Solare Prozesswärme – CO_2 freie Wärme für die Industrie

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Dr. Jakob energy research GmbH & Co. KG

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Hintergrund

Solare Prozesswärme bietet die Möglichkeit den CO_2 Fußabdruck in der Produktion zu verringern und Klimaschutz direkt umzusetzen.

2/3 des industriellen Endenergieverbrauchs sind thermische Energie

1/3 des industriellen Prozesswärmebedarfs liegt unter 200°C

Kollektortypen für Prozesswärme

Quelle: Fraunhofer ISE

Quelle: Wagner & Co

Quelle: Ritter XL Solar

Quelle: Smirro

Quelle: Industrial Solar

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Temperaturbereich für Prozesswärme

250-450 °C	Large troughs and Fresnel	Utility scale power Generation Industrial Process Heat
130-250 °C	Small troughs and Fresnel	Industrial Process Heat Solar Cooling (double-, triple-effect H_2O-LiBr) Commercial Water Heating Distributed Power Generation
90-130 °C	Vacuum tube CPC Collectors	Solar Cooling (single-effect NH_3-H_2O) Low Temperature Process Heat
40-90°C	Flat Plate Collectors	Domestic Water Heating Space Heating Solar Cooling (single-effect H_2O-LiBr, -Silica gel, -Zeolite)

Quelle: Industrial Solar

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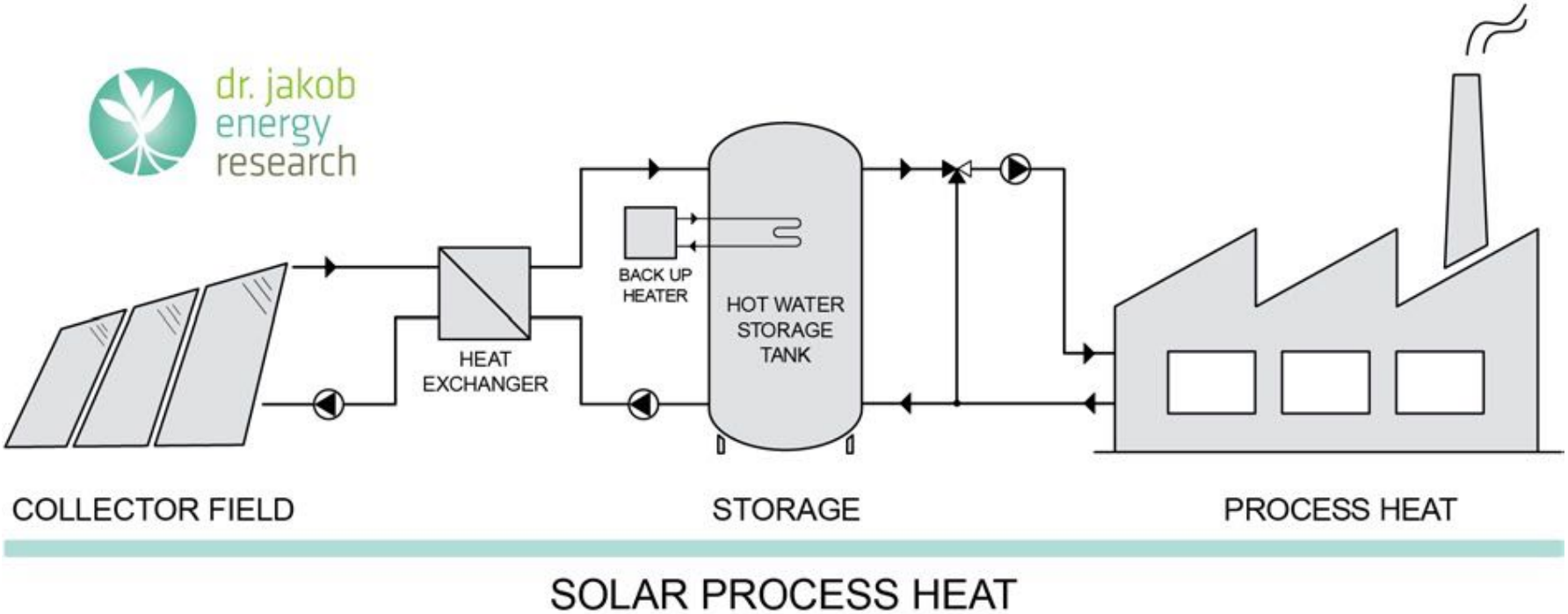
Einbindung solare Prozesswärme



Quelle: JER

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Systemintegration solare Prozesswärme in der Industrie

Zuerst Reduzierung des Endenergieverbrauchs heutiger Prozesse durch:

- Wärmerückgewinnung
- Effiziente Energieversorgung
- Effiziente Regelungstechnik
- Wartung (Kundendienst)

dann Einsatz neuer Technologien

- Kraft-Wärme-Kopplung (BHKW)
- **Solarthermie**

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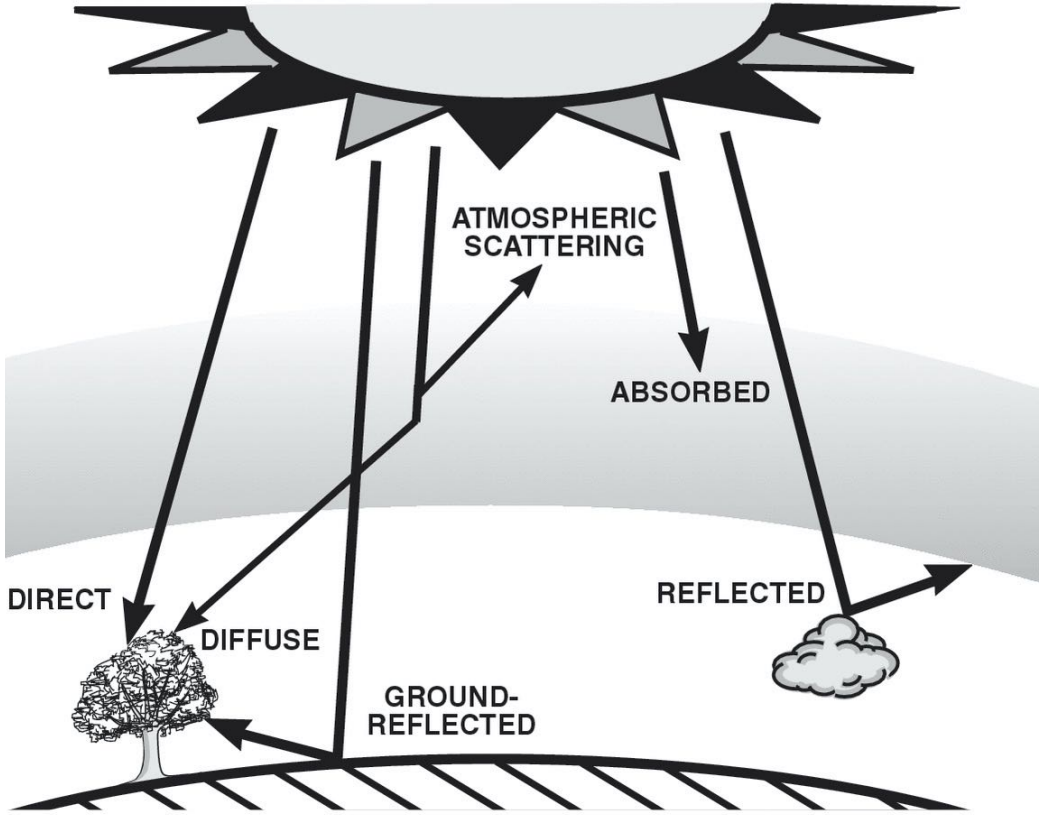
Solarstrahlung – Generelle Definitionen



