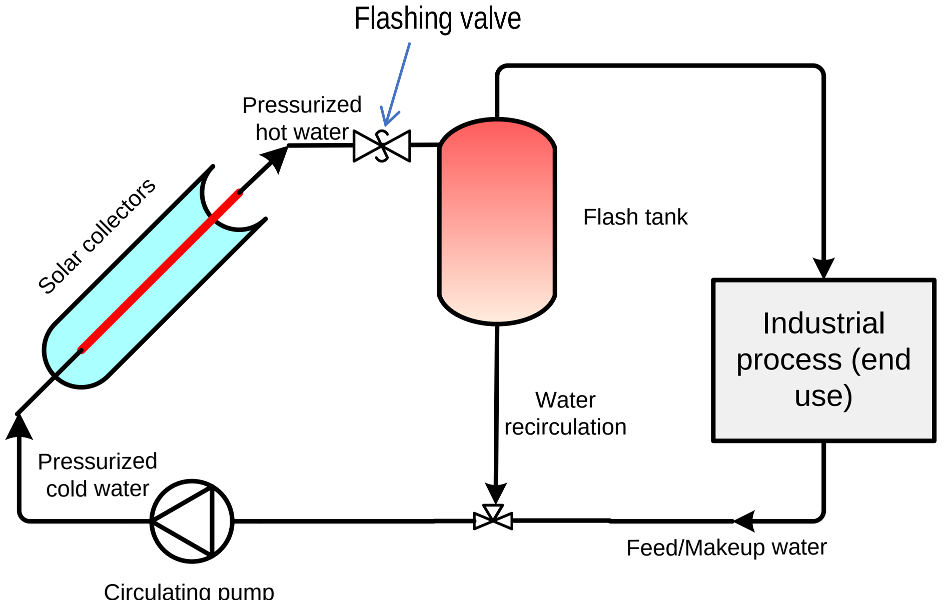


Flash boiler based SHIP system

SHIP: Options for Steam Generation

Flash boiler

- Saturated steam produced in the vessel is delivered to the steam mainstreams of the industrial process
- The rest of the water is recirculated through the collector field
- Flashing is up to about 10%, depending on the temperature of the heated water and the pressure difference between the solar field and flash tank



Flash boiler based SHIP system

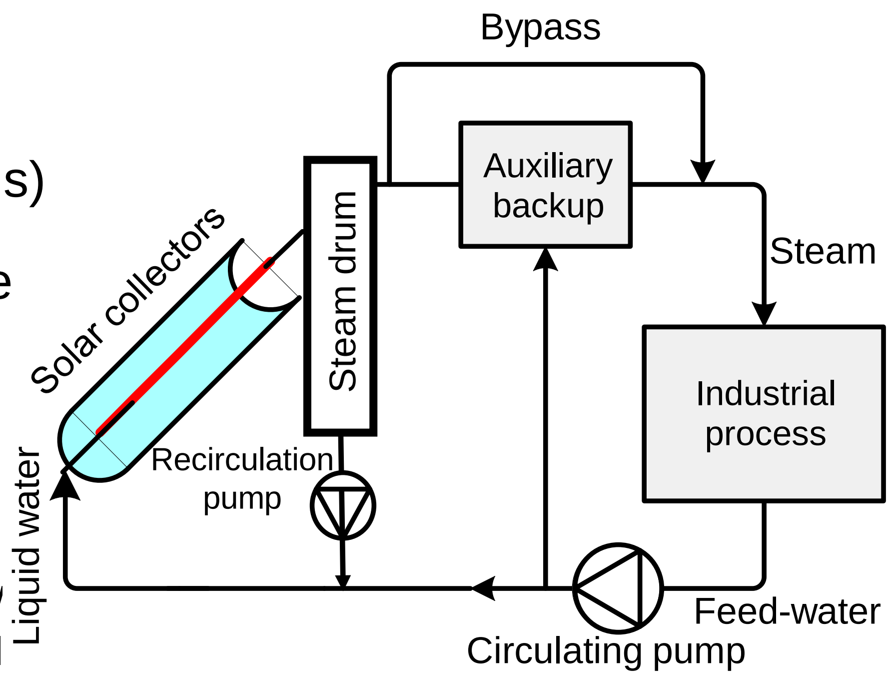
SHIP: Options for Steam Generation

Direct Steam Generation

- Steam is directly produced inside the receivers of the solar collectors (2 options)

✓ Water can be partially evaporated in the collector:

- ➢ Water is circulated through a steam drum where steam is separated from the water
- ➢ Feed water is added to the steam drum or mixed w the recirculated water at a rate regulated by a level controller in the drum



Direct steam production in collectors with auxiliary backup <u>and partial evaporation in the solar field</u>

SHIP: Options for Steam Generation

Direct Steam Generation

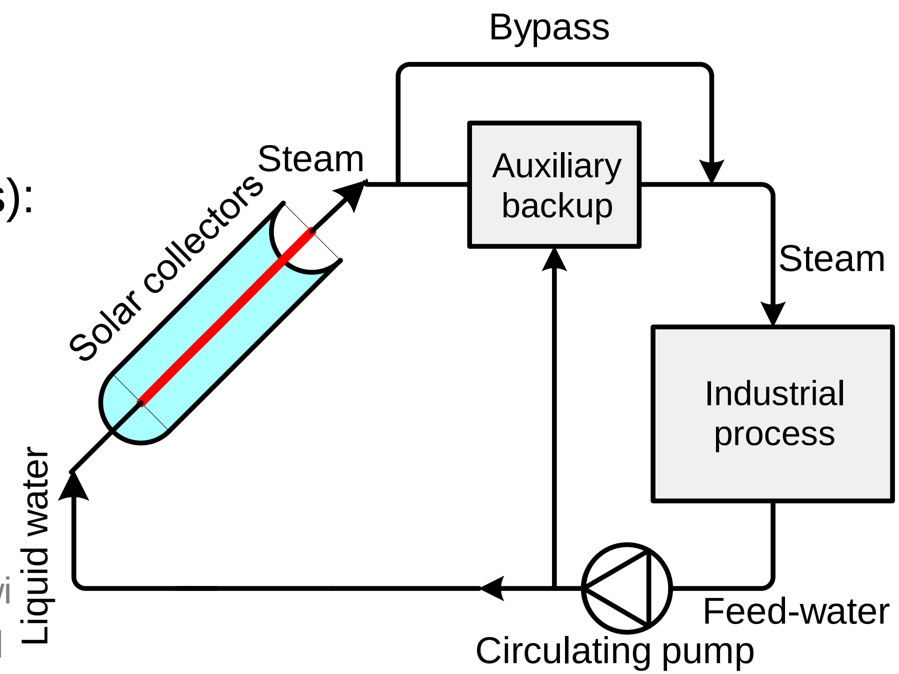
- Steam is directly produced inside the receivers of the solar collectors (2 options):

