European Union's Horizon2020 Research and Innovation programme under grant agreement n°823802

**SFERA-III 2nd Summer School**
**October, 5th- 6th, 2021**
**Almería (Spain)**

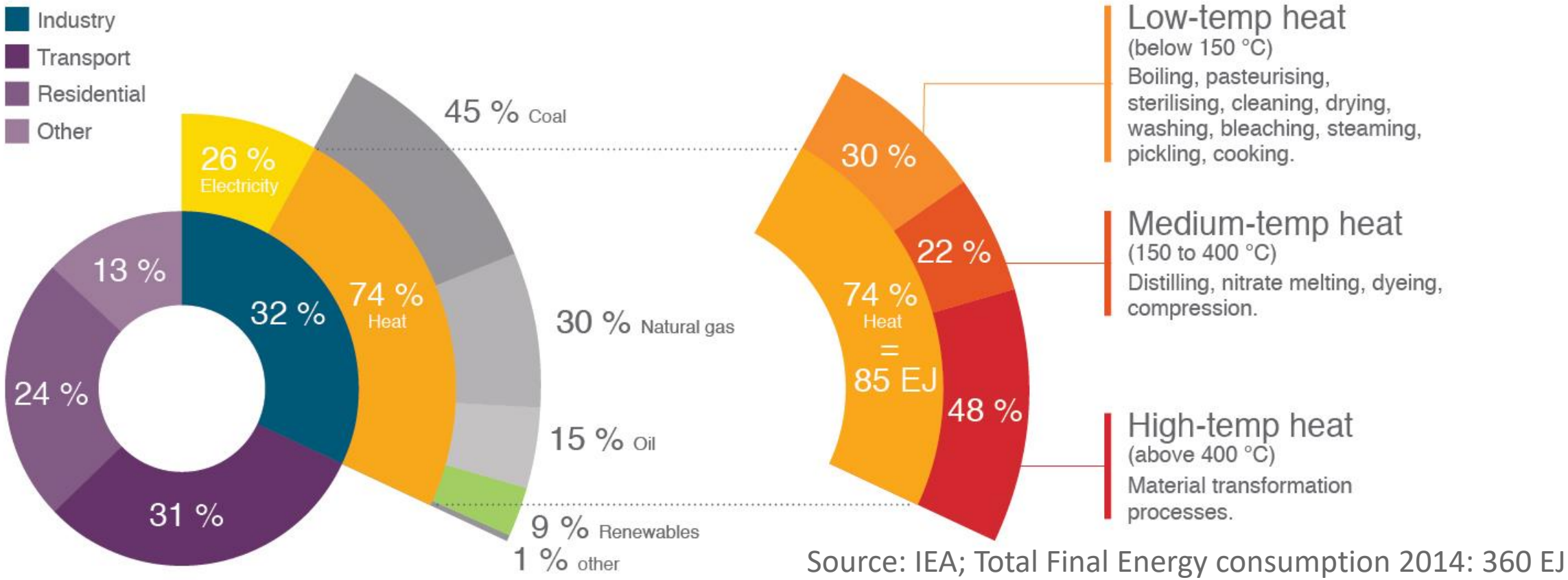
# Lecture:
# SHIP applications at-medium temperatures

Prepared by:
Dirk Krüger
DLR – Institute of Solar Research
Dirk.Krueger@dlr.de

## Content:

- General demand of heat
- Overview on the status of concentrating solar systems
- Examples of installations
- Performance in moderate climates

# Enormous global heat demand in industry




Source: IEA; Total Final Energy consumption 2014: 360 EJ

**There is more final energy consumption of heat in the global industrial sector than there is electricity consumed worldwide!** Source: www.solar-payback.com

# Demand of heat and electricity

## End energy use in 2018 in Germany

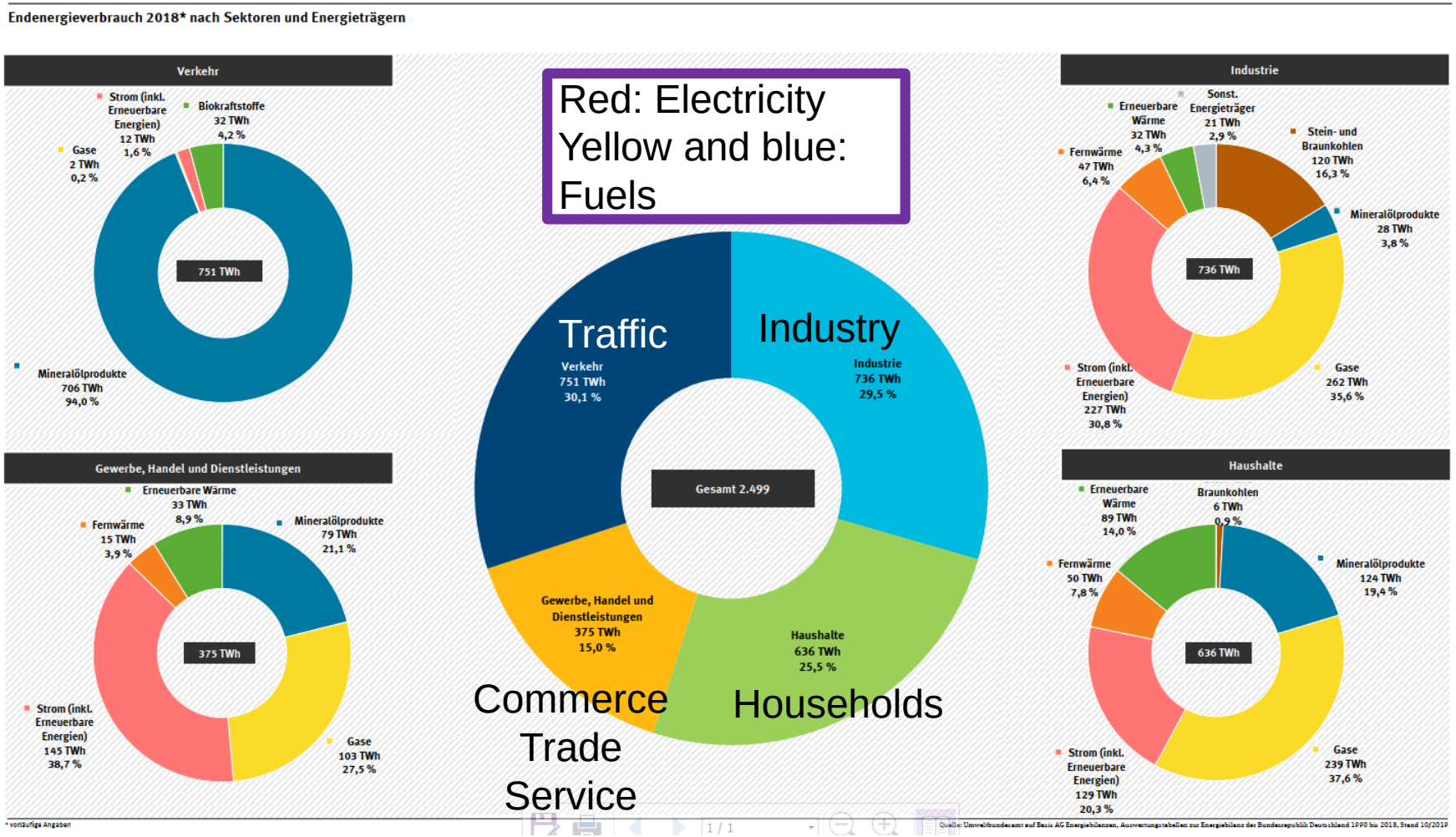
**Electricity makes up for 21% of the end energy use in Germany**

Fuels:

| | |
|---|---|
| Industry | 508 TWh/a |
| Households | 509 TWh/a |
| Commerce, trade, services | 230 TWh/a |
| Total | 1247 TWh/a |

Electricity:

| | |
|---|---|
| Total | 513 TWh/a |




BMWi „Dialogue Climate Neutral Heat “ 2021: In Germany more than half of the total end energy use of 2,500 TWh comes from the heat consumption, about 1,400 TWh.

# Dynamic market development of solar industrial heat

SHIP – Solar Heat in Industrial Processes

**125 SHIP systems**
**(end of 2012)**

**➢817 SHIP systems**
**(end of 2019)**

20 SHIP systems with concentrating collectors commissioned in 2019

→ Adding up to 267,280 $m^2$ (187 $MW_{th}$)

→ vast majority are parabolic trough collectors

→ installed in China, India, Mexico, Belgium, Oman, Senegal, Spain, USA, Portugal, Turkey, Cyprus

Source: Solar Payback

# Driving factor: Growing and submitted supply chain

## Suppliers of Turnkey Solar Process Heat Systems

| | |
|---|---|
| Supplier ready-to-offer | 13 |
| Collector producer ready-to-offer | 5 |
| Supplier with references | 22 |
| Collector producer with references | 42 |

**Rackam, Canada**
Number of references: 8
Total collector area of references: 3,400m$^2$
Link to references
Produced collector type: Parabolic Trough

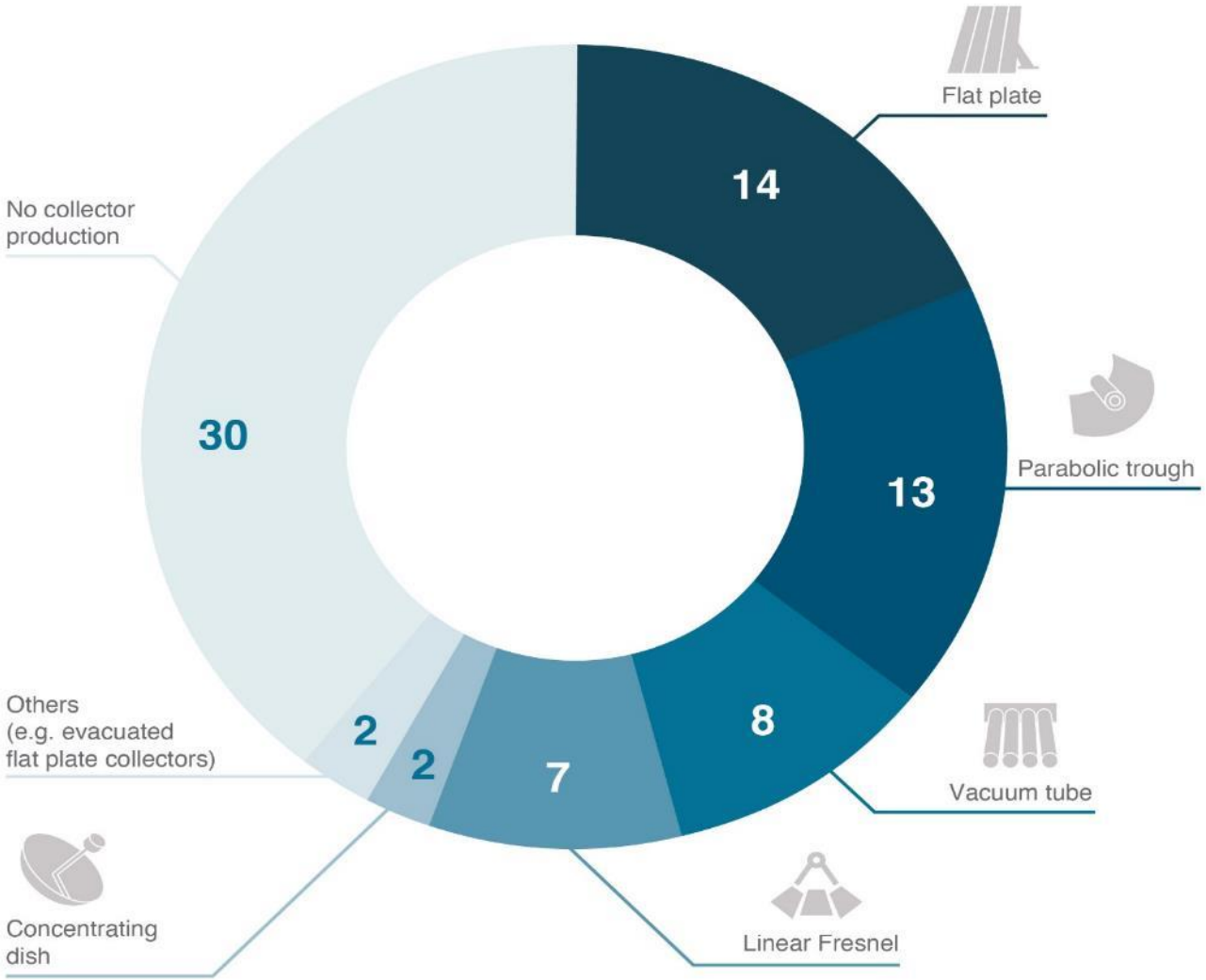
More info

https://www.solar-payback.com/suppliers/
available in English, Spanish and Portuguese

epp@solrico.com

# 76 turnkey SHIP suppliers are currently depicted on the world map

61 % of the listed companies produce collectors in-house or on-site




Solar Payback

# Ranking of the most experienced SHIP technology suppliers

Turnkey solar industrial heat suppliers with more than 10 reference projects at the end of 2019