Quelle: Newport.com

- <u>Direktstrahlung:</u> Sonneneinstrahlung direkt von der Sonnenscheibe
- <u>Diffuse Strahlung:</u> Sonneneinstrahlung aus allen anderen Richtungen (dadurch können wir im Schatten sehen)
- <u>Bodenreflexion:</u> vom Boden nach oben reflektierte Strahlung

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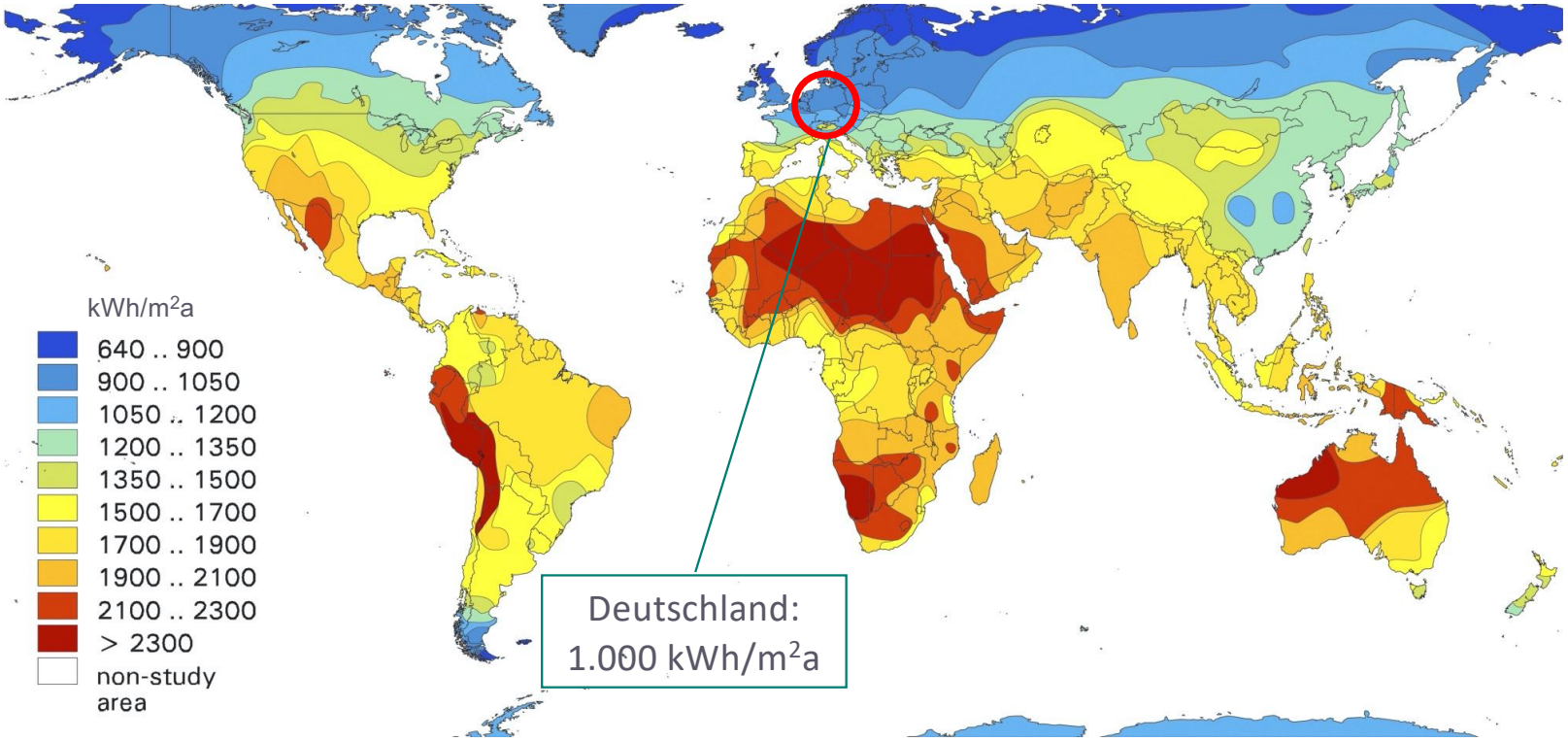
Durchschnittliche Jahresglobalstrahlung weltweit



Quelle: Meteonorm (data), Friedemann Jung

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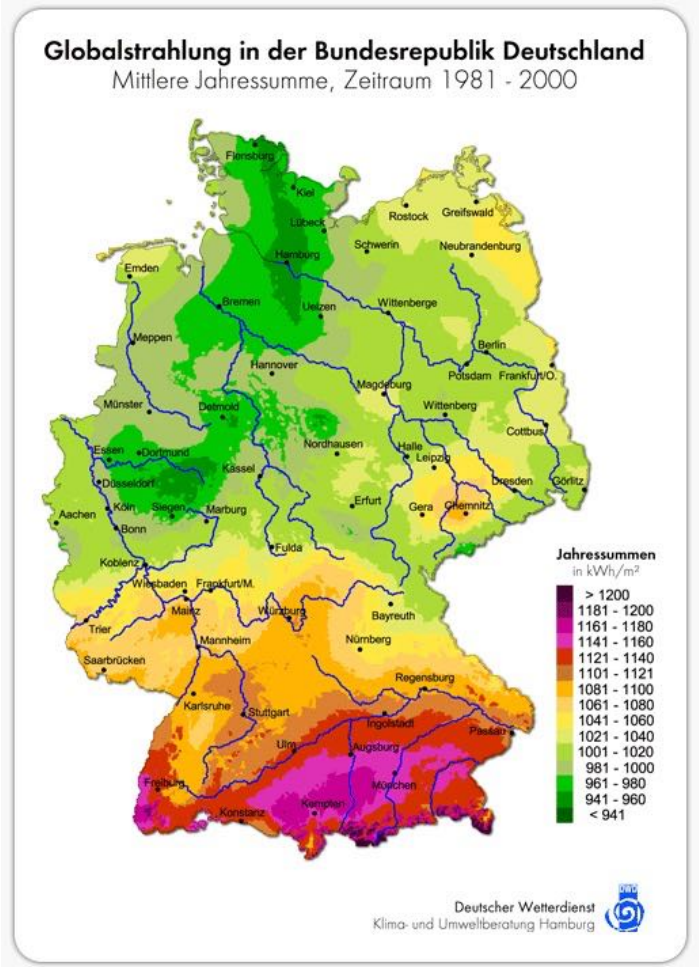
Globalstrahlung Deutschland



Quelle: DWD

- Globalstrahlung zwischen 900 und 1.200 kWh/m²a
- Durchschnittlich in Deutschland 1.000 kWh/m²a