✓ Water can be partially evaporated in the collector:

- ➢ Water is circulated through a steam drum where steam is separated from the water
- ➢ Feed water is added to the steam drum or mixed wi the recirculated water at a rate regulated by a level controller in the drum

✓ Water can be completely evaporated in the solar field

- ➢ Feed water is added directly to the collector field inlet



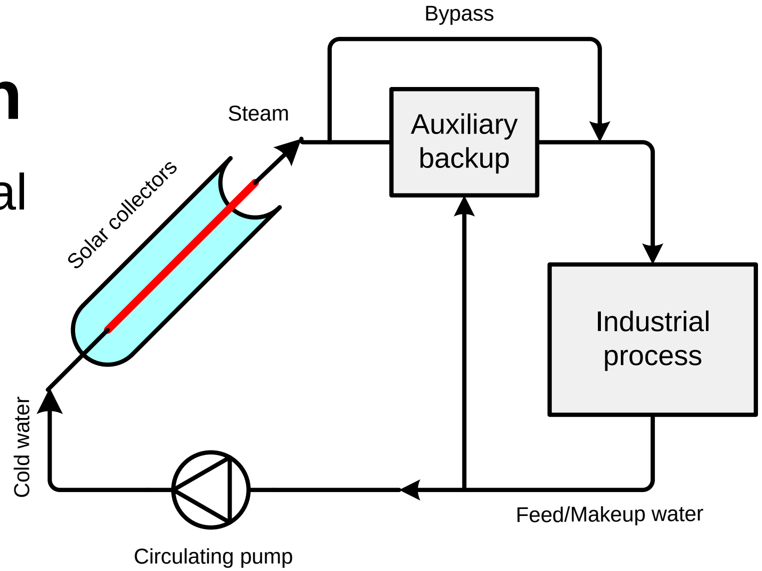
Direct steam production in collectors with auxiliary backup <u>and 100% evaporation at the solar field</u>

SHIP: Options for Steam Generation

Direct Steam Generation

➢ Advantages versus HTF option

- Environmental risks associated with thermal oil are eliminated (fires and leaks)
- Oil/steam heat exchanger is unnecessary
  - ➢ Overall plant efficiency is higher
  - ➢ Solar field requirement and investment is lower
  - ➢ Plant configuration is simplified
  - ➢ Auxiliary thermal oil systems are eliminated
- O&M costs are reduced
  - ➢ Auxiliary heating system for thermal oil is eliminated
  - ➢ 3% of yearly oil make-up is avoided



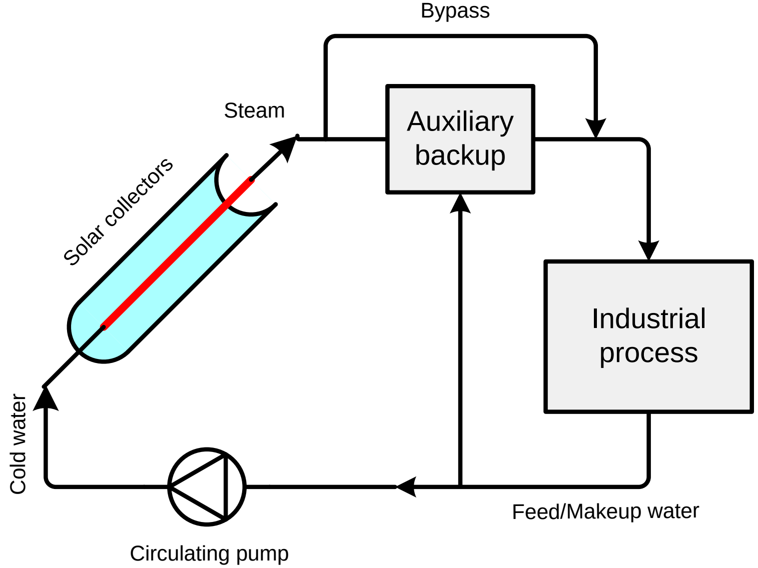
Direct steam production in collectors with auxiliary backup

SHIP: Options for Steam Generation

Direct Steam Generation

➢ Disadvantages versus thermal oil

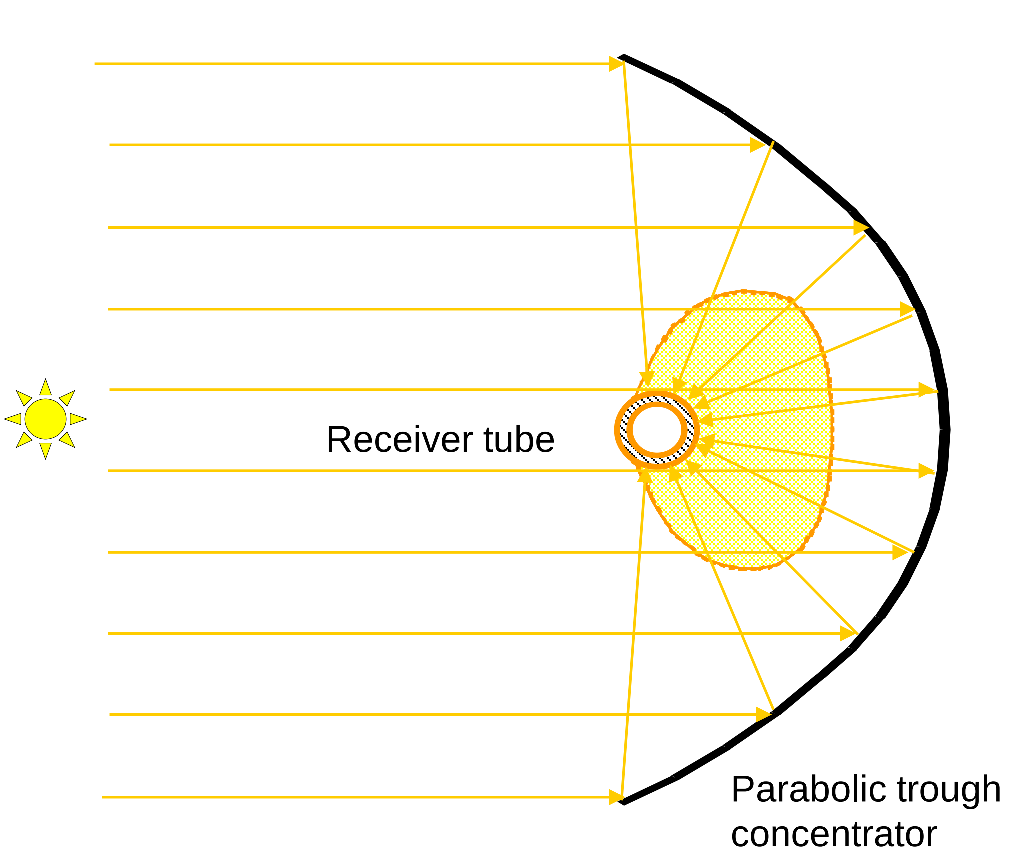
- Higher solar field operating pressure requires suitable hydraulic components, which increases costs
- Water may freeze in cold weather conditions
- Liquid water stratification problems