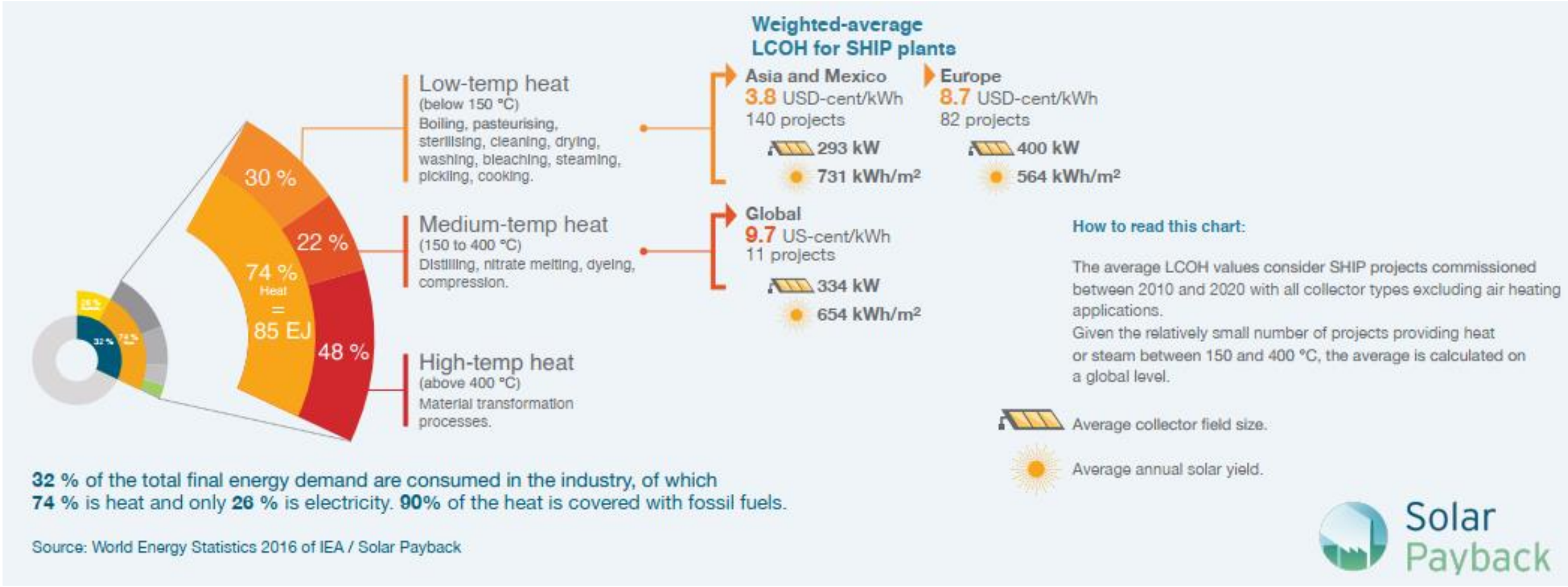
| | | | |
|---|---|---|---|
| 89 | **Módulo Solar** Mexico | 22 | **Millennium Energy Industries** Jordan |
| 72 | **Sunrain** China | 21 | **Inter Solar Systems** India |
| 66 | **Inventive Power** Mexico | 20 | **Soliterm** Germany |
| 47 | **Linuo Paradigma** China | 16 | **Sunda** China |
| 32 | **Megawatt Solutions** India | 15 | **Himin** China |
| 29 | **Ritter XL Solar** Germany | 15 | **Solid Energy Systems** Austria |
| 28 | **SEA Sistemas de Ecotecnias Ambientales,** Mexico | 14 | **Casolar** Mexico |
| 24 | **Vicot Solar Technology** China | | |

Industry hubs: China, Mexico, India and Germany

Established suppliers of concentrating collectors

Source: Solar Payback surveys

# Cost development of solar collector installations stationary and concentrating



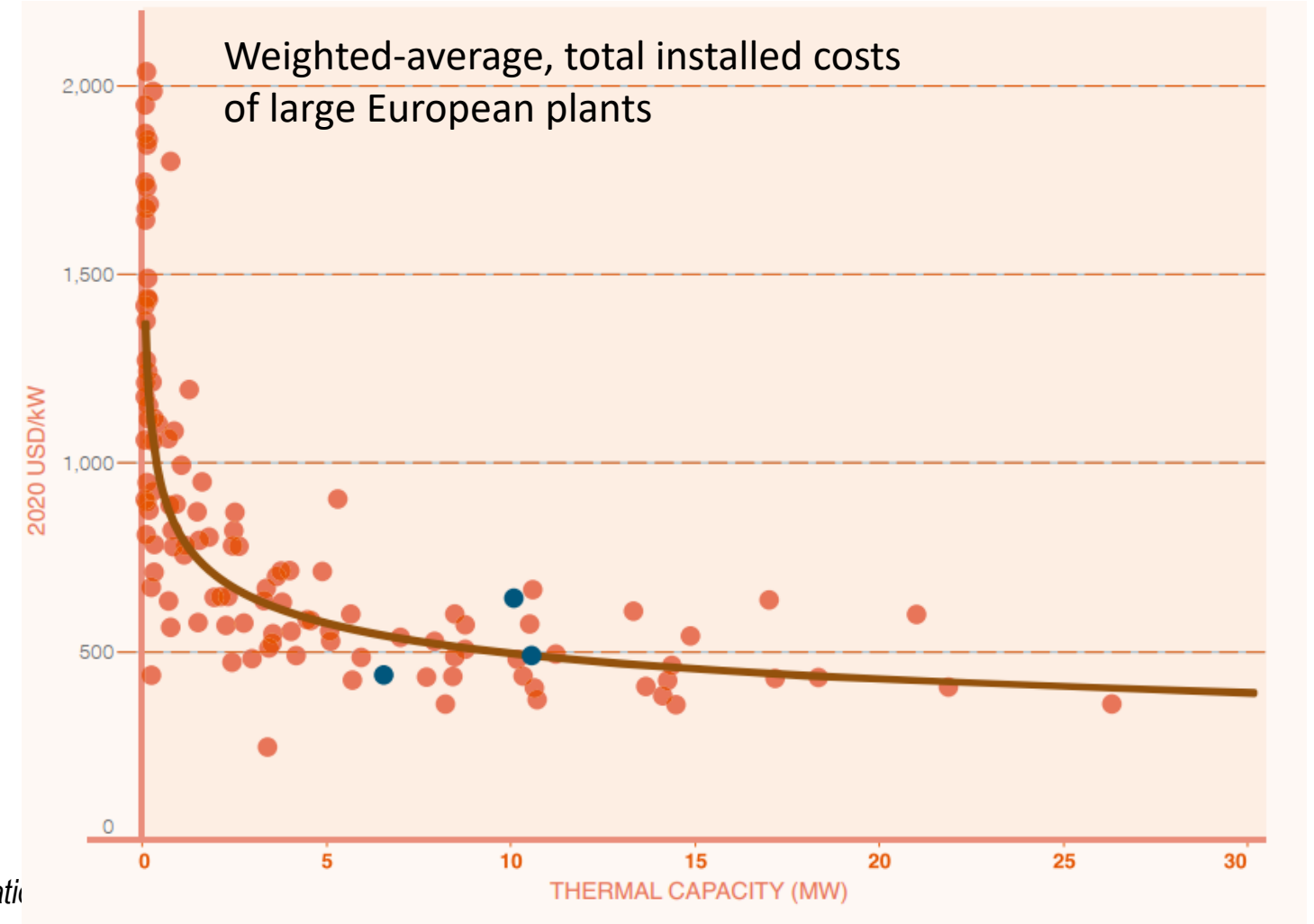
# Cost development by economies of scale: Weighted-average, total installed costs of large European plants

Each orange circle shows one SDH project and each blue circle shows one of the large multi-MW SHIP plants commissioned between 2010 and 2021 in Europe.

97 % of the SDH projects have been installed in three countries Austria, Germany and Denmark.

The fitted, trend line shows the cost degression for increased plant sizes in MW.

Source: IRENA and Solar Payback, 2021



# The MW-class: 360 MW of parabolic troughs in glasshouses are in operation in Oman for Enhanced Oil Recovery

Second phase with 360 MW transferred to customer in spring 2020

May 2020 bankruptcy of GlassPoint

Photos: GlassPoint

# ESCO SHIP projects – Mega Trend in France

Project Developer **NewHeat**, France, closed a EUR 13 million EUR bank loan deal in August 2020 to finance five ESCO solar heat projects in France with 28 $MW_{th}$ in total

Photo: NewHeat

**Kyotherm,** a renewable heat third party financer, has the largest SHIP project in Europe under construction

- 14,000 $m^2$ flat plate collectors (10 MW) for a malting plant in the south of France
- EUR 6 million CAPEX
- Negotiated heat price: 26 EUR/MWh plus inflation over 20 years

# Commercial role-out of SHIP systems in Mexico

Inventive Power commissioned at least 66 SHIP systems between 2010 and 2019

>100 installations process heat and domestic heating

Many installations provide pre-heating in steam systems or hot water

Total costs including: Collector field and circuit - Solar storage tank - Planning and installation costs (Not included: equipment for integration into client's network, financing costs, subsidies and VAT)

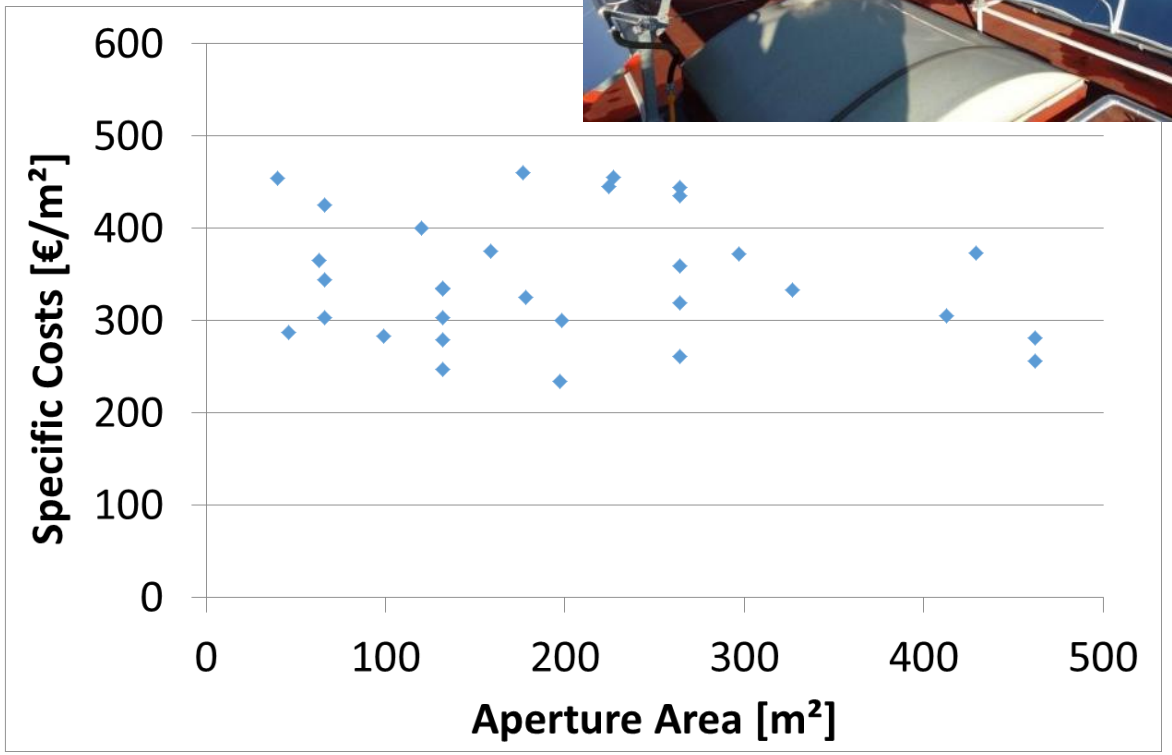



Photo: Inventive Power / AEE Intec http://ship-plants.info

# Installations in Turkey and Afghanistan

Collector supplier and EPC Soliterm

2020: Izmir, Turkey – 5,500m² process heat for packaging industry

2018: 5 Plants in total 14,558 m² e.g. Bursa/Turkey – 4,320 m² steam for textile process