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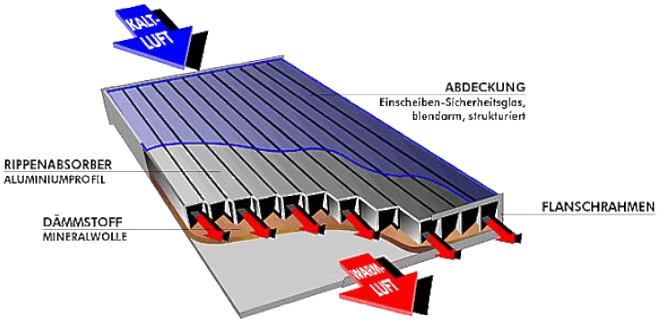
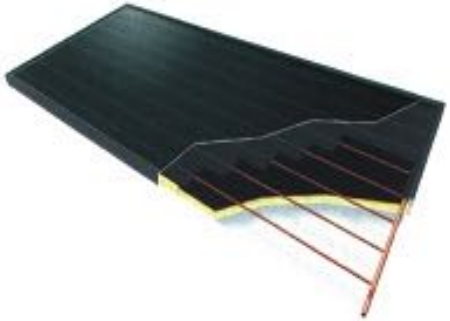
Kollektortechnologien (1)

Luftkollektoren

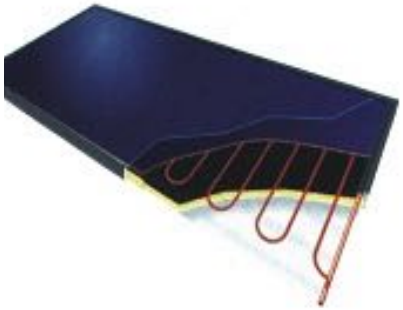


Kanäle Quelle: Grammer Solar GmbH

Flachkollektoren



Harfe Quelle: Solarpraxis AG



Mäander Quelle: Solarpraxis AG

Wärmeträger:	Luft	Wasser-Glykol
Max. Temperatur:	50-70°C	70-90°C

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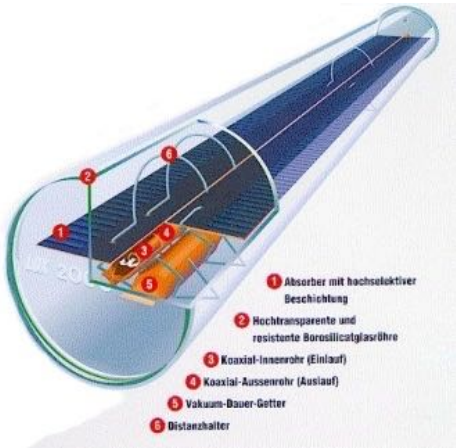
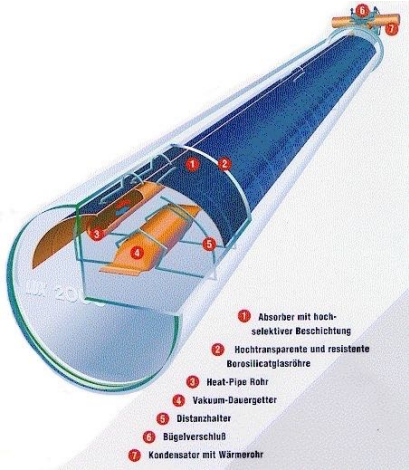
Kollektortechnologien (2)

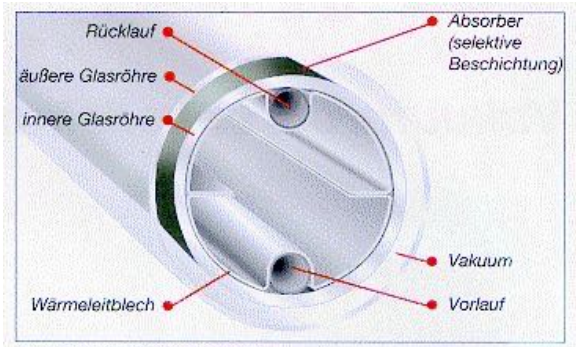
Vakuumröhre



direkt durchströmt
Quelle: ThermoLux Solar



indirekt durchströmt /
Heat pipe Quelle: ThermoLux Solar



Sydney – Vakuumröhre Quelle: Geysol Solartechnik AG

Wärmeträger:	Wasser-Glykol, Wasser (dann aktiver Frostschutz!)
Max. Temperatur:	80-140°C

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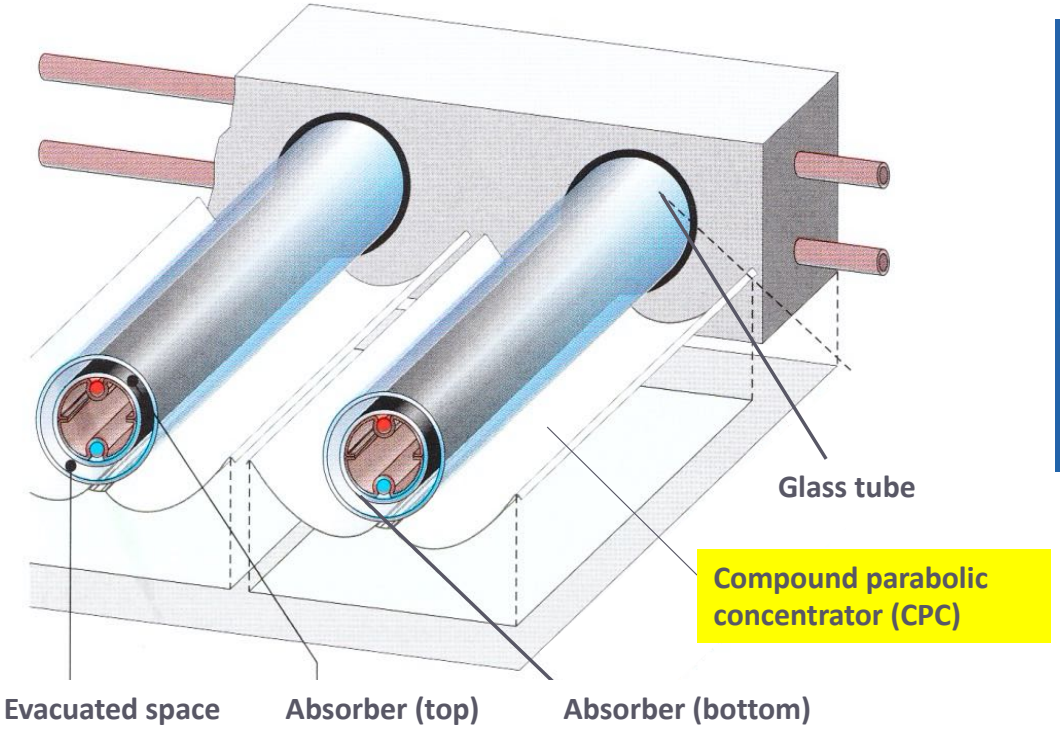
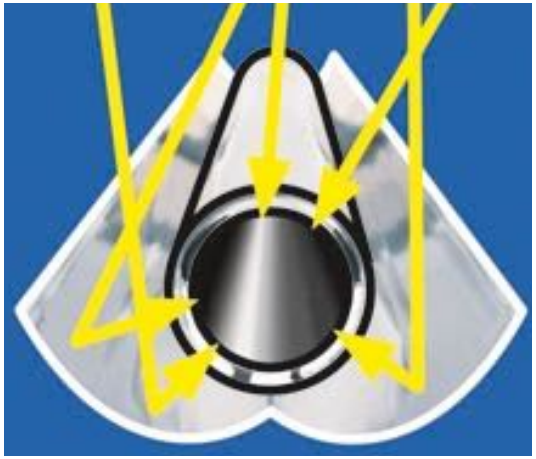
CPC Vakuumröhrenkollektor