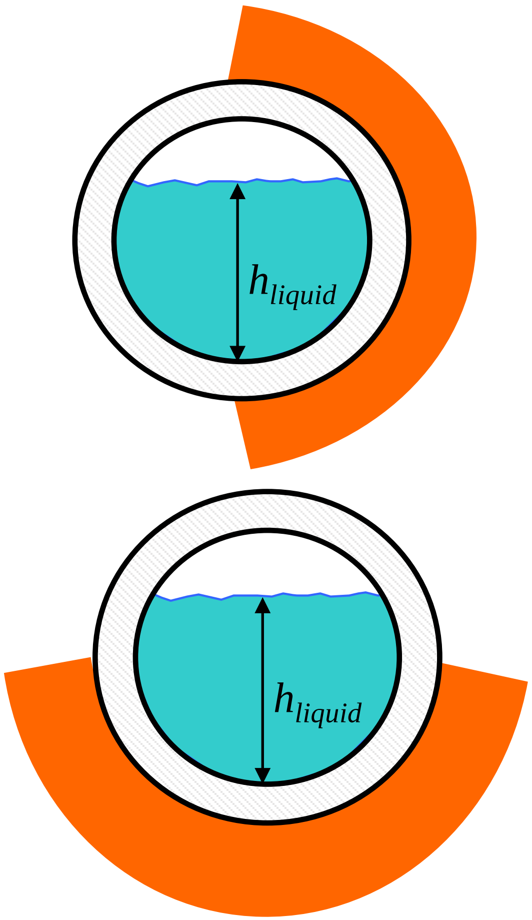


Direct steam production in collectors with auxiliary backup

Direct Steam Generation

Water stratification problems in Solar Fields with Direct Steam Generation



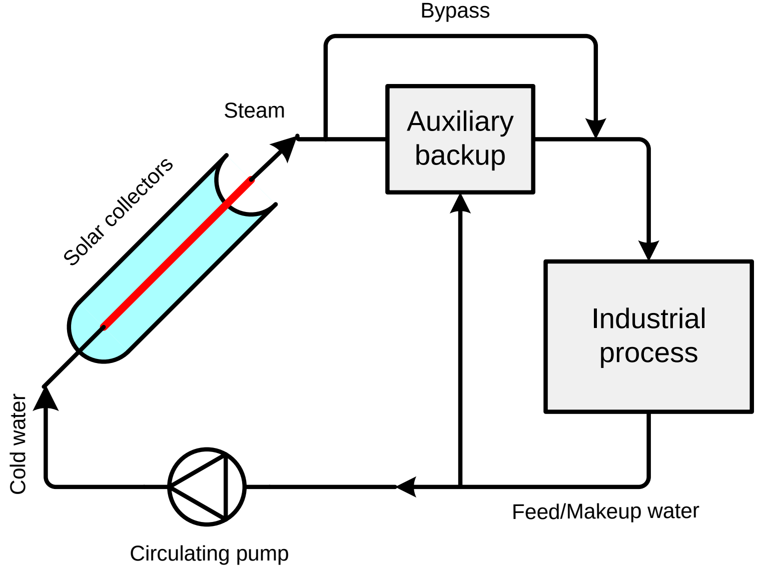


SIPH: Integration options of solar fields

Direct Steam Generation

➢Disadvantages versus thermal oil

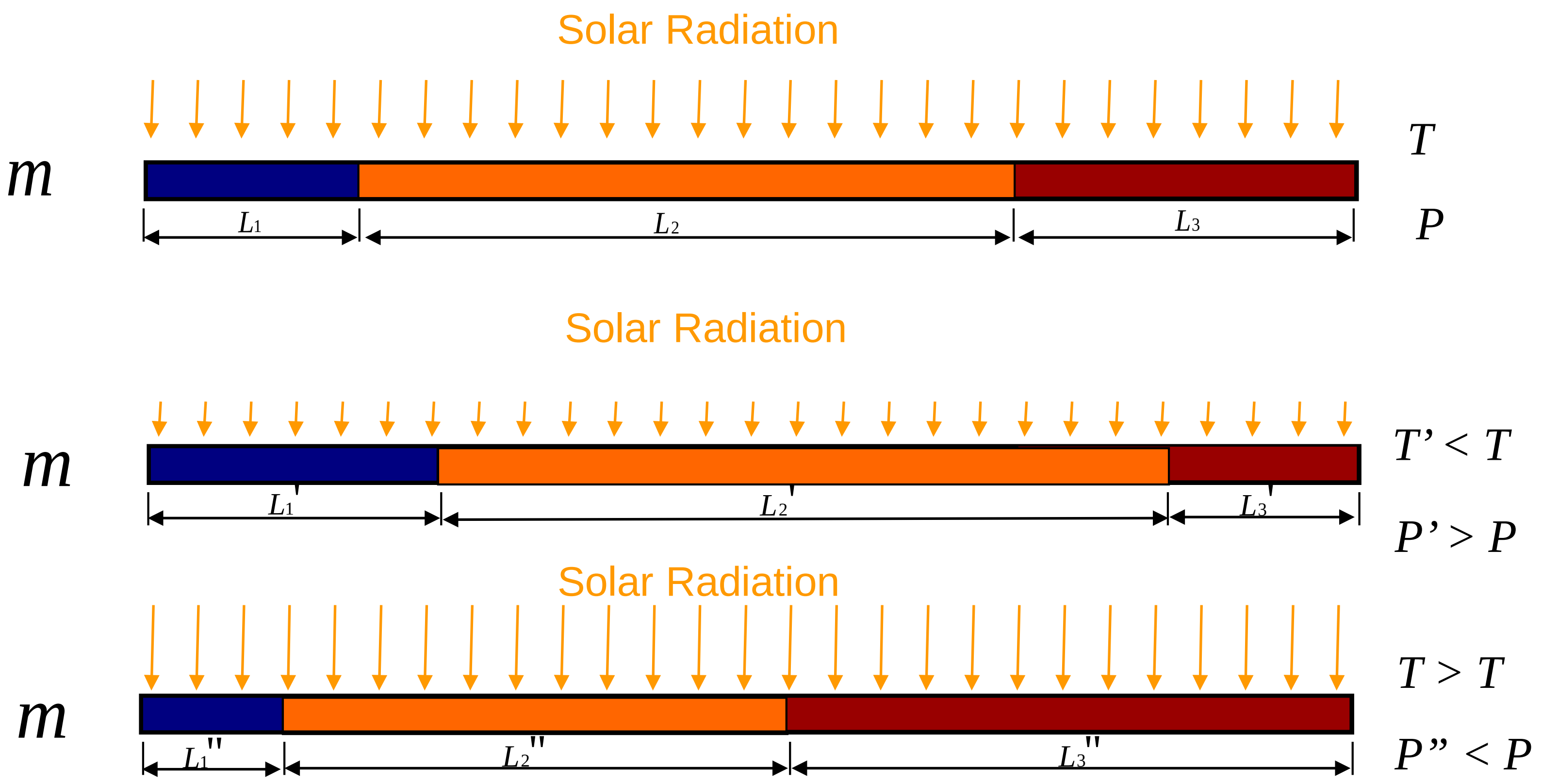
- Higher solar field operating pressure requires suitable hydraulic components, which increases costs
- Water may freeze in cold weather conditions
- Liquid water stratification problems
- Control systems required for the solar field are more complex and expensive (two-phase flow)