Herat Afghanistan – 3,240 m2 butchery

2017: Kaya Laundry, Turkey – 4,996 m² steam support of the laundry

Motivations customers:

- Replace gas
- Sustainable and manageable heat supply reducing dependency on volatile fuel prices
- $CO_2$ reduction – avoid $CO_2$ taxes

# Combination trough with concrete storage and CPC collectors

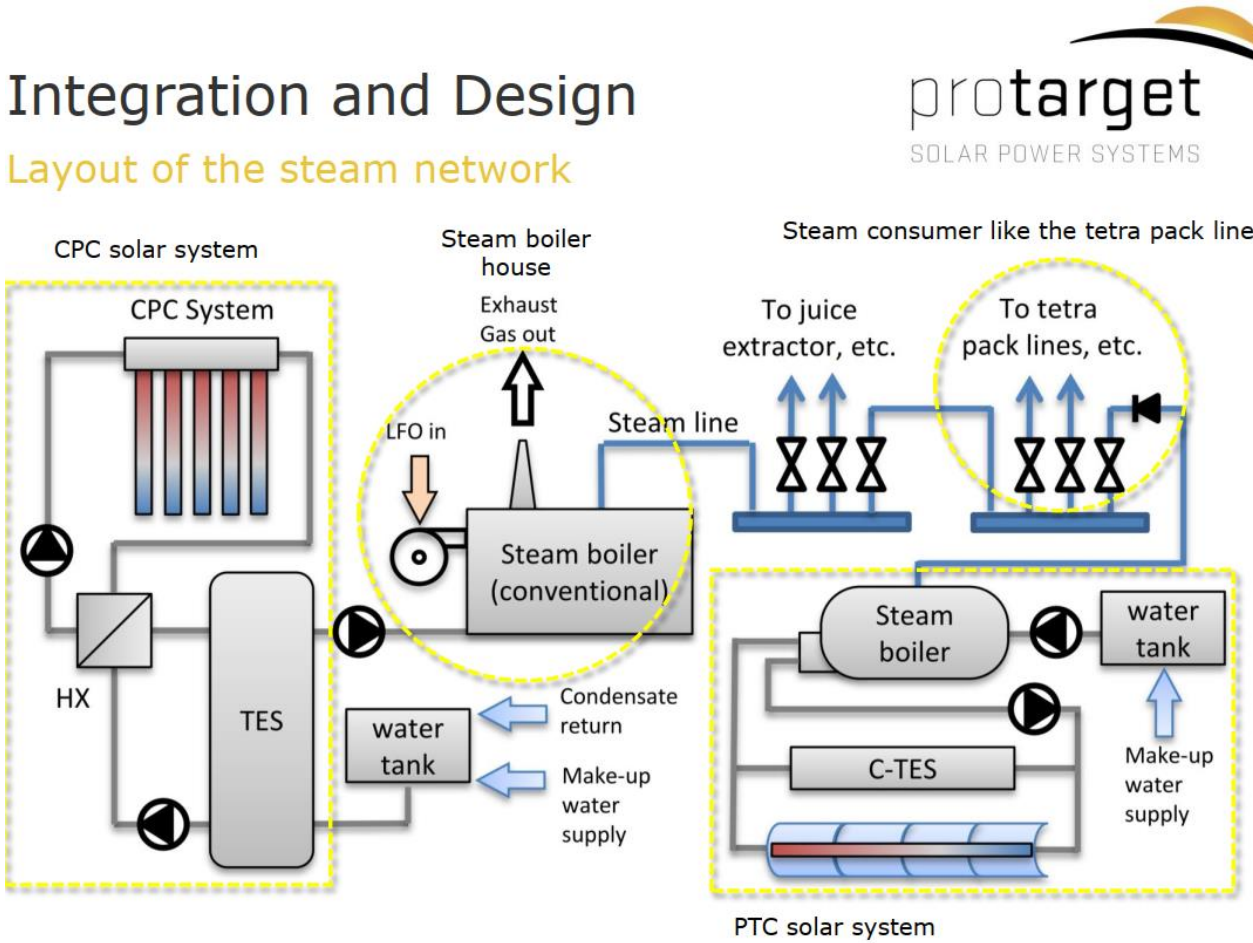
Juice production in Cyprus

EPC and collectors protarget

PTC 283 m², steam at 11barg and 188°C

Solar field up to 410°C to load a concrete storage

CPC 225 m², hot water at 95°C for feedwater




Photo, layout: protarget

# Transportable, prefabricated linear Fresnel collector from Spain

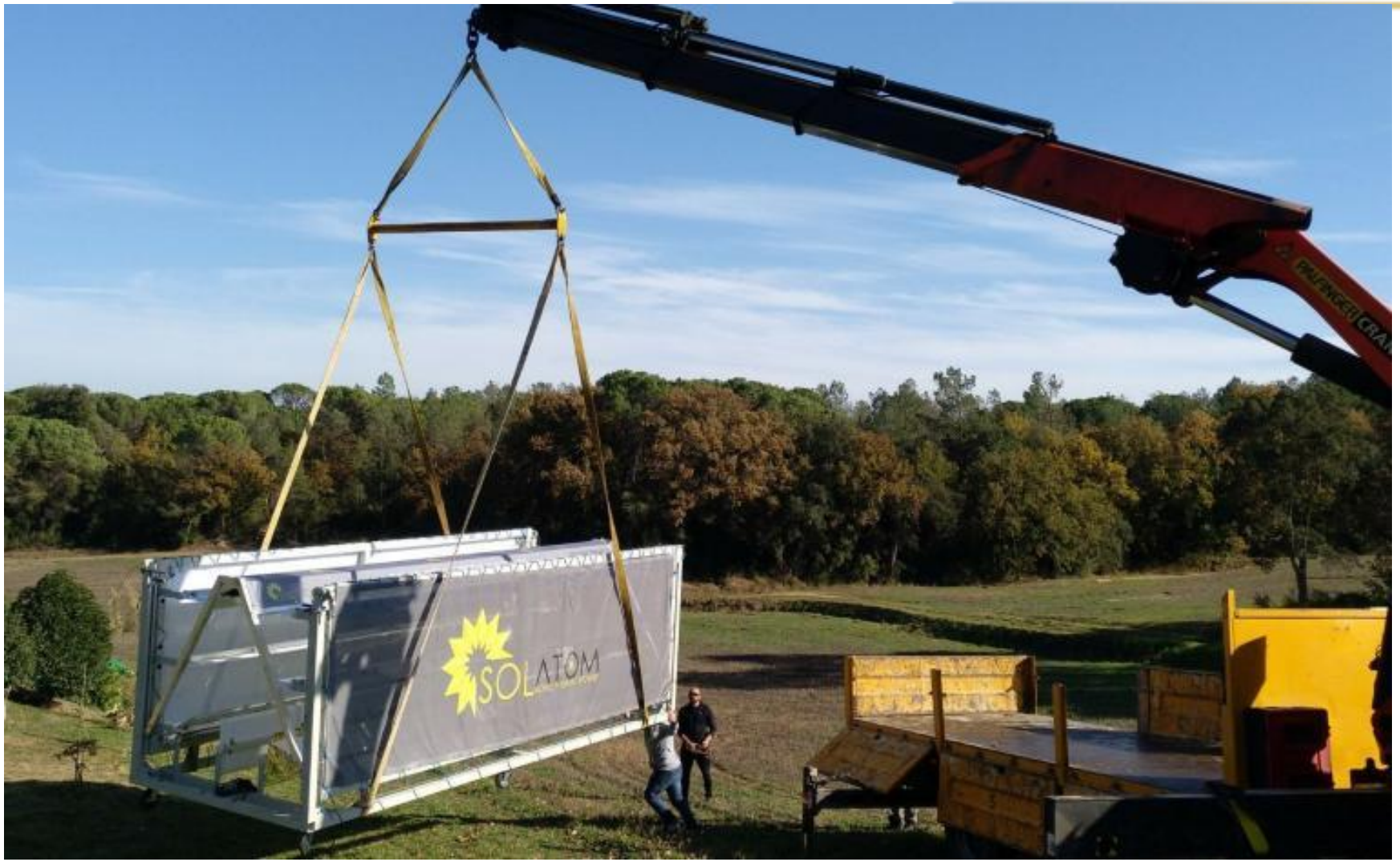



Photo: Solatom

Fresnel module with 20 kW

less than 23 kg/m$^2$

# Direct steam generation with Ruth storage

Amman, Jordan, JTI – Japan Tobacco International

Collectors and EPC: Industrial Solar

1,254 m² Fresnel collector field in operation since 2017

Rooftop installation

Max. 220°C steam temperature

15 m³ steam drum allows 1 hour storage at full load

Steam for production and for double-effect absorption chiller for climatisation

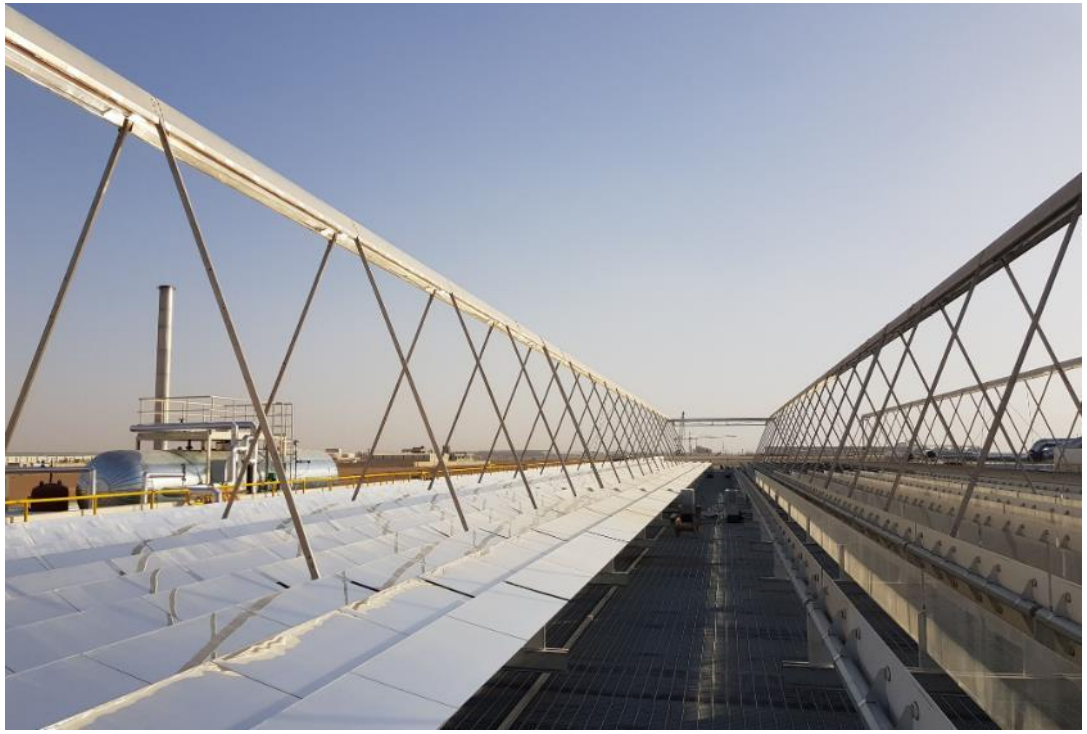


Photo: Industrial Solar

# Collector certified according to ISO 9806

Collector with glass cover instead of receiver glass pipe

Producer Absolicon

Certificate:
reliable information for customers on efficiency
annual yield for collector comparison