Vakuumröhre mit CPC Reflektor (Compound parabolic concentrator)



Quelle: Solarpraxis



Quelle: Paradigma

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Kollektortechnologien (3)

Parabolrinnenkollektoren

Quelle: NEP Solar

Fresnel-Kollektoren

Quelle: Mirroxx

Wärmeträger:	Wasser, Dampf, Thermoöl
Max. Temperatur:	220-250°C

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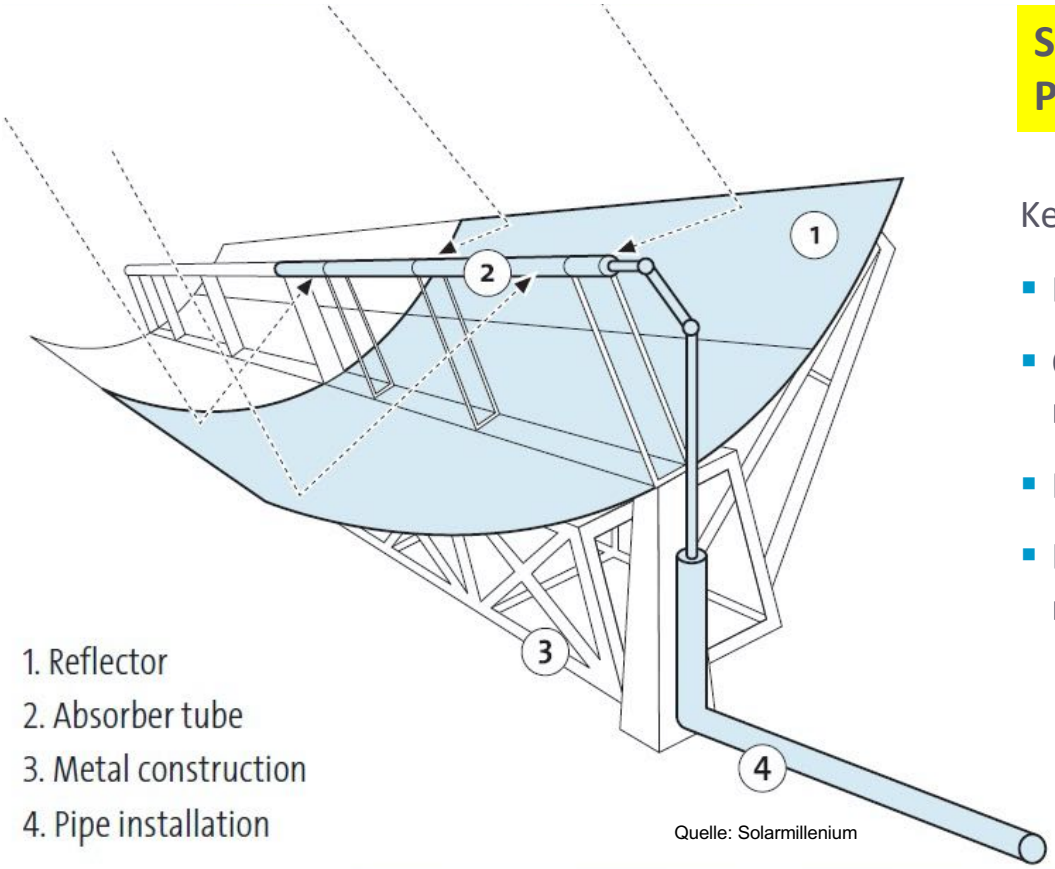
Konzentrierende Kollektoren – Parabolrinne



Quelle: Solarmillenium

Schematic :
Parabolic trough collector

Key points:

- Direct radiation only
- One-axis tracking required
- N-S or E-W alignment
- Larger installations only, not residential

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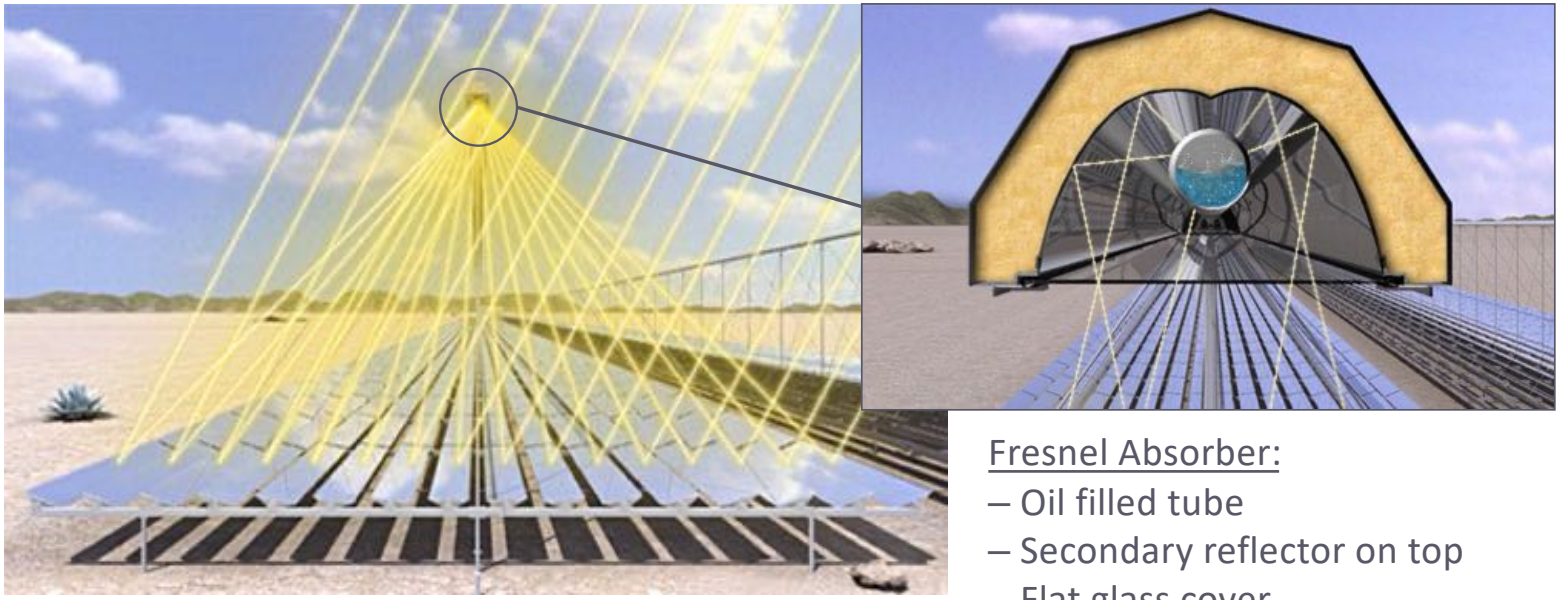
Konzentrierende Kollektoren – Fresnel



Quellen: Novatec

Fresnel collector:
– Multiple smaller mirrors
– Secondary reflector
– Absorber stationary
– Mirrors one-axis tracking

Fresnel Absorber:
– Oil filled tube
– Secondary reflector on top
– Flat glass cover
– Insulated frame

Schematic : Fresnel collector

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Kollektorvergleich – Wirkungsgrad Berechnung / Hersteller Datenblatt

Quelle: Fischer

$$\eta_{(G,(t_m-t_a))} = \eta_0 - a_{1a}\frac{t_m - t_a}{G} - a_{2a}\frac{(t_m - t_a)^2}{G}$$

with $t_m = \frac{t_e + t_{in}}{2}$

G = global irradiance on collector area (W/m^2)
t_{in} = collector inlet temperature (°C)
t_e = collector outlet temperature (°C)
t_a = ambient temperature (°C)
t_m = mean collector temperature (°C)

η_0 = optical efficiency (without heat losses), mean collector fluid temperature is equal to the ambient temperature.
a_{1a} = heat loss due to conduction and convention
a_{2a} = heat loss due to radiation

Incidence angle: defined as the angle between the position vector of the sun and the vector perpendicular on the collector aperture. The dependency of the thermal performance is described by the incidence angle modifier.