Direct steam production in collectors with auxiliary backup

Direct Steam Generation

Control-related problems in Solar Fields with Direct Steam Generation



SHIP: Options for Steam Generation
Summary of pros and cons

Unfired boiler	Flash boiler	Direct steam generation
In case of using thermal oil: • Lower pressure in the solar field piping • High temperature steam • Most of the thermal oils currently available have a low freezing point	• Same Fluid in the collector field may be used also in the process • No need of HX • Good heat transfer media (high specific heat capacity and high thermal conductivity)	• Same Fluid in the collector field may be used also in the process • No need of HX • Good heat transfer media • Phase change reduces flow rate required through solar collectors
In case of using thermal oil: • Fire risk due to leakages (need of ATEX specifications in some cases) • Expensive and pollutant • High viscosity at low temperature→high pressure losses	• Risk of freezing in the collector field • Limited steam temperature becaue fluid temperature in the solar field >>> process steam temperature • Economical viability only if max. pressure < 30 bar • Very high pumping power	• Risk of freezing in the collector field • Uneven heat transfer in the receiver tubes with water stratification • Controllability of the process in solar field more complex

SHIP: Commercial examples

Source: Abengoa Solar

Plant /aplication:	Minera El Tesoro (Antofagasta), Chile
Solar field configuration:	**Unfired boiler based SHIP system**
Processes:	Steam (150°C) & hot water (80°C) for solvent extraction and electro-generation (processes to obtain copper cathodes)
Year:	2013
Solar collector type:	Abengoa-PT1 (2.3m x 6.1 m, T_{max} = 288ºC, C ~ 40) (Reflector : Aluminum/Steel)
Number of solar collector units:	1280
Total collectors area:	16742 m^2
Thermal power:	7 MW_{th}

SHIP: Commercial examples

Plant /application:	El Nasr plant (Cairo), Egypt
Solar field configuration:	**Flash boiler based SHIP system**
Processes:	Steam (173°C/8 bar) for a pharmaceutical industry
Year:	2004
Solar collector type:	IST(Abengoa)-PT1 (2.3m x 6.1 m, T_{max} = 288ºC, C ~ 40) (Reflector : Aluminum/Steel)
Total collectors area:	1900 m^2

SHIP: Commercial examples

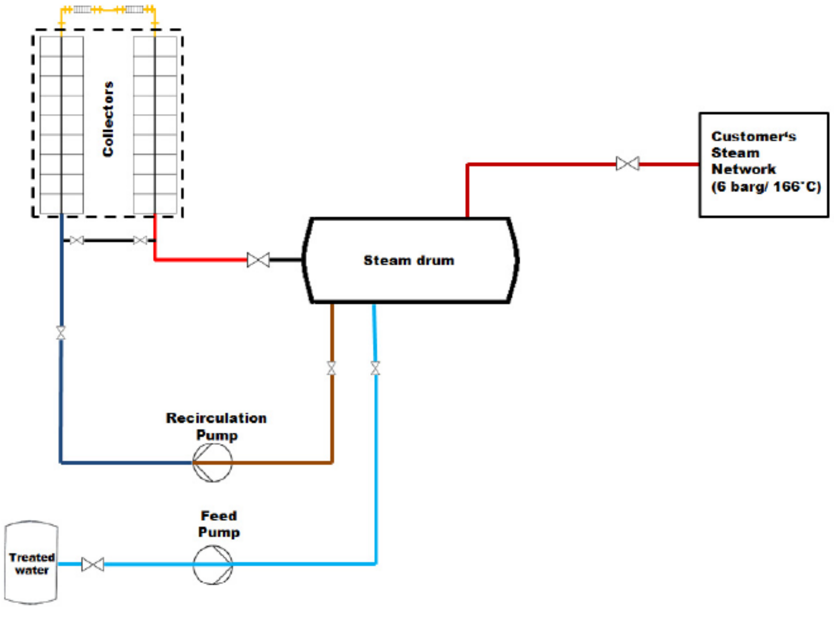


Figure 3. Conceptual P&I diagram of solar process heat installation at RAM Pharma

Source: Haagen et al. Energy Procedia 70 (2015), 621-625

Plant /application:	RAM Pharma (Sahab), Jordan
Solar field configuration:	**Direct steam generation**
Processes:	Steam (160°C/6 bar) for a pharmaceutical industry
Year:	2015
Solar collector type:	LF-11 Industrial Solar (22 m^2 per module)
Total collectors area:	396 m^2
Thermal power:	222 kW_{th}