Photo: Absolicon

# Green heating policy in China drives huge investment in parabolic fields

Site: Baotou, Inner Mongolia, China

Collectors, EPC, operator: Xuchen Energy, Inner Mongolia

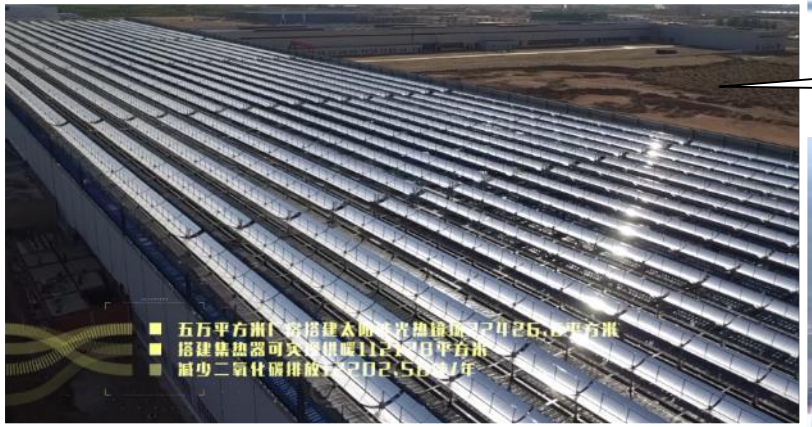
93,000 m³ in operation since 2016 of which 22.000m² on roof

66,000m³ water storage up to 95°C

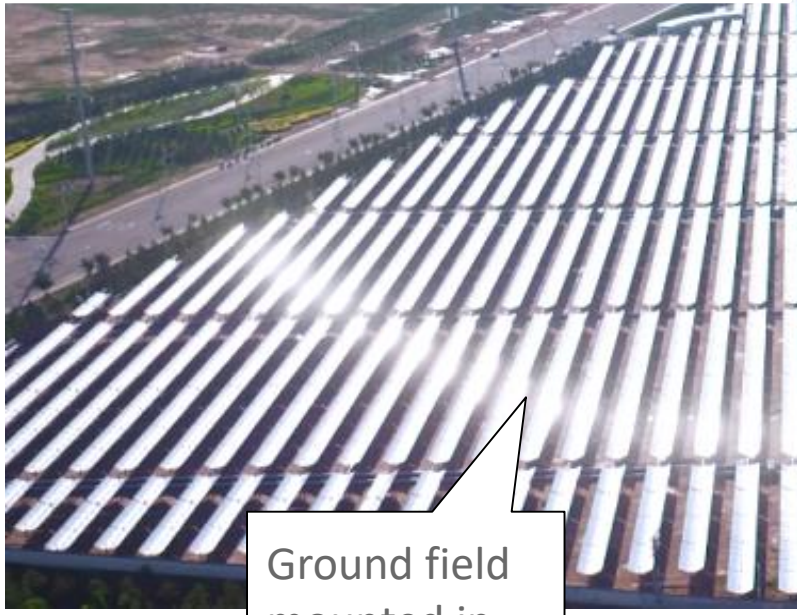
Up to 220°C in solar field

Space heating for buildings

100 % subsidised by the central government within green heating policy



Roof top installation



Ground field mounted in east-west axis

Photos: Xuchen

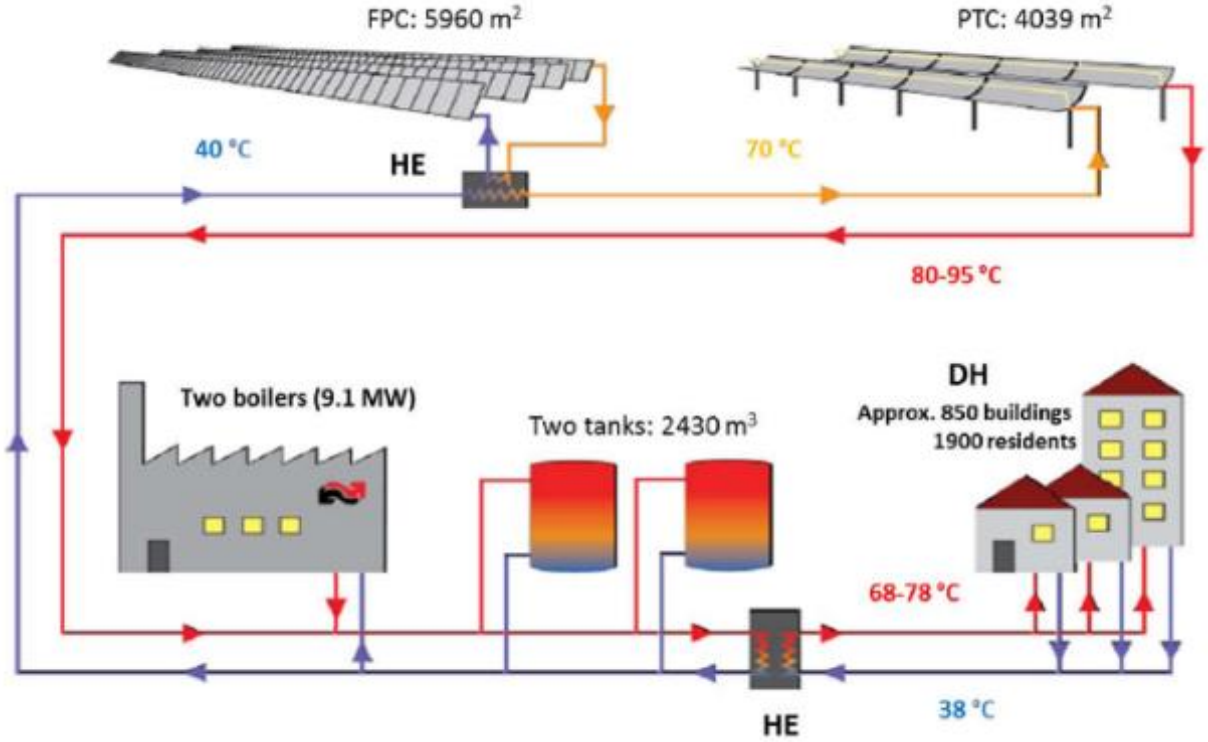
# Example Denmark: Combination of Technologies

District heating Taars, Denmark

5972 m² Flat plate collectors (40°C→ 70 °C)

3039 m² Parabolic trough collectors (70°C→ 98 °C)

Flow in series




Left: PTC, right FPC

# ESCO collector fields Belgium for chemical industry

Azteq - ESCO, Solarlite - EPC

Commissioned 2019/2020, in operation

Parabolic trough collectors 1100 m²

Field temperatures 220°C/330°C

Process steam generation at 6 bar, 155 °C and 11 bar, 185 °C

Roughly 1 hour of cold start early morning,
warm start in summer 20 minutes,
hot start-up 1 to 3 minutes

Cleaning by rain

Antwerpen, Belgium
Photo: DLR

Oostende, Belgium
Photo: Solarlite

# Concentrating collectors in moderate climates

Status: Concentrating collector systems are not established for moderate climates:

"Direct normal irradiance is low" (compared to global irradiance) in these regions

"Energy yield is not attractive"

"Costs are way down to high"

→ **Studies show that these statements are rather intuitive but not valid**

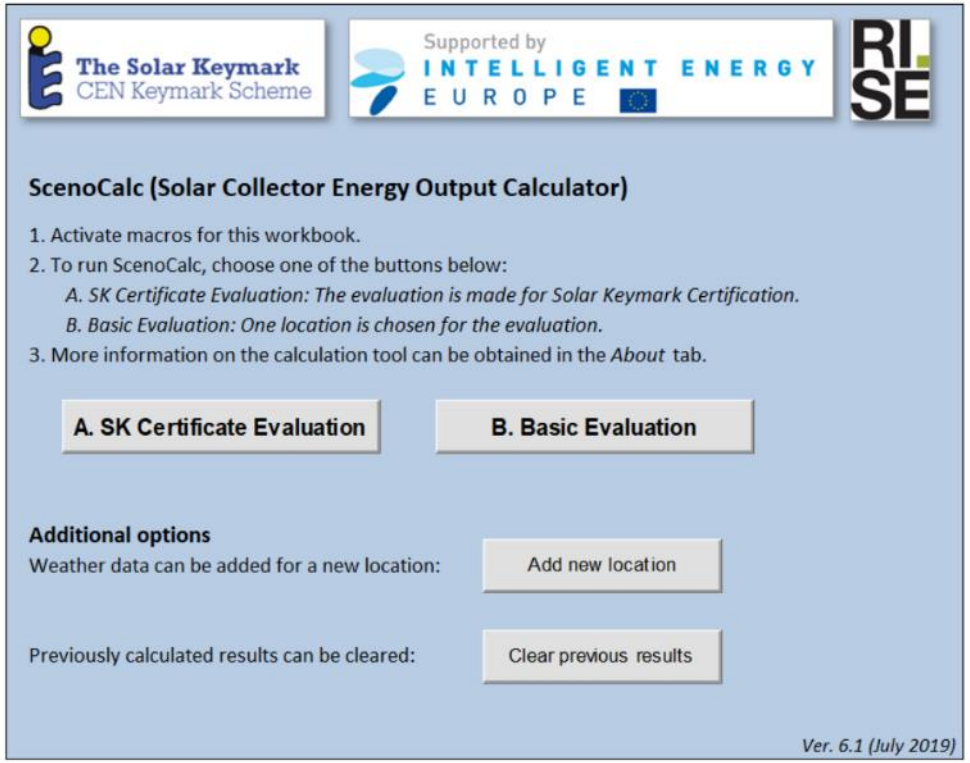
Approach:

- Benchmark with established best stationary collectors
- Choose a climate with a comparatively low DNI at about 1000 kWh/(m²*a)
- Calculate the technical yield
  - Using ScenoCalc software (collector performance)
  - Using Greenius software (system performance)
- Compare costs of the systems

# ScenoCalc

ScenoCalc is a European tool for calculating energy yield for the SolarKEYMARK certificate. It is a well established means for evaluating the output of stationary and tracking solar collectors.