Incidence angle modifier (IAM): defined by the ratio of the collector output at a given incidence angle *q&(θ) and the collector output at normal incidence*

Heat capacity: Thermal capacity of liquid in collector

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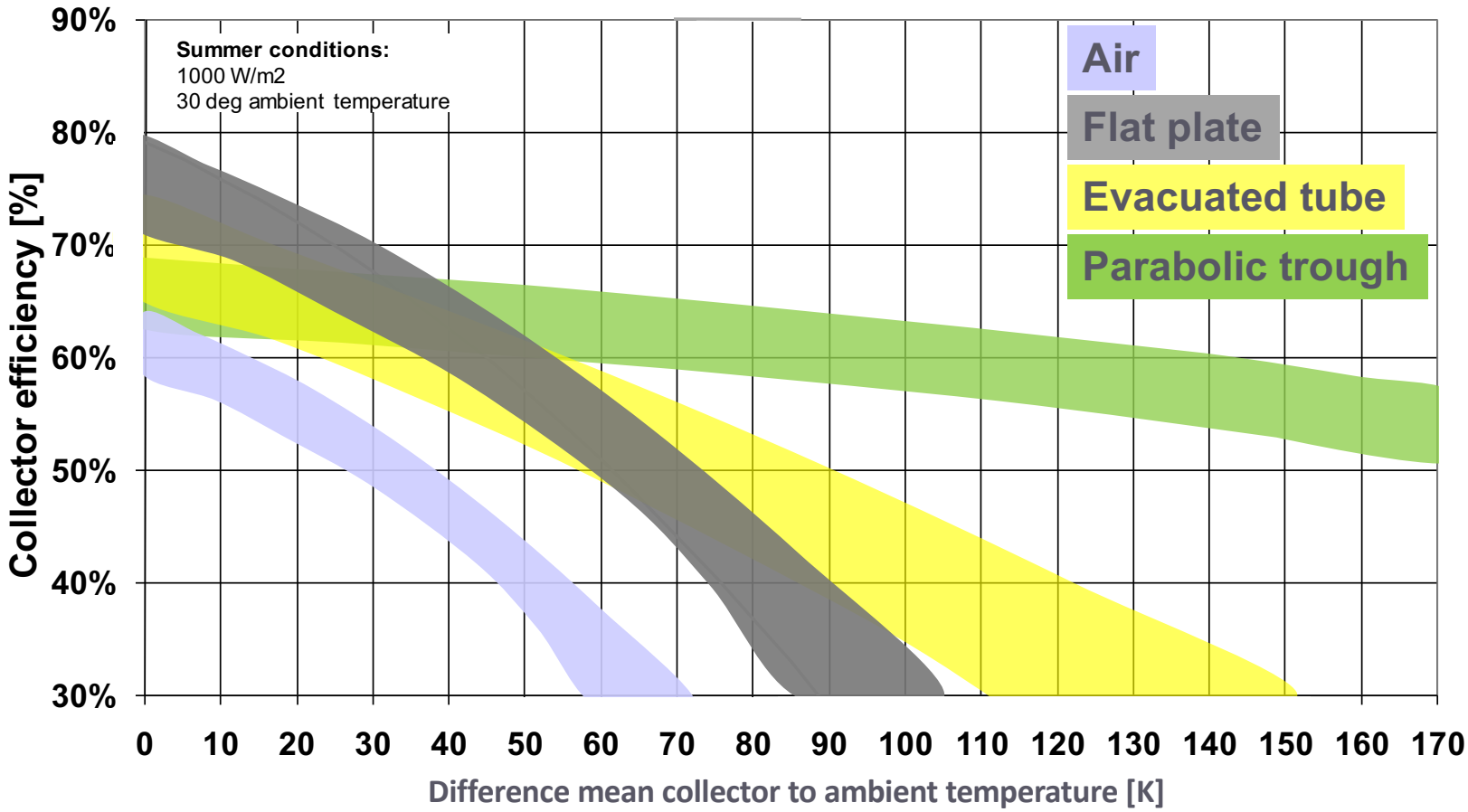
Kollektorvergleich – Wirkungsgradkennlinien



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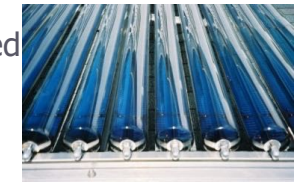
Kollektorvergleich für Prozesswärme – Anwendungen

Solar thermal collector	Heat transfer medium	Collector temperature	Application	Concentration ratio (number of suns)
Air collector	Air	40-60ºC	Space heating, drying	1
Flat plate collector	Water, Water-Glycol	70-90ºC	Hot water, space heating, cooling	1
Evacuated tube collector 	Water, Water-Glycol	90-120ºC	Hot water, space heating, cooling, process heat	1 (without reflector) 1-2 (CPC)
Parabolic Trough / Fresnel collector	Thermal oil, Water	120-250ºC	Process heat, cooling	8-80

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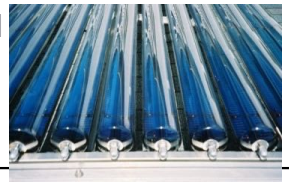
Kollektorvergleich für Prozesswärme – Eigenschaften

Solar thermal collector	Pro's	Con's
Air collector	– most simple construction – Easy installation	– low temperatures – Lower efficiency – No hot water directly
Flat plate collector	– simple, robust construction – Technically matured – Good value for money – Easy to integrate with roofs	– Lower temperatures – Lower efficiency
Evacuated tube collector 	– Higher temperatures – Lower thermal losses – Sealed construction (no leaks)	– High stagnation temperature – Higher cost per m2
Parabolic trough / Fresnel collector	– High temperatures – High efficiency	– High cost per m2 – Not suitable for residential application – Tracking needed – Limited to direct radiation (DNI)