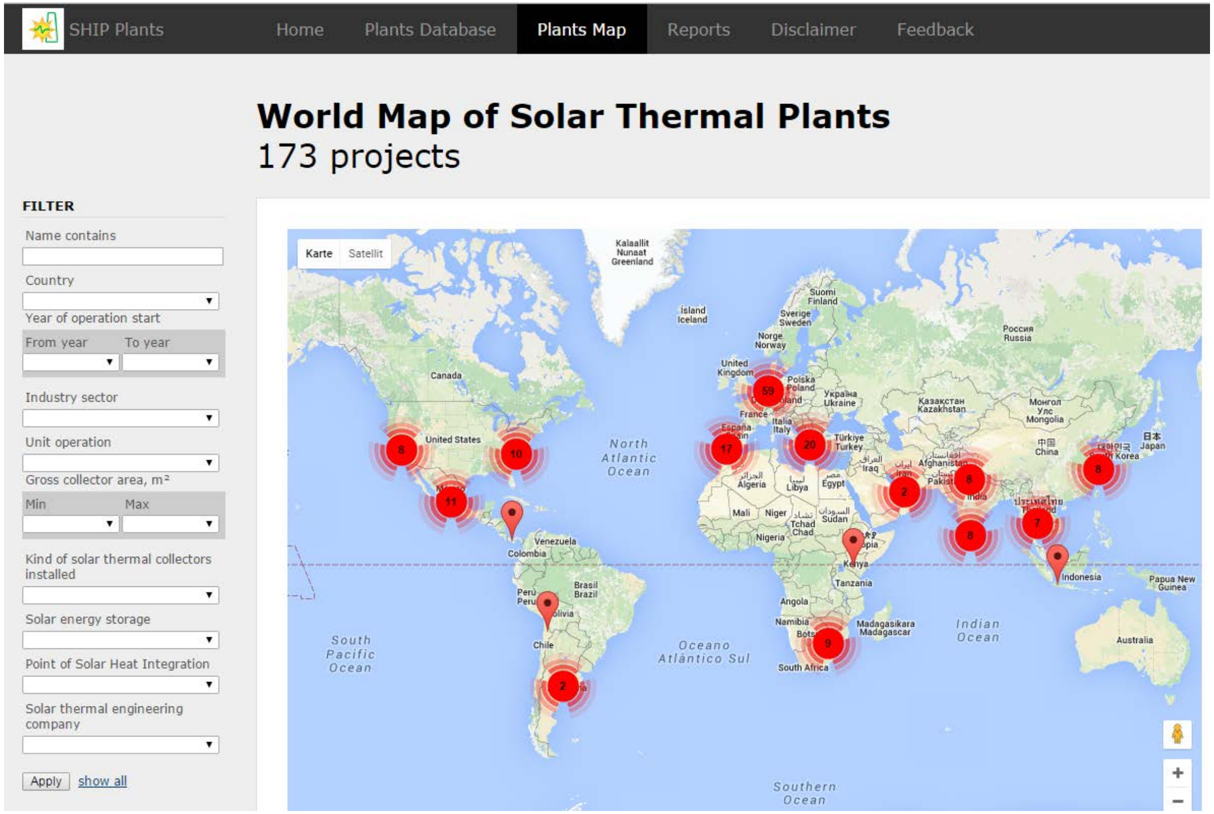
SHIP: Commercial examples

Plant /application:	Parker-Lincoln Building (Raleigh), USA
Solar field configuration:	**Unfired boiler based SHIP system**
Processes:	Pressurized hot water (170°C) coupled to a a double effect absorption chiller (cooling system) (steam @165ºC, COP = 1.23)
Year:	2002
Heat transfer fluid:	Water
Solar collector type:	Power Roof™ Solargenix (T_{max} =400ºC)
Total collectors area:	549 m^2

SHIP: Commercial examples

For more details of demonstration and commercial SIPH systems around the world:

www.ship-plants.info



Solar heat for industrial processes (SHIP)

➢Barriers for large scale deployment of SHIP systems:

- Difficulty in integrating SHIP in existing and optimized process heating systems
- Not many suppliers of components for small sized line-focus collectors suitable for SHIP applications
- Unavailability of qualified designers, installers as well as software support
- Unavailability of adequate policy and regulatory support (e.g. compared to PV or solar thermal power generation)

Contents

- Solar Heat for Industrial Processes (SHIP)
- ☛ Solar thermal electricity (STE)

Solar thermal electricity (STE)

What is a Concentrating Solar Thermal Power (CSTP) or a Solar Thermal Electricty (STE) plant?

A CSTP plant is a system where **direct solar radiation is concentrated** and then **converted into thermal energy** at medium/high temperature (300°C - 600°C). This thermal energy is then **used in a thermodynamic cycle** to produce electricity.

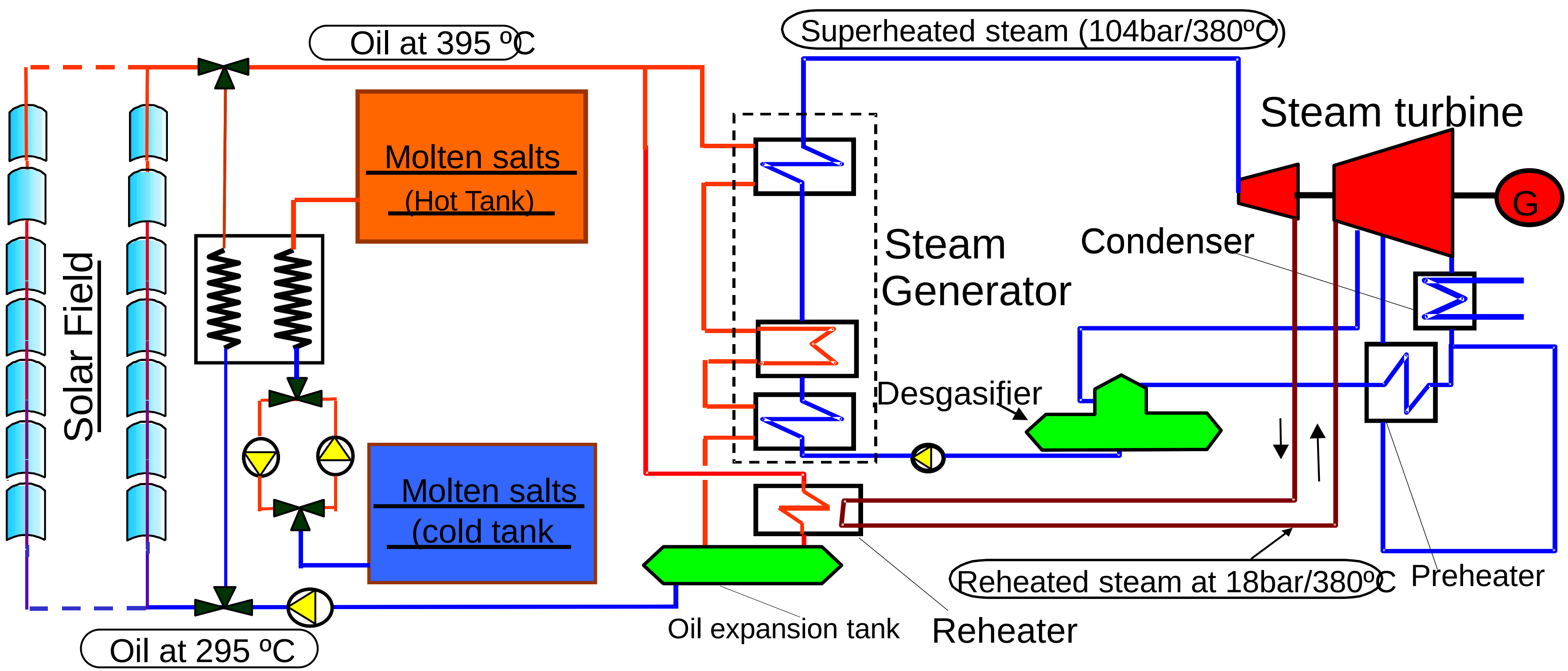
A line-focus solar field may be used to thermally feed:

- **Steam power cycles** (Rankine cycles)
- **Organic Rankine power Cycles** (ORC)

Solar thermal electricity (STE) with PTCs

The technology using PTC with oil as heat transfer fluid is fully proven (>5GWe).