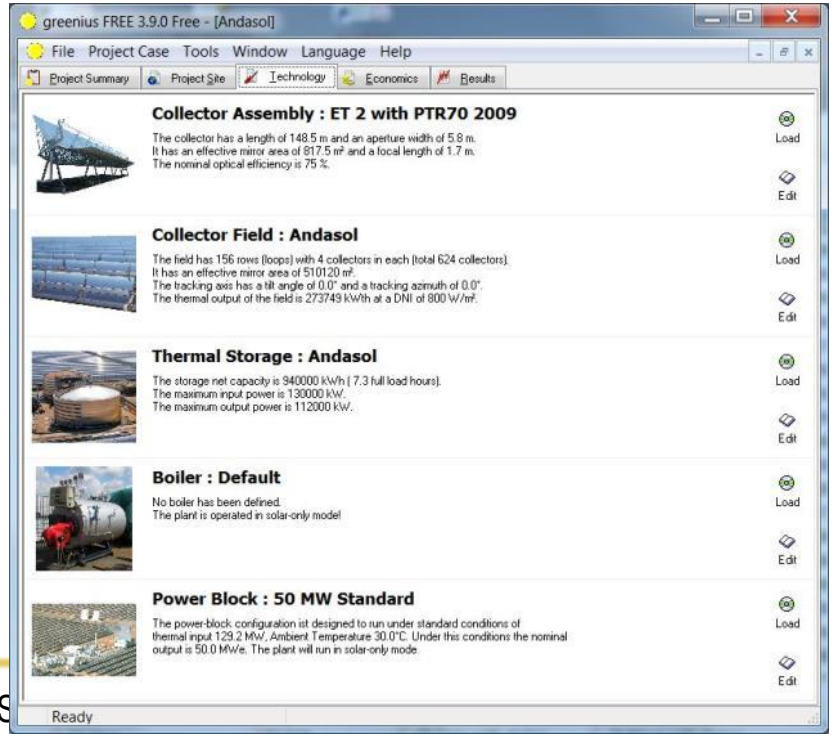
- ScenoCalc
  → well suited for collector comparison
  → Uses efficiency and IAM function for 4 weather files
  → resulting (gross!) energy yields does not include system losses
  difference can be 1/3
- ScenoCalc calculates yield without heat losses in piping
  or heat capacities and therefore reaches high values.
- For operational temperatures 25 to 100°C
- IAM function implementation under check



# Greenius

- Greenius is a free tool for calculating energy yield and economic data for renewables with a focus on solar thermal concentrating power plants. It has been validated well in comparison studies e.g. in the IEA Task on Solar Process Heat. Yield calculations include e.g. heat losses in piping, heat capacities and soiling to achieve realistic results. Alternative: SAM
- Freegreenius is available here:

https://www.dlr.de/sf/en/desktopdefault.aspx/tabid-11688/20442_read-44865/




# Collector technology

Energy yield in dependency of collector operating temperature for parabolic trough, vacuum tube and flat plate collectors calculated. Solar tower and Fresnel technology are alternatives but not investigated here.

The energy yield of parabolic trough technology is being calculated and compared with benchmark technologies which are commercially successfull. The presentation consists of:

Inputs:

- Solar field 10.000 m²
- Piping, and heat capacities included

Troughs only:

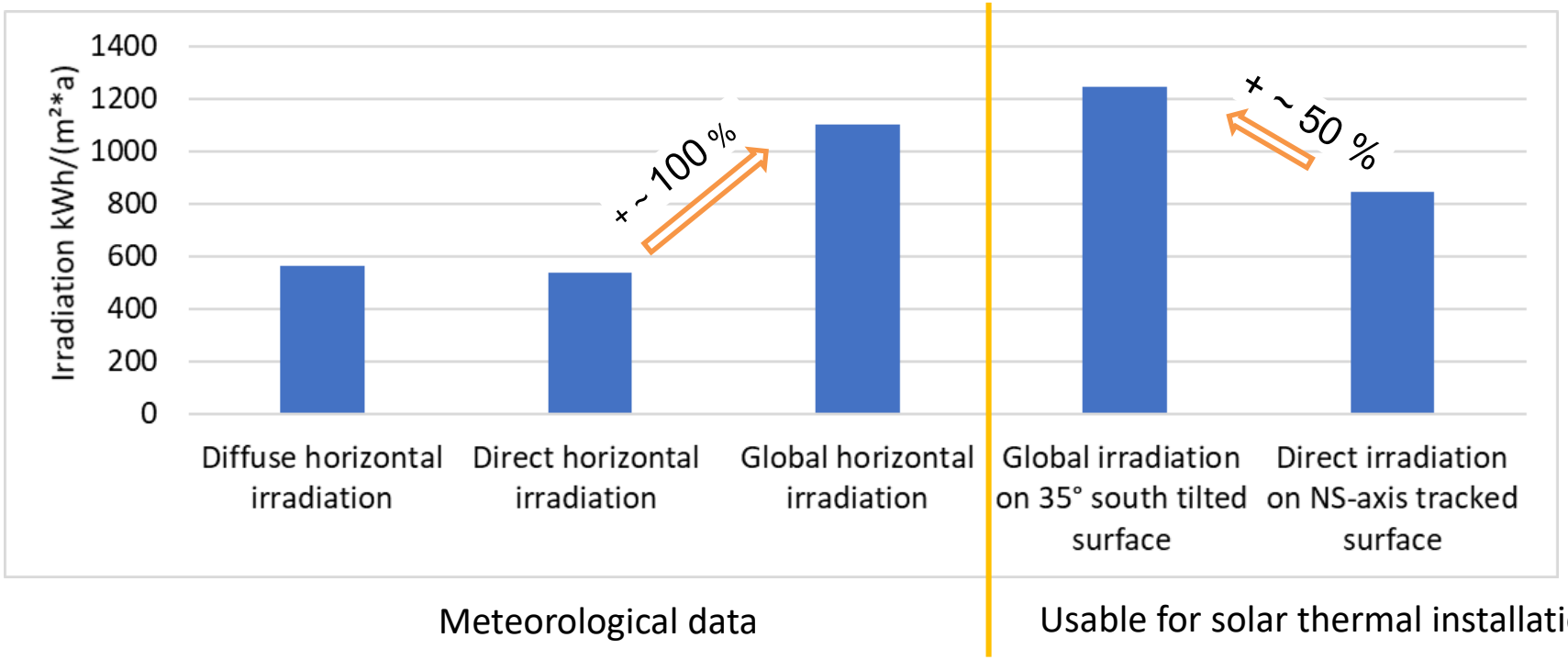
- Shading, distance 3 x aperture width
- Mirror cleanliness at 98%, availability 99%.

Calculations for trough based on high efficiency components

- Glas/silver mirrors
- Antireflex coating
- Vacuum receiver
- High absorptance
- High cleanliness
- High precision in form and tracking

# Relations of irradiations on different surfaces

Radiation for the site of Würzburg, Germany, a typical spot in Central Europe

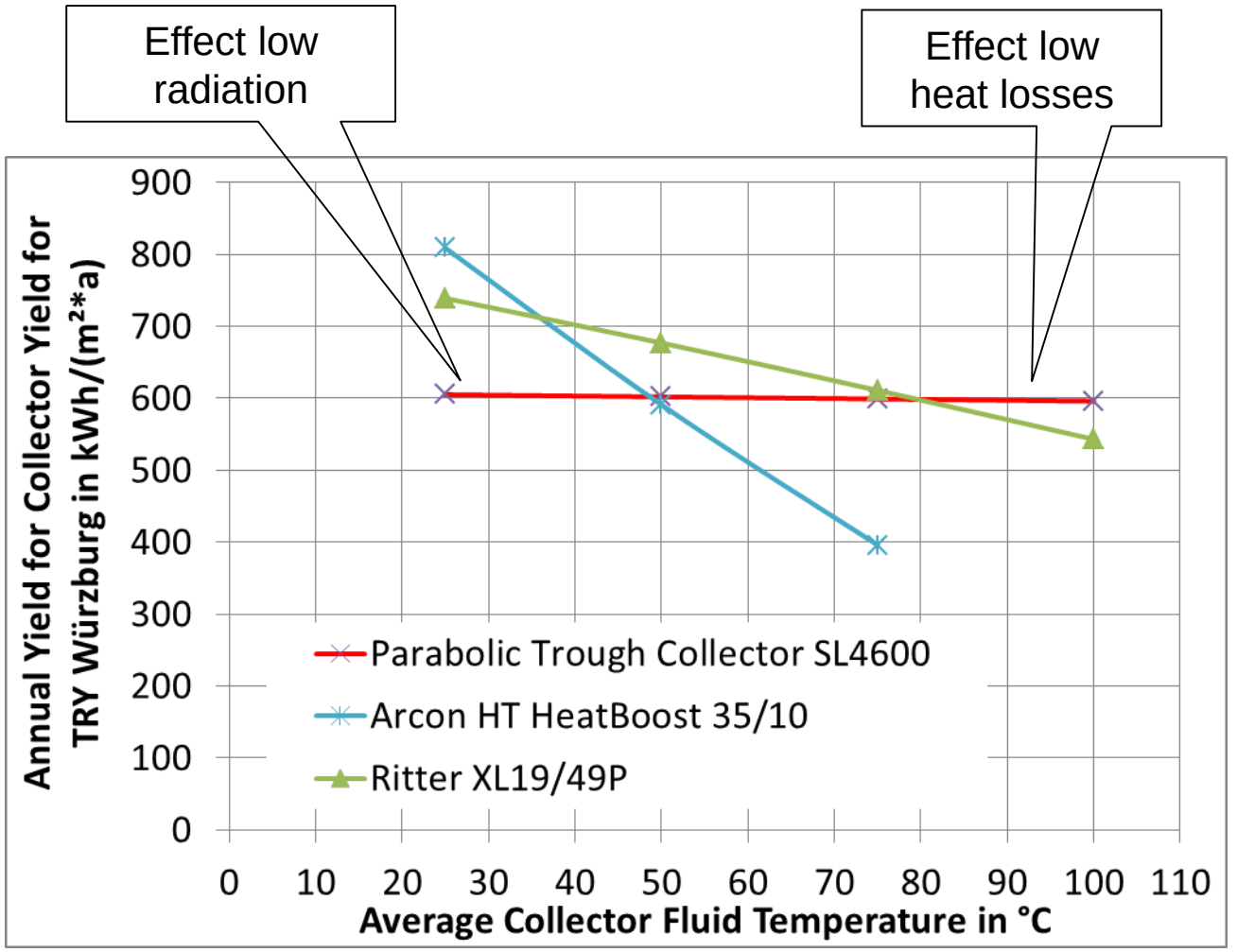



Related to the horizontal the global irradiation is twice as high as the direct irradiation
Usable irradiation on collector surface is ~ 50% higher for stationary collectors

# Results ScenoCalc 6.1

Collectors and set-up:
Parabolic Trough: NS axis, horizontal
Flat Plate Collector: tilted 35° to south
Vacuumtube with CPC: tilted 35° to south

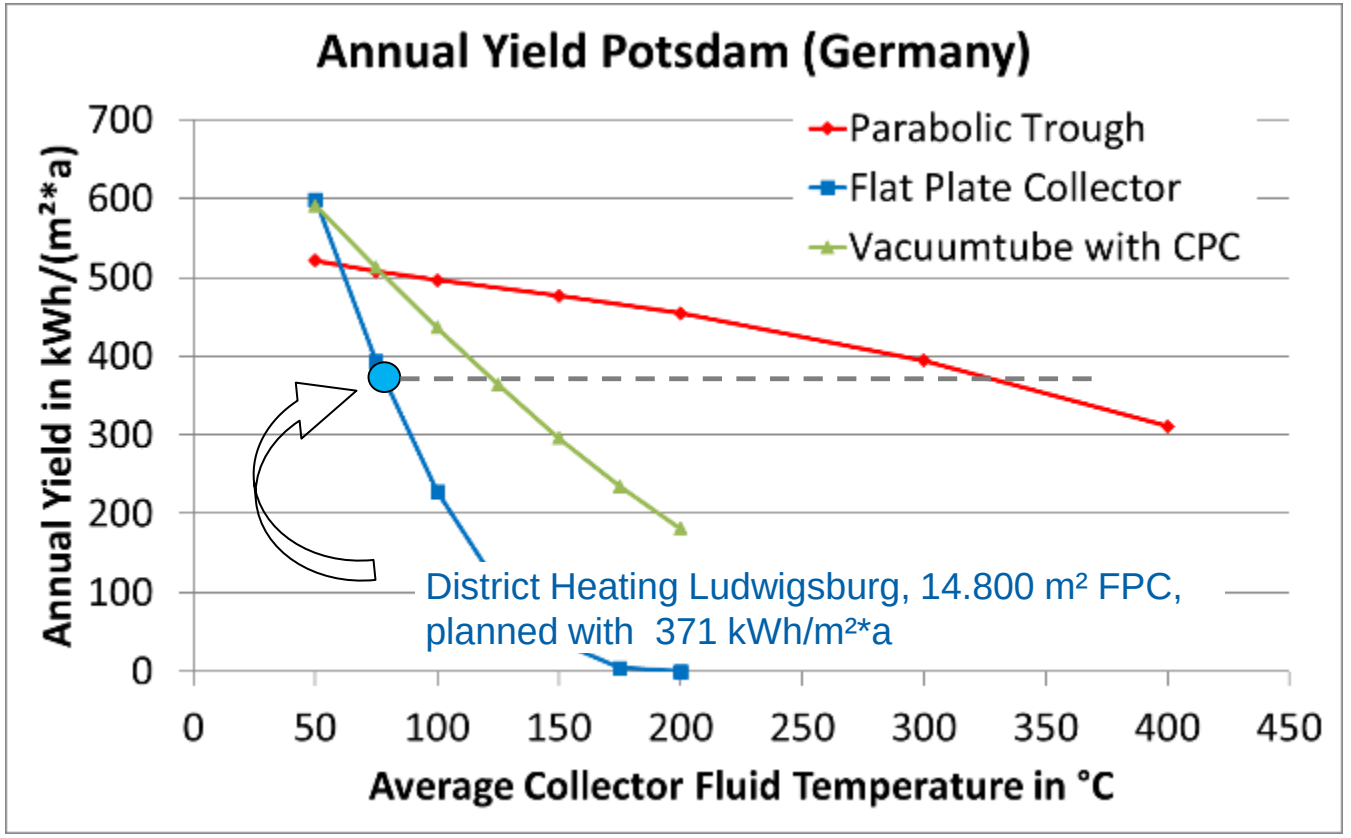
| Weather data Würzburg, Germany of ScenoCalc | kWh/(m²*a) |
|---|---|
| Diffuse horizontal irradiation | 562 |
| Beam horizontal irradiation | 540 |
| Direct normal irradiation | 1014 |
| Global irradiation tilted 35° south | 1244 |
| Direct irradiation on NS-axis tracking surface | 848 |