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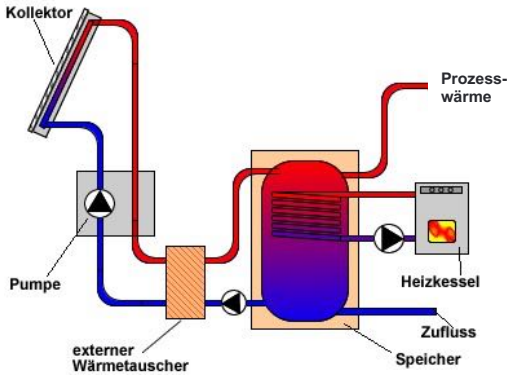
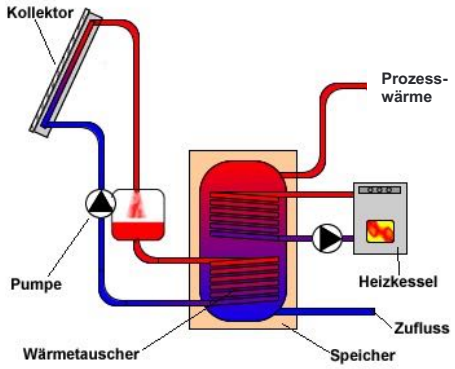
Solarthermie Anlagen – Grundlagen

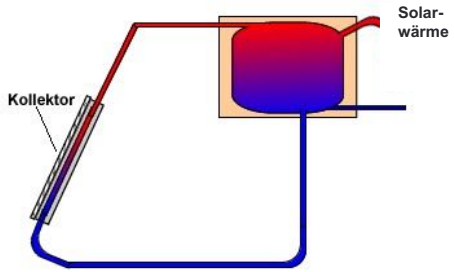
Standardanlagen



Drainback-Systeme



Thermosyphon-Systeme



Quelle: solaranlagen-portal.de

- Zwangsumlauf oder Schwerkraftsysteme
- Prozesswärme, Heizungsunterstützung und/oder Trinkwarmwasserbereitstellung
- Wasser oder Frostschutzmittel-Gemisch als Wärmeträger
- Druckbehaftete Systeme oder drucklose Systeme (drain back)
- Durchfluss High Flow (30-70 l/m^2h) oder Low Flow (10-20 l/m^2h)

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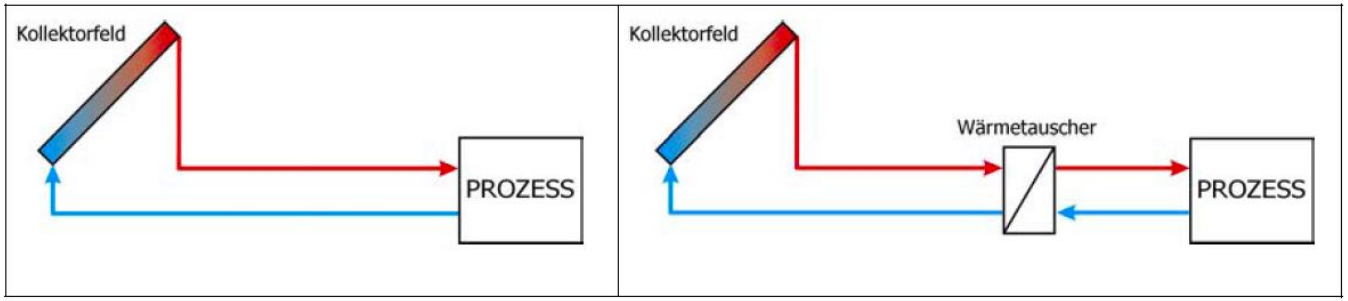
Einbindung solare Prozesswärmeanlagen (1)

- System without heat storage

a) direct heat exchange b) indirect heat exchange



Quellle: AEE Intec

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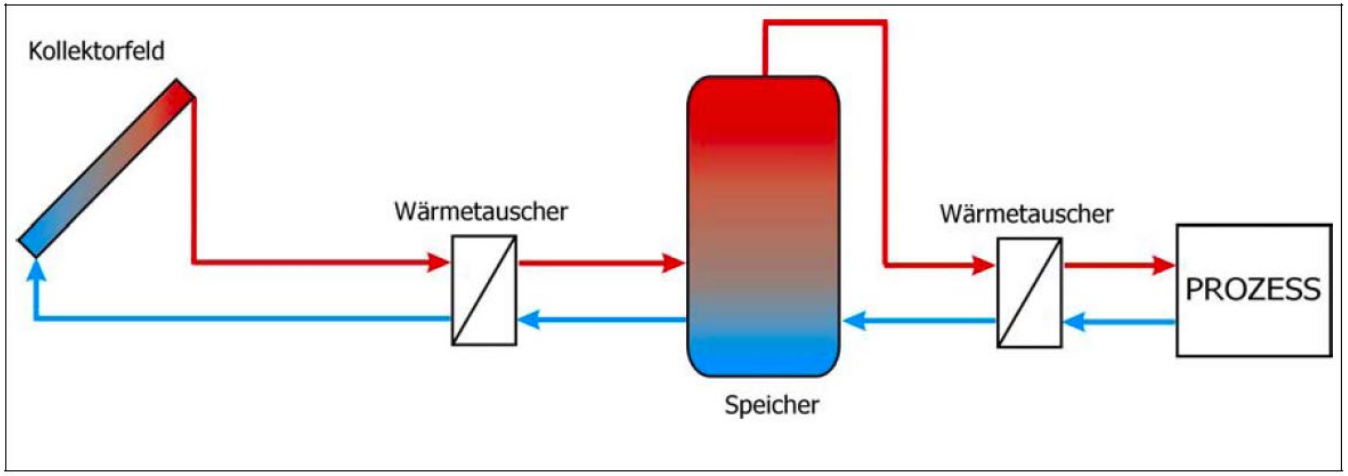
Einbindung solare Prozesswärmeanlagen (2)

- System with heat storage

c) indirect heat exchange and heat storage



Quelle: AEE Intec

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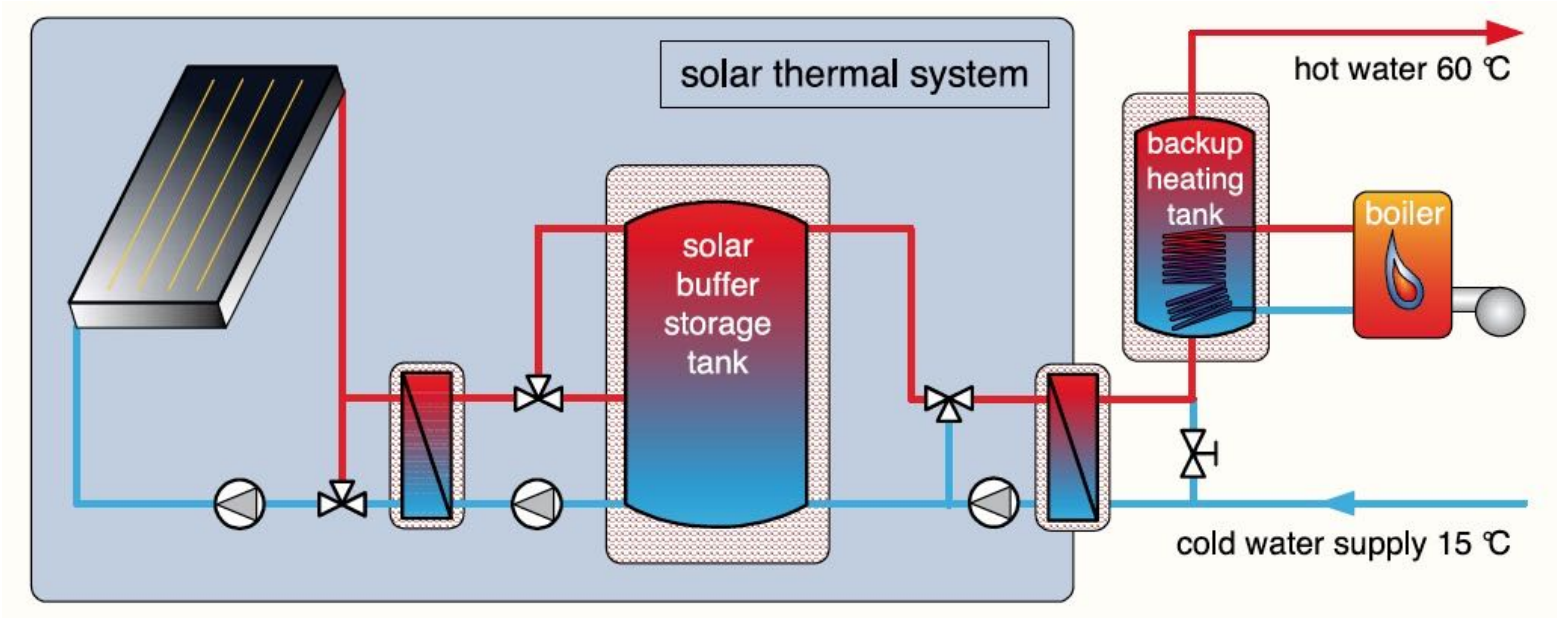
Erwärmung von Warmwasser zum Waschen oder Reinigen