Molten-salt (potassium + sodium nitrates) storage systems are becoming the preferred option for storage.

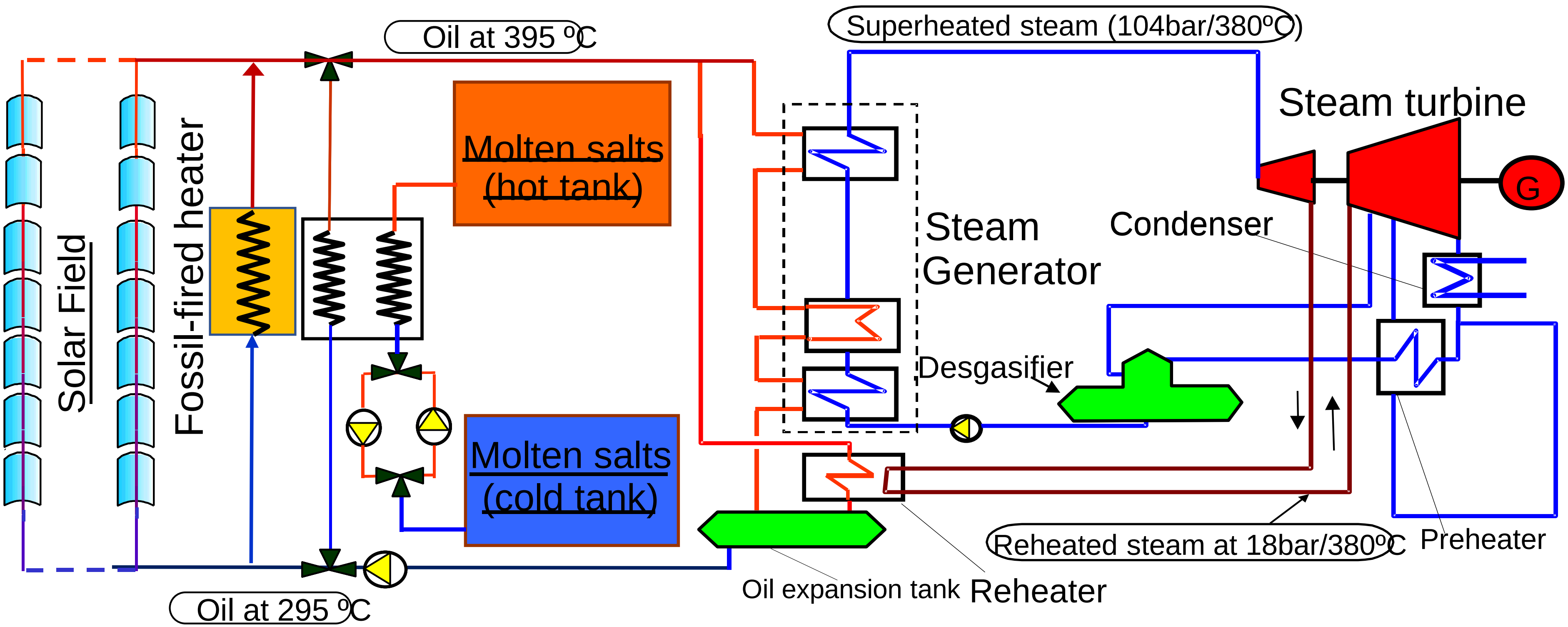


Tipycal CSTP plant with molten-salt thermal storage system

Solar-fossil fuel hybridization of a STE Plant

Hybridization of a CSTP plant

Thermal oil is heated with fossil fuel when solar radiation is not available



Hybrid CSTP plant with molten-salt thermal storage system

Solar Thermal Electric (STE) Plants

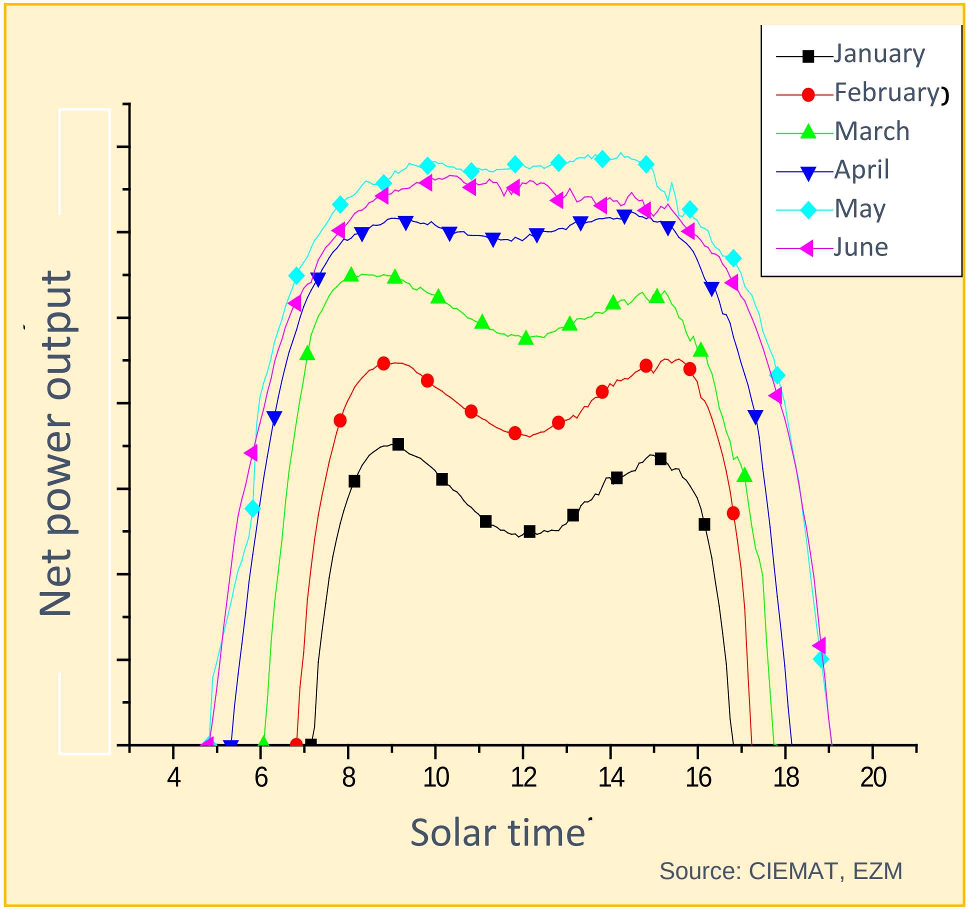
Why are Solar Thermal Electric plants interesting nowadays?:

- ✓ They are already profitable in some countries
- ✓ They have a large potential market (electricity market) Worldwide
- ✓ They are many places in the World with high solar radiation
- ✓ The technology is mature enough for commercial deployment
- ✓ These plants demand a lot of manpower (600-2200 jobs/50MW plant)
- ✓ These plants do not produce CO_2 emissions :