# Results greenius for Potsdam, Germany

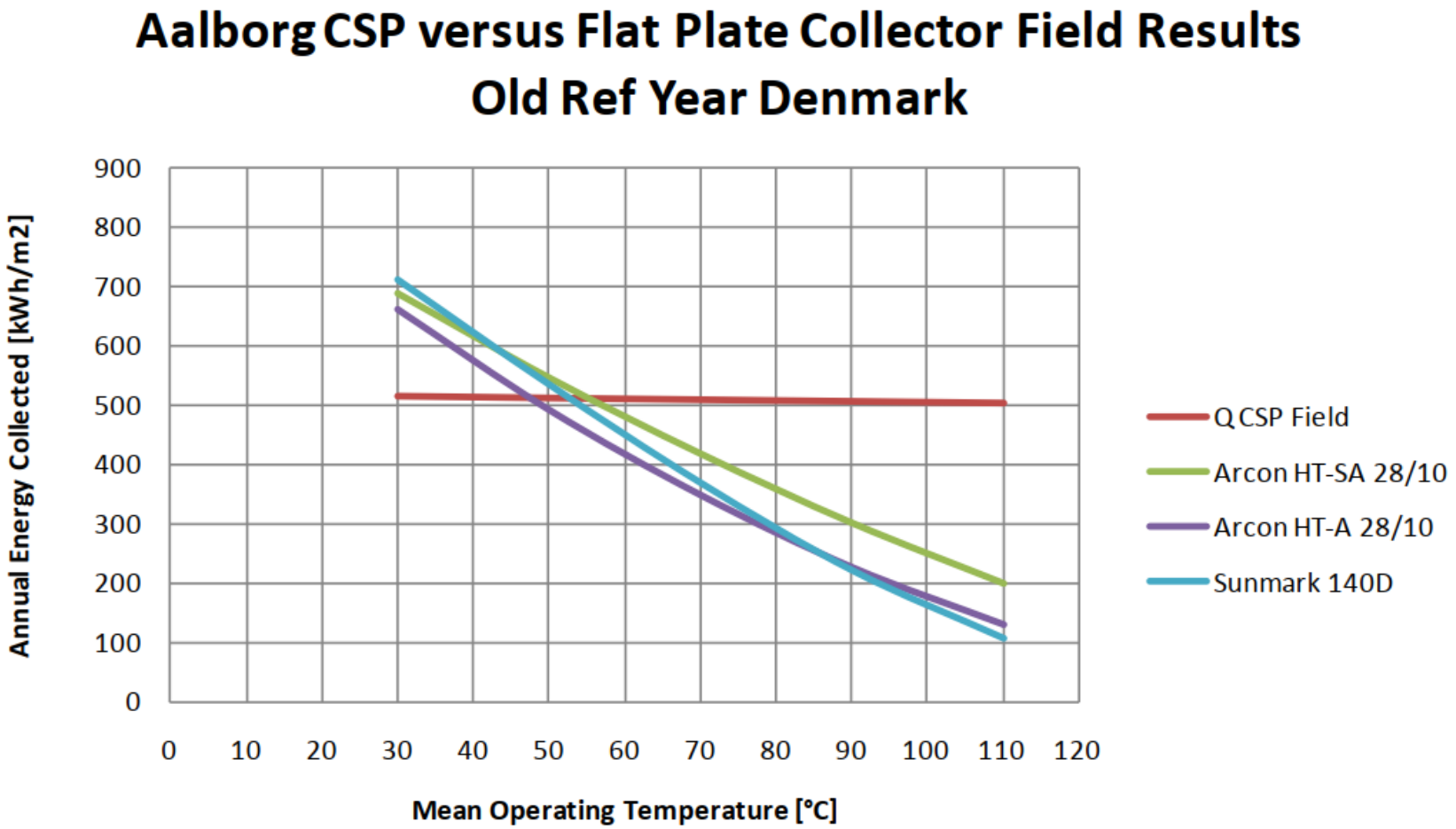
Energy yield in dependency of collector operating temperature for parabolic trough, vacuum tube and flat plate collectors calculated with greenius.

| Weather data Potsdam, (near Berlin) Germany of Meteonorm kWh/(m²*a) | |
|---|---|
| Diffuse horizontal irradiation | 566 |
| Beam horizontal irradiation | 489 |
| Direct normal irradiation | 967 |
| Direct irradiation on NS-axis tracking surface | 808 |



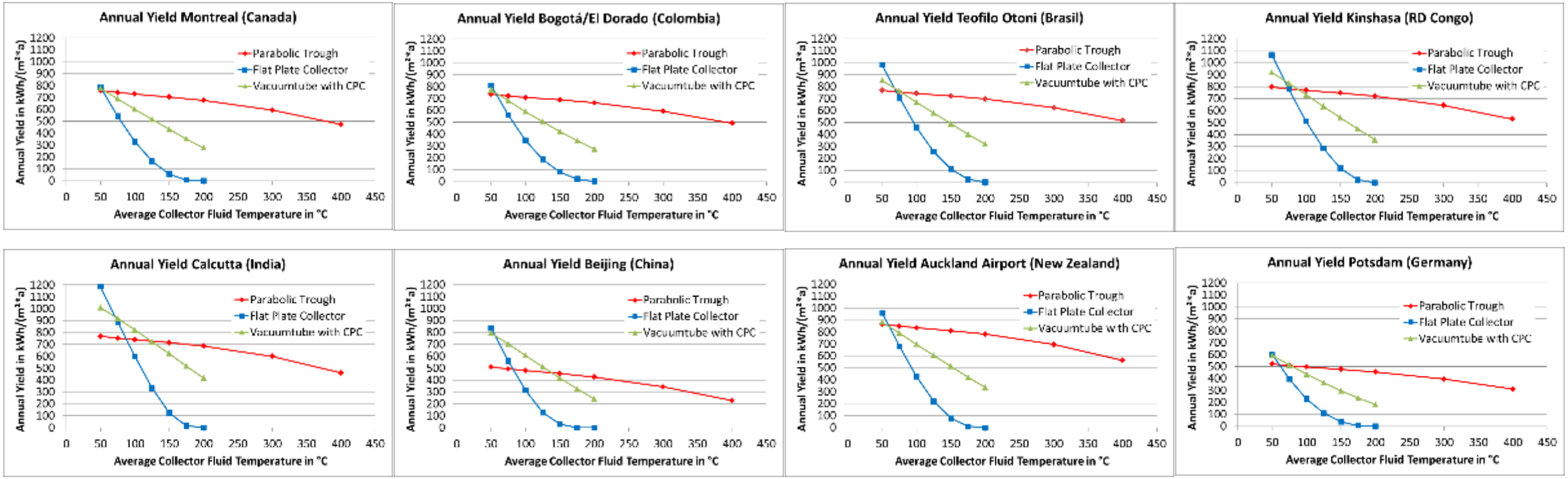

→ Break-even point 50…80 °C confirmed for moderate central European climate

# Energy Yield in Calculations by DTU




Annual yield of a parabolic trough collector compared to flat plate collectors for a Danish climate
Danish Technical University Civil Engineering Report R-292 (UK), 2013

# Annual Yields for Various Sites with DNI around 1000 kWh/m²*a




Annual yields for various sites as a function of mean operation temperature for high efficient collector technologies

# Results from collector field at ADPO in Belgium for chemical industry

Results provided by the company Solarlite CSP Technology
Commissioned 2019/2020
Parabolic trough collectors 1100 m²
Field temperatures (primary circuit) 200°C/300°C
Process steam generation at 160 to 170°C
Collector has only been cleaned by rain
Short 15 m piping between solar field and steam generator

| | | |
|---|---|---|
| Yield measured | 452 | $MWh_{th}$ |
| Yield corrected | 468 | $MWh_{th}$ |
| Gross aperture | 1107,8 | m² |
| Spec. yield measured | 408 | kWh/m² |
| Spec. yield corrected | 422 | kWh/m² |
| DNI | 834 | kWh/m² |
| DNI corrected by 10 % | 917 | kWh/m² |
| **Annual efficiency measured** | **49** | **%** |
| **Annual efficiency corrected** | **46** | **%** |

Measured yield in primary circuit for period 01.08.2020 to 31.07.2021

Elevated solar collector field
Photo: DLR

# Supply Characteristics and Serial Combination

Different supply along the day

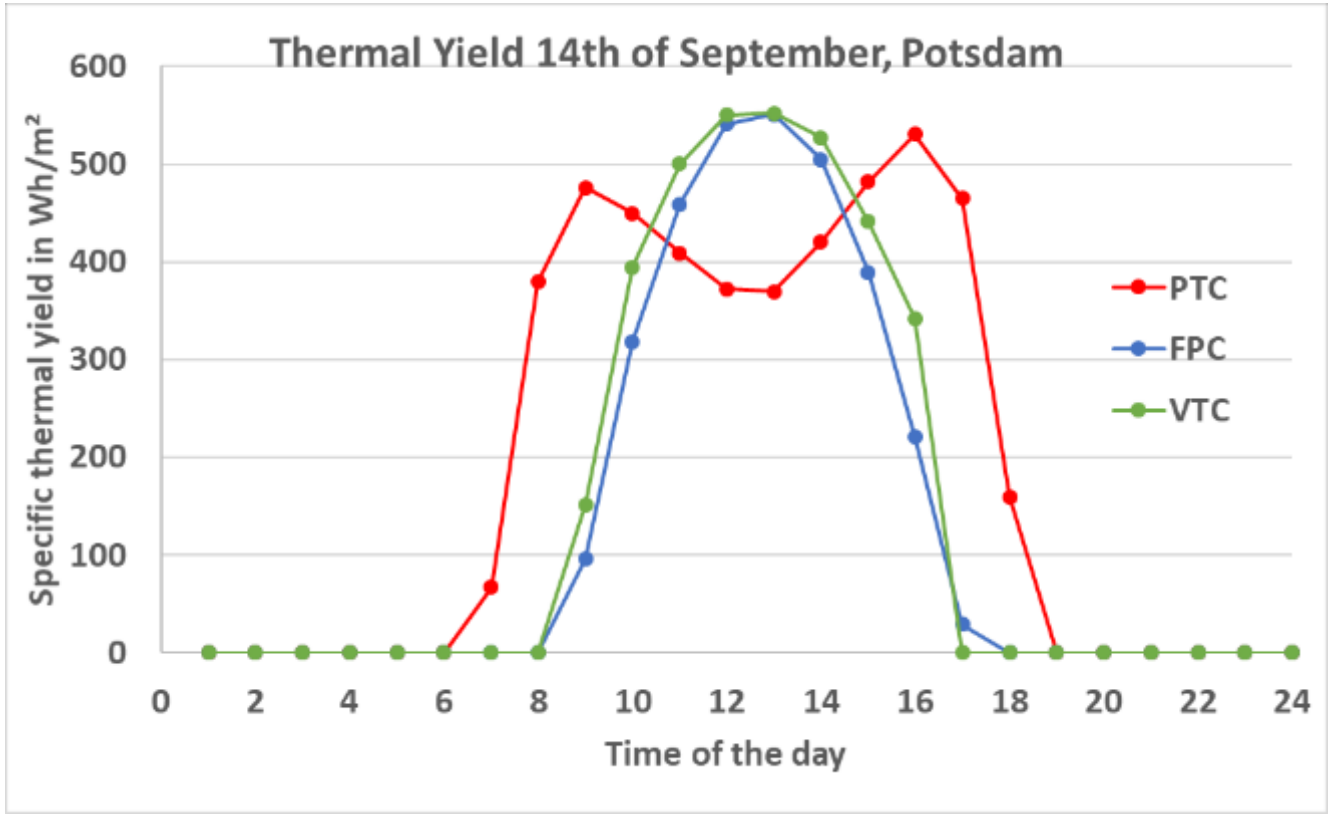
Usually PTC systems are controlled to supply the desired outlet temperature.