Quelle: So-Pro



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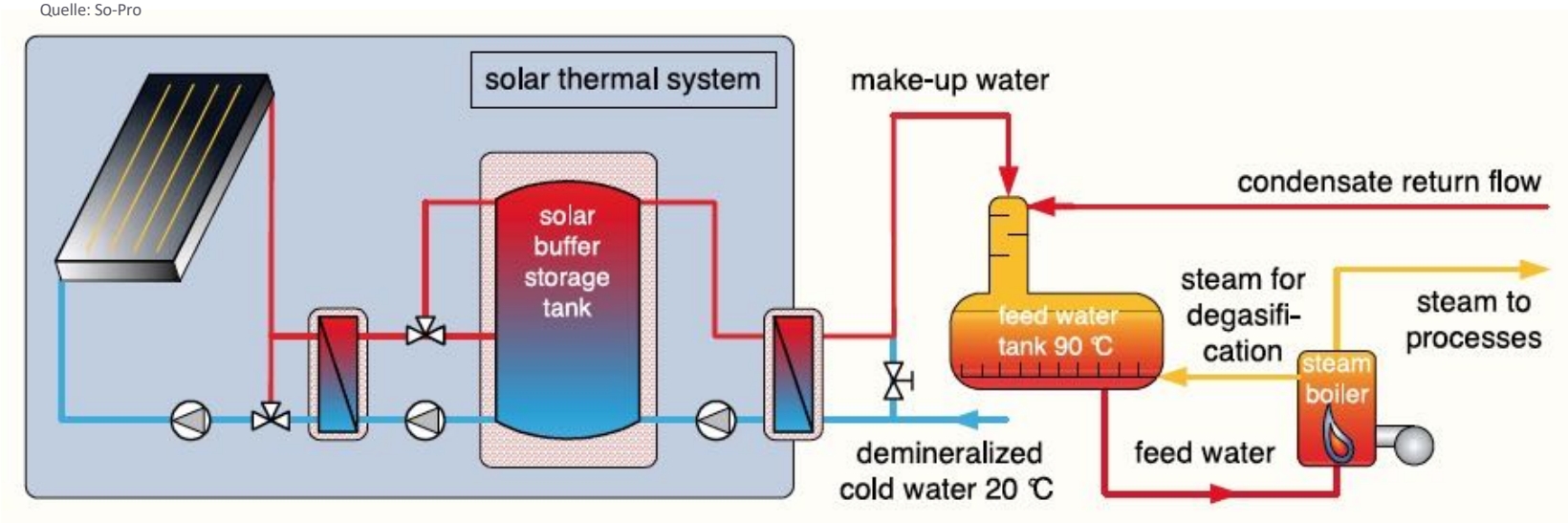
Erwärmung von Speisewasser für Dampfnetze

Quelle: So-Pro



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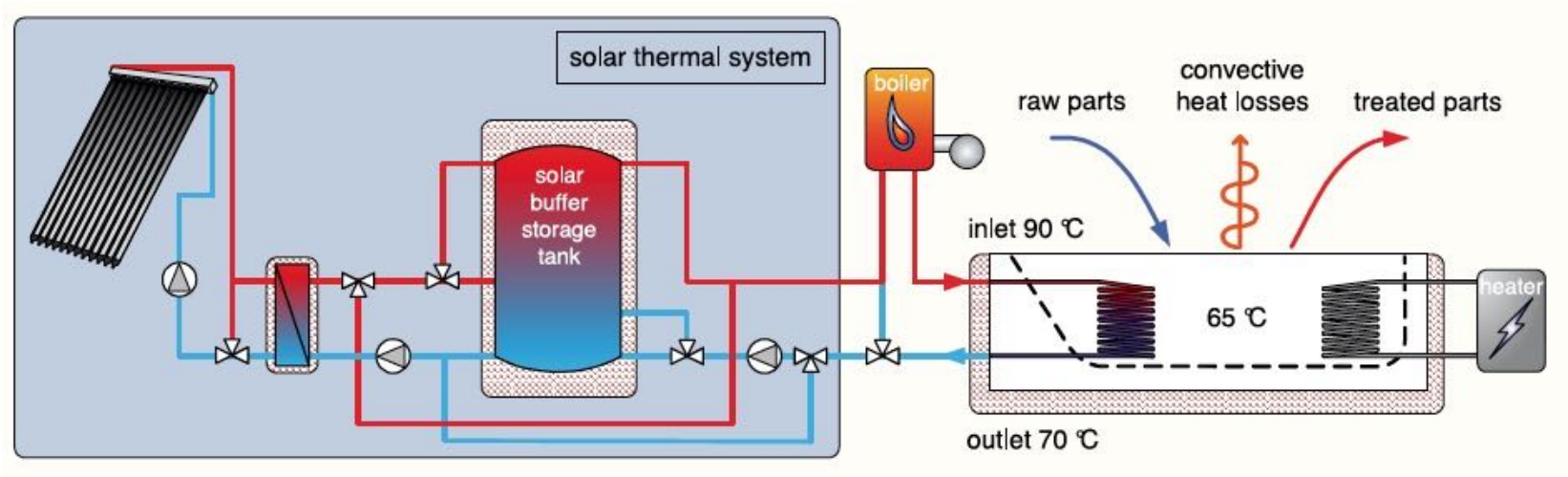
Beheizung von Prozessbädern oder Behältern