  - 1 GWh of solar thermal electricity saves 800 Tm of CO2

STE plants with PTCs: Seasonal dependence of thermal energy production

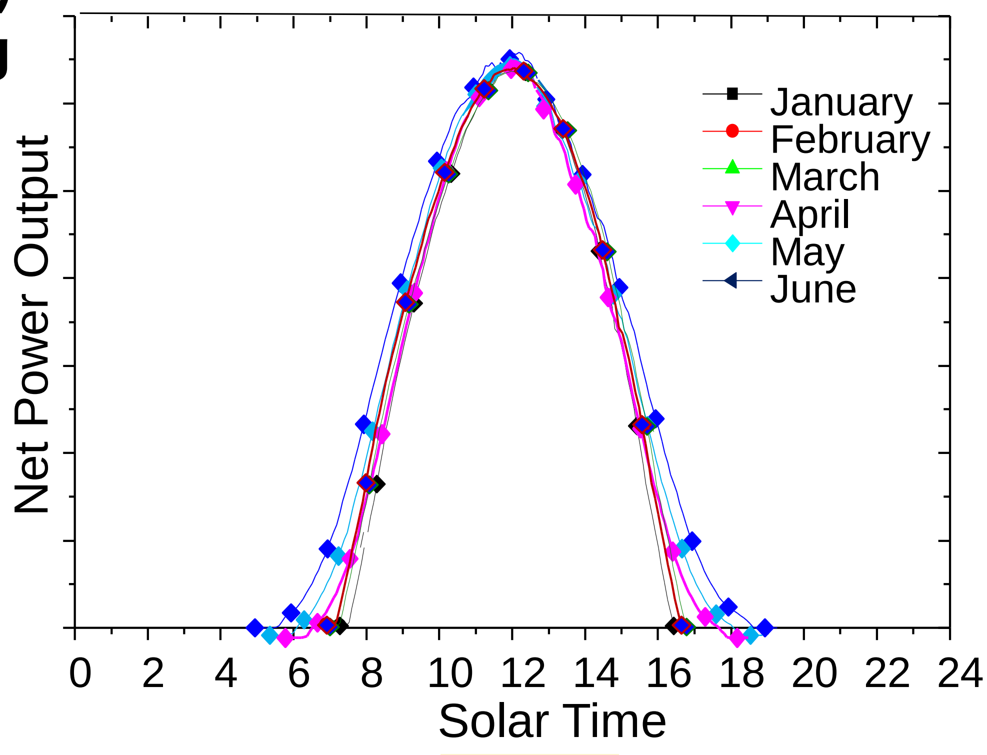
- **Thermal energy delivered by a solar field** with **North-South (N-S)** oriented PTCs **varies a lot during the year**. Three (3) to four (4) times more energy is delivered daily during summer months than in winter months.



Daily profile of the energy delivered by a N-S PTC solar field (Latitude of southern Spain)

STE plants with PTCs: Seasonal dependence of thermal energy production

- **Thermal energy delivered by a solar field** with **North-South (N-S)** oriented PTCs **varies a lot during the year**. Three (3) to four (4) times more energy is delivered daily during summer months than in winter months.
- Thermal energy delivered by **PTCs oriented East-West (EW) does not vary much from summer to winter**.
- The **yearly thermal energy output of a NS-type solar field is greater** than that of a EW-type solar field.

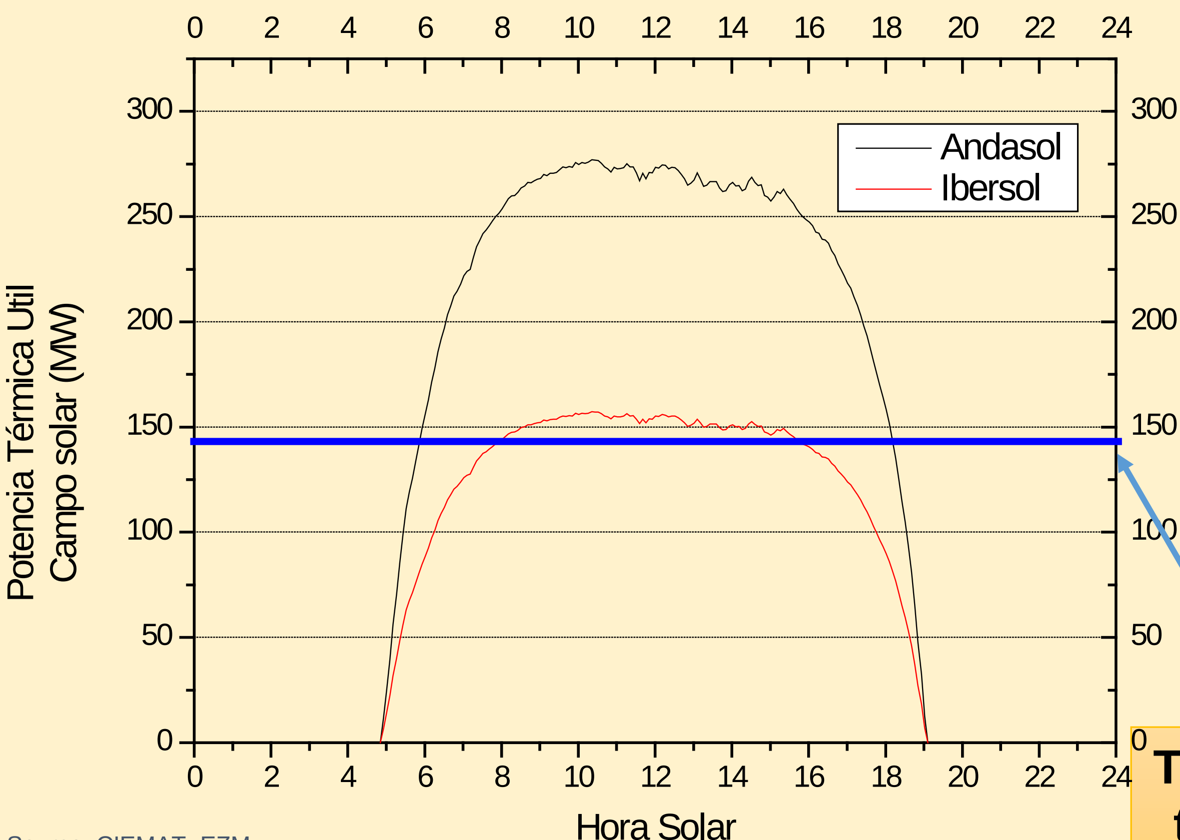


Source: CIEMAT, EZM

Daily profile of the energy delivered by a E-W PTC solar field (Latitude of southern Spain)

STE plants with PTCs

Thermal power produced by two 50 MWe plants, with a without thermal storage system (in a Sunny day in June, Spain)