Status with FPC/VTC?

Combination of mass flows

Serial connection may be difficult to control outlet temperature?

=> Investigate options for combinations, also with heat pumps

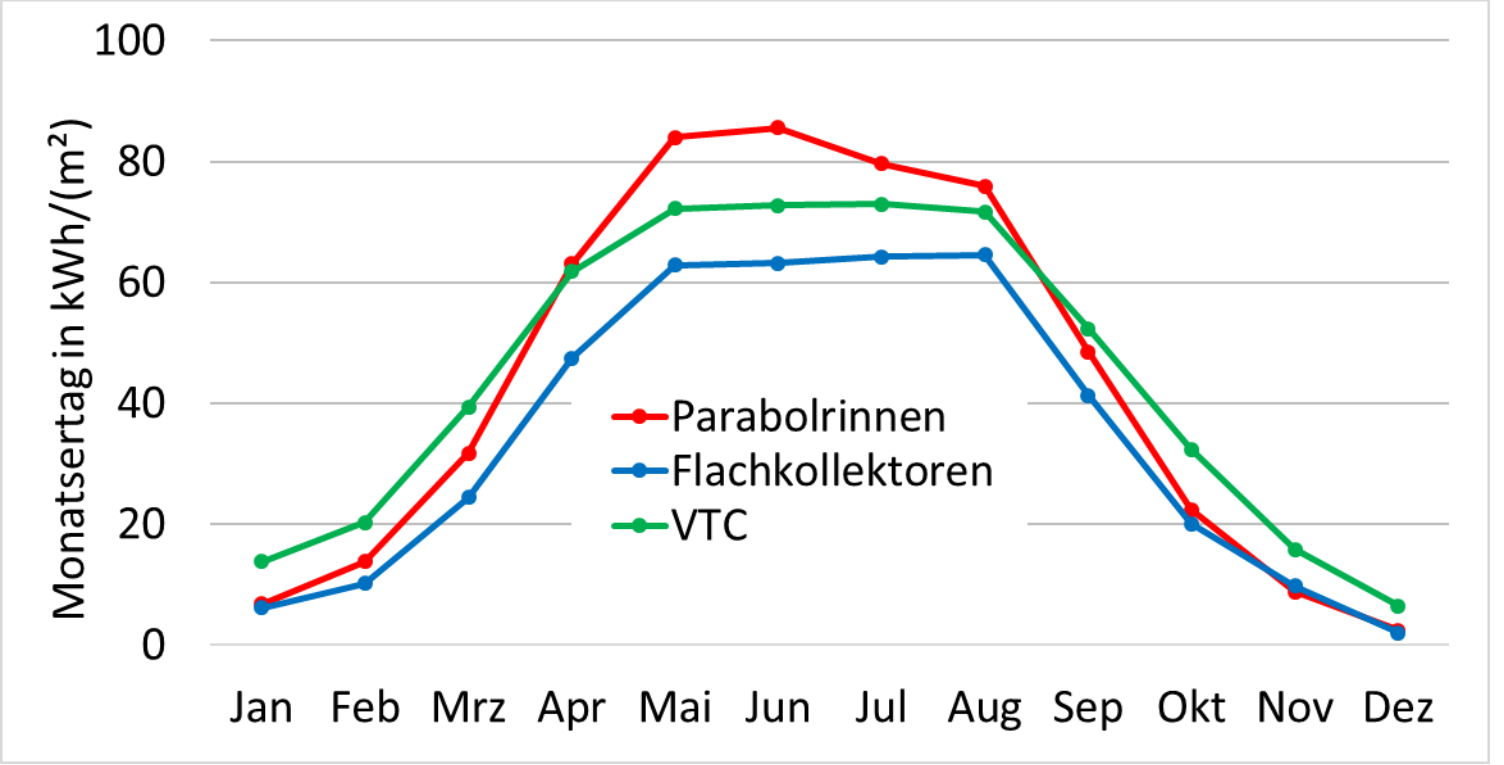



Different yield characteristics for solar systems

Graph for N-S Axis, East-West axis more similar to stationary collectors

# Seasonal behaviour

Data for 75°C average collector temperature
Parabolic trough: Stronger peak in summer
Vacuum tube with beeter distribution along the year



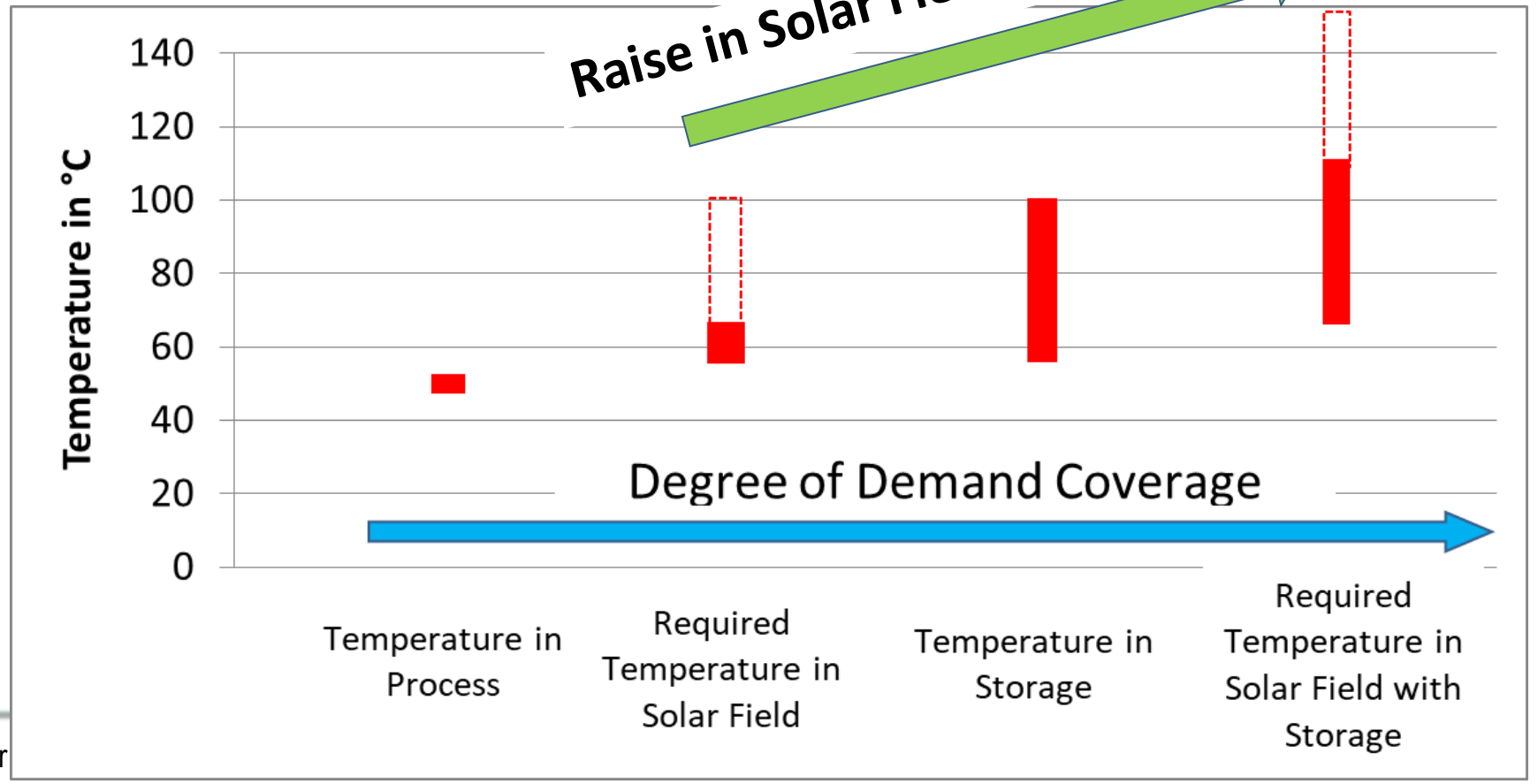

Saisonale thermische Erträge bei 75° C Betriebstemperatur Potsdam

# Effects of Storage on Temperature Level

To cover significant amounts of demand, storage will be necessary.

- higher collector operation temperatures
- can be covered well with concentrating solar systems
- reduced storage volume possible

But storage options beyond pressurised water still too expensive



# Pros/Cons of parabolic troughs related to flat plate and vacuum tube collectors

Pros:

- Higher energy yield at operating temperatures of 60°C to 80°C
- Higher temperature achievable with low losses
- Integration of heat is simple: E.g. as saturated steam
- Intrinsic stagnation safety by defocussing
- Better distribution of heat supply during the day
- Thermal storage easier to be supplied with high efficiency

Cons:

- Better know how needed for operation personnel
- More effort required for cleaning of collectors
- Higher costs for maintenance

# Investment costs and LCOH

Costs highly depend on solar field size, supplier, technology, temperature, pressure, country

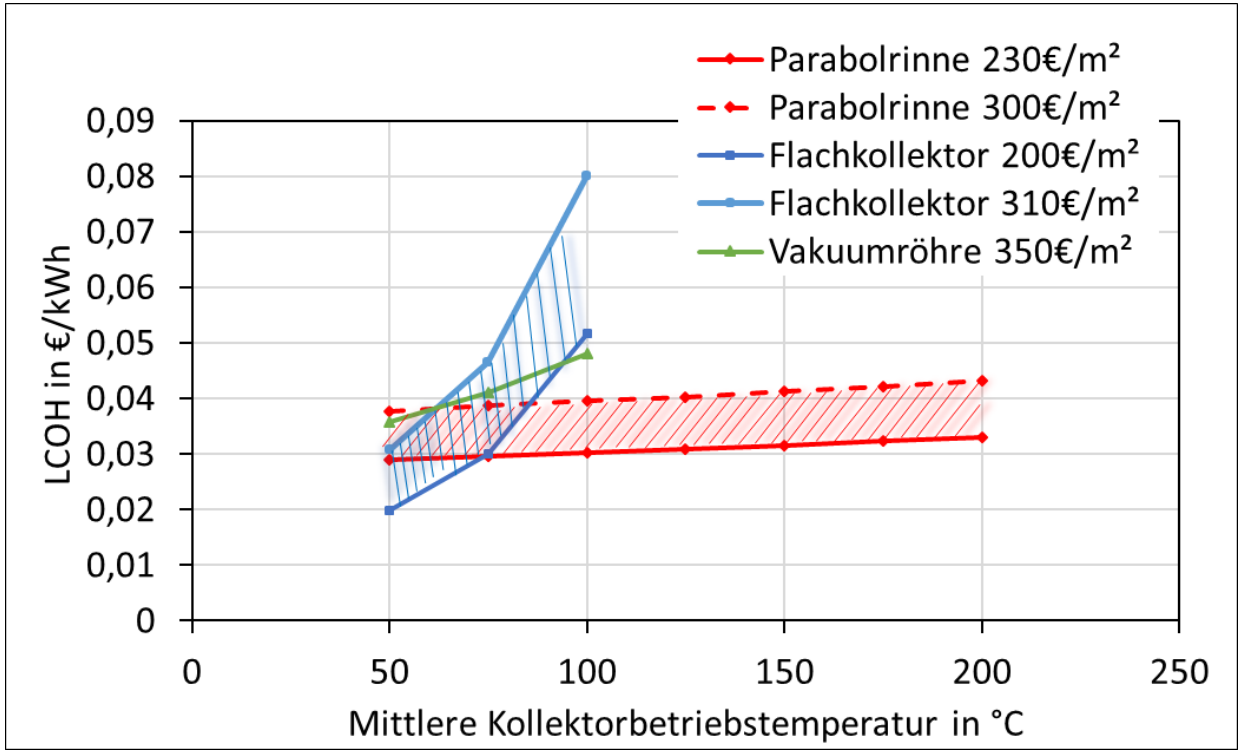
Related to field size of 10.000 m²

Costs for ready installed solar field and BoP according to parabolic trough producers protarget und Solarlite between 230 and 280 €/m²

Costs vacuum tubes according to producers for realised field installations: 350 €/m²

Costs flat plate collectors assumed to range between 200 and 310 €/m²

Krüger, Fischer, Nitz, Iñigo Labairu: Chancen für den Einsatz konzentrierender Kollektoren in Mitteleuropa, Solarthermiesymposium 2021




LCOH weather data Potsdam

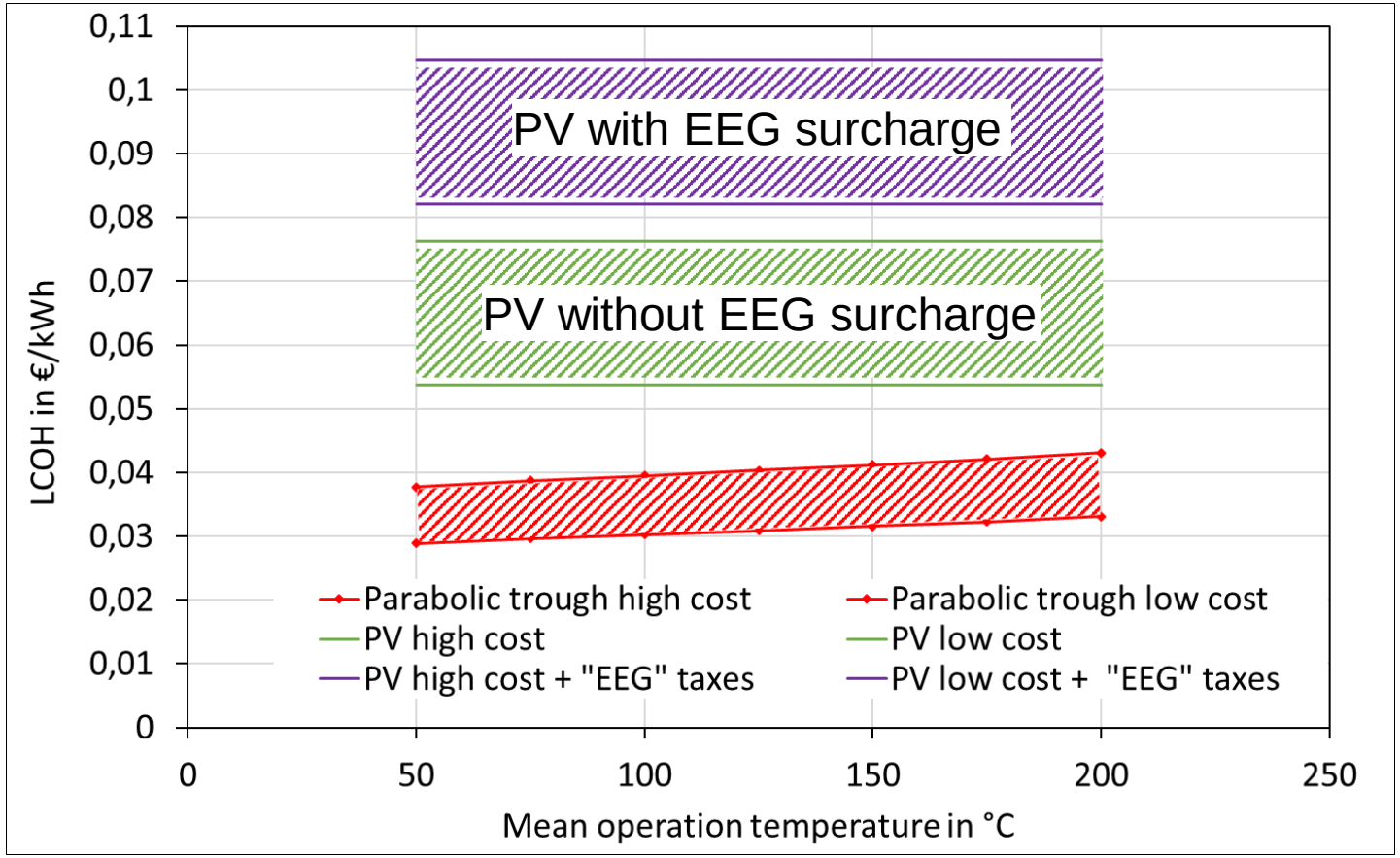
# Investment and heat costs - comparison with PV + electrical heater

**Assumptions PV**

Related to field size of 9400 m²

| | | High | Low |
|---|---|---|---|
| PV Field | €/kW_DC | 700 | 500 |
| Inverter | €/kW_AC | 70 | 55 |
| Electrical heater | €/kW_AC | 100 | 100 |
| EPC surcharge | % | 32 | 32 |
| Total Costs PV heat | €/kW_AC | 1192 | 858 |
| O&M & Insurance | % | 1,0 | 0,5 |

***Installed power several dimensions higher for PV => Higher cost reduction by economies of scale achieved***




LCOH for Potsdam

# IEA Task 64/IV – Solar Process Heat
# Joint Task by SolarPACES and SHC

The scope of the Task is on solar thermal technologies for converting solar radiation into heat and further the intelligent integration of the produced heat into industrial processes

https://task64.iea-shc.org/

Currently discussion on the conversion factor
$m^2$ to kW – Should it be 0.7 ?


Subtask A: Integrated energy systems
Subtask B: Modularization
Subtask C: Simulation and design tools
Subtask D: Standardization and Certification
Subtask E: Guideline to market

# IEA Task 55 Follow-up: Efficient solar district heating systems

Considering higher temperatures and digitalization measures

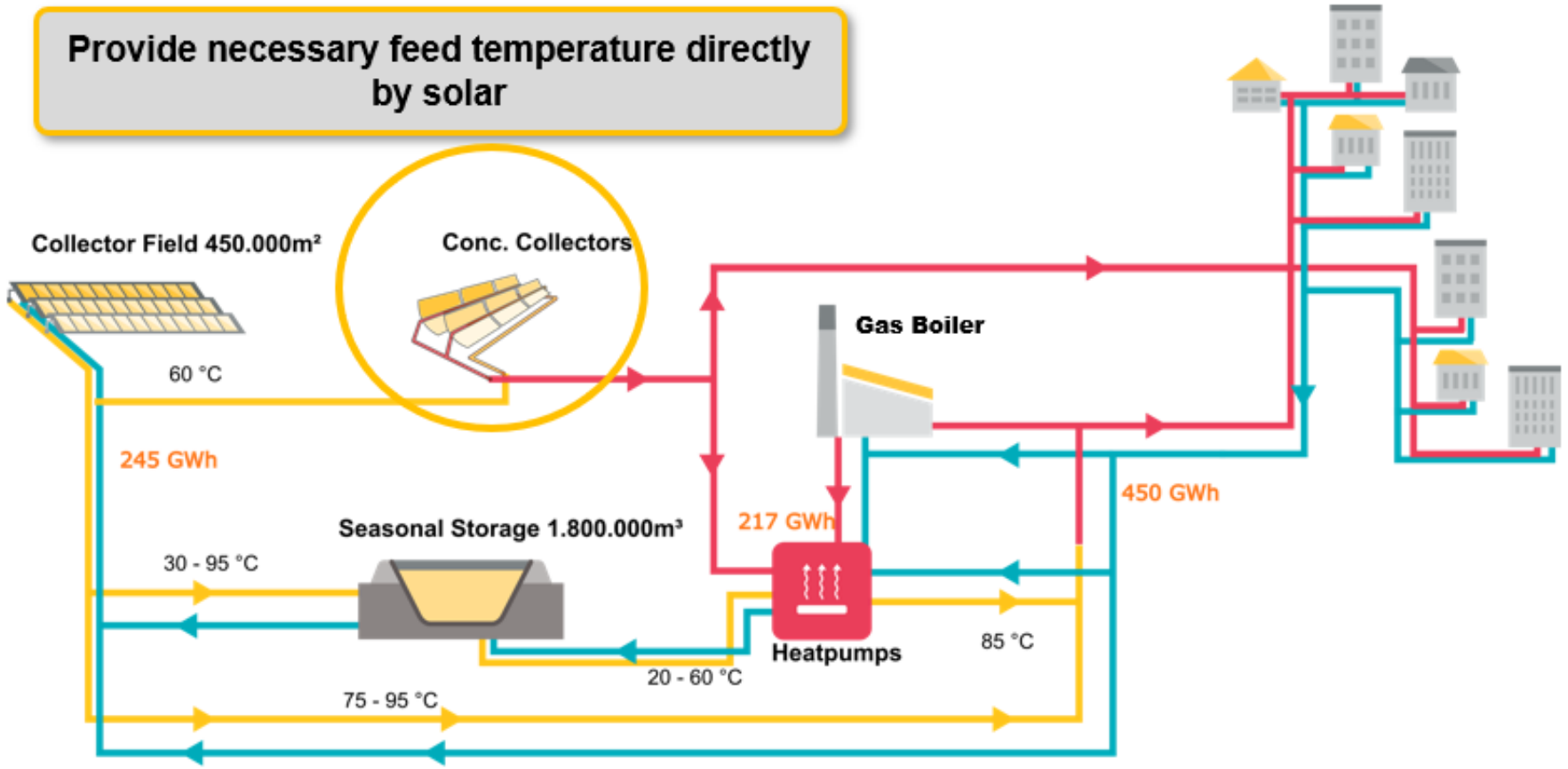
1st main objective:

"Integration of medium to high temperature heat into large-scale solar thermal heating systems"

2nd Task Definition Meeting on 8th of October

Contact:

viktor.unterberger@best-research.eu



# Trends I

Customers ask for a **high solar share** or even for a vision to supply 100% of the heat, influencing the technology choice.

=> to which extend can solar thermal systems cover the demand over the full year

=> moves storage more into focus

For component suppliers the industrial market offers much shorter development times as products are applied quicker and with less risk => **Faster renewal** and price reduction

# Trends II

Customers choice of **technologies relates with the producers** in the same country:

- Spain: 3 of 4 installations have been realised with Fresnel and the three Spanish suppliers Solatom, Rioglass Solar and Covalersa all produce Fresnel collectors.
- Mexico: all installations parabolic trough technology from Inventive Power.
- India: many installations with dishes by Megawatt Solutions and Quadsun.

Operating temperatures in solar field significantly above demand requirements - **high delta T** in solar fields – small pump and heat exchanger

**District heating** also realised by Aalborg in Denmark, other suppliers aim at this application

# Final remarks

- An increased number of concentrating collector manufacturers discovers the huge potential of industrial solar heat
- ESCO is a suitable business model to convince reluctant industrial decision makers
- Research: Find answers on near to 100% renewable heat supply
- Research: Storage solutions: developments for > 150°C required
- High potential for parabolic trough collectors as an alternative in moderate climates - even below 100°C
- Not only process heat but also district heating is potentially an application for concentrating solar collectors
- Light tower projects are needed