Source: CIEMAT, EZM

With thermal storage

- 50 MWe nominal power
- 510000 m^2 of PTCs (155 collector loops; 4 PTCs per loop)

Thermal storage 1000 MWh

Without thermal storage

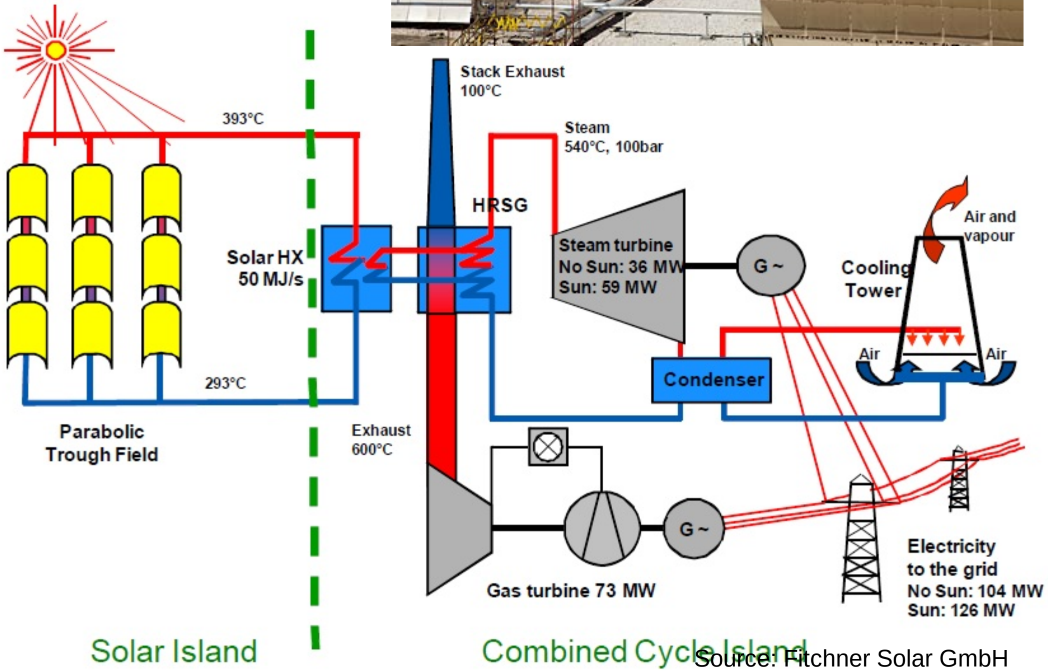
- 50 MWe nominal power
- 288000 m^2 of PTCs (88 loops of collector; 4 PTCs per loop)

NO thermal energy storage

Thermal power required by the power block (50 MWe)

STE plants: Integrated Solar Combined Cycles Systems (ISCCS)

- It is basically a Combined Cycle plant with a small PTC solar field
- The solar field is integrated in the bottoming cycle of a combined-cycle gas-fired power plant
- The solar yearly contribution is small (10-12%)
- It is a good option for those countries willing to get experience with CSTP plants without taking a great risk



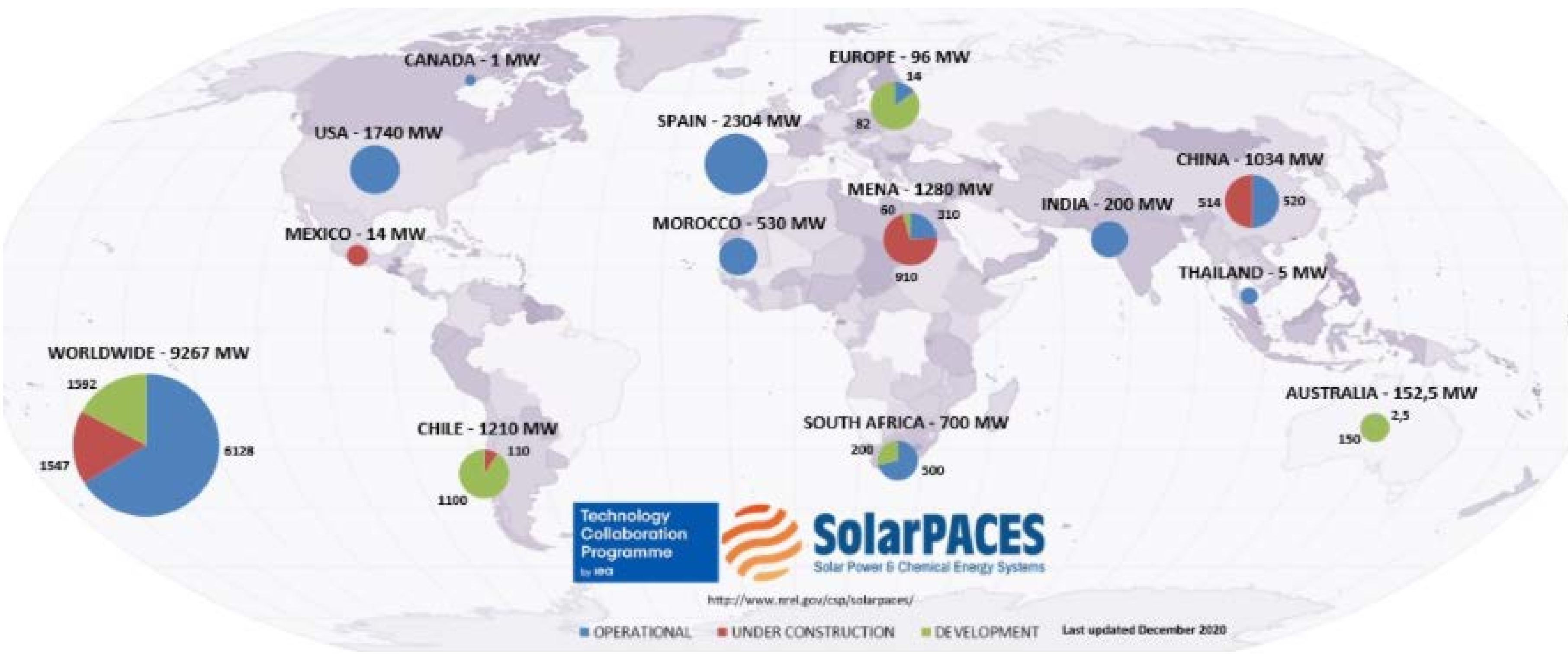
Source: Fitchner Solar GmbH

Solar thermal electricity (STE) Plants

There is a complete data base of STE plants in the World at the link:

https://solarpaces.nrel.gov/

CSP Projects Around the World



First Summer School

Part A: Line-focus Solar Thermal Technologies

September 20-24, 2021

Lecture 7:

SHIP Applications and Electricity Generation with Line-Focus Collectors

- **Thank you very much for your attention**
- **Questions?**

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