Quelle: So-Pro



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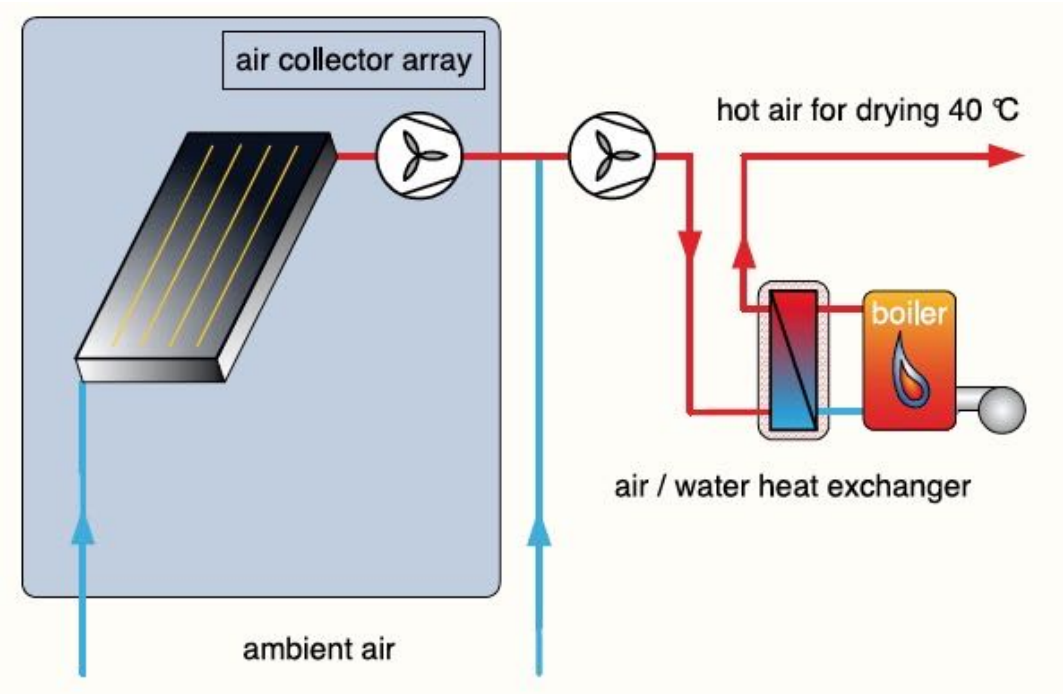
Konvektionstrocknung mit erwärmter Luft

Quelle: So-Pro



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Anwendungsbereiche für solare Prozesswärme

- Molkerei (Pasteurisierung von Milch, Käseherstellung)
- Fleisch & Fisch verarbeitende Betriebe
- Getränke (Abfüllanlagen, Brauereien)
- Konservenfabriken (Obst, Gemüse)
- Trocknung von Lebensmitteln (Nüsse, Früchte, Kartoffelchips)
- Gummifabrik – Reifenherstellung
- Textil- und Kleidungsfertigung
- Oberflächenbehandlung von Metallen
- Wäscherei und Leinenbleicherei
- Sägewerke (thermische Behandlung von Holz), Zellstoff und Papier
- Medikamentenherstellung
- Parfüm und Essenzherstellung (Brennereien)
- Krankenhäuser (Dampfsterilisation)
- Betonfertigteilindustrie
- etc.

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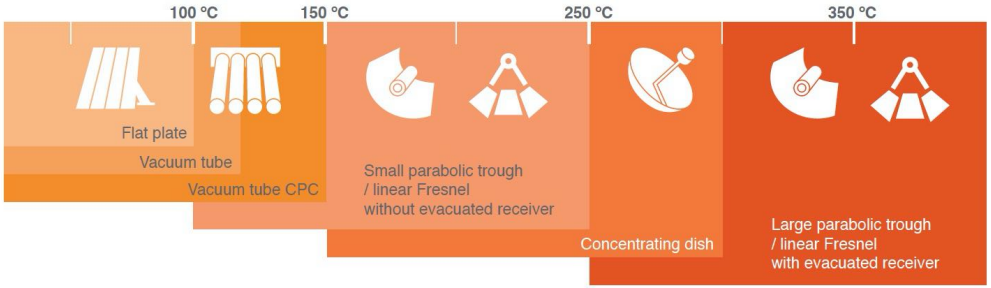
Verfügbare Kollektortypen je Anwendungsbereich

INDUSTRY	LOW Below 150 °C	MEDIUM 150 to 400 °C	HIGH > 400 °C
Chemical	• Boiling	• Distilling	
Food and beverage	• Drying • Boiling • Pasteurising • Sterilising		
Machinery	• Cleaning • Drying		
Mining	• Copper electrolytic refining • Mineral drying processes	• Nitrate melting	
Textile	• Washing • Bleaching	• Dyeing	
Wood	• Steaming • Pickling • Cooking	• Compression • Drying	



Source: IEA SHC Task 49

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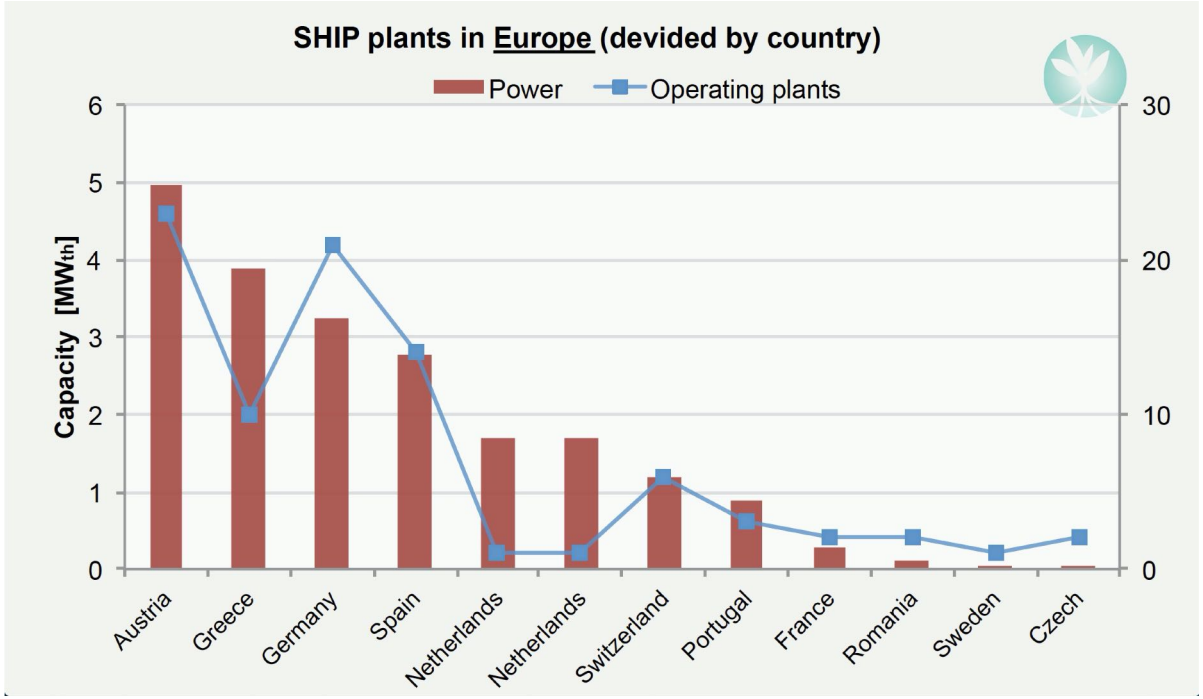
Solare Prozesswärmeanlagen in Europa (2015)



Quelle: JER,
Daten von AEE Intec

- ca. 85 Anlagen mit einer installierten Wärmeleistung von 20 MW_{th}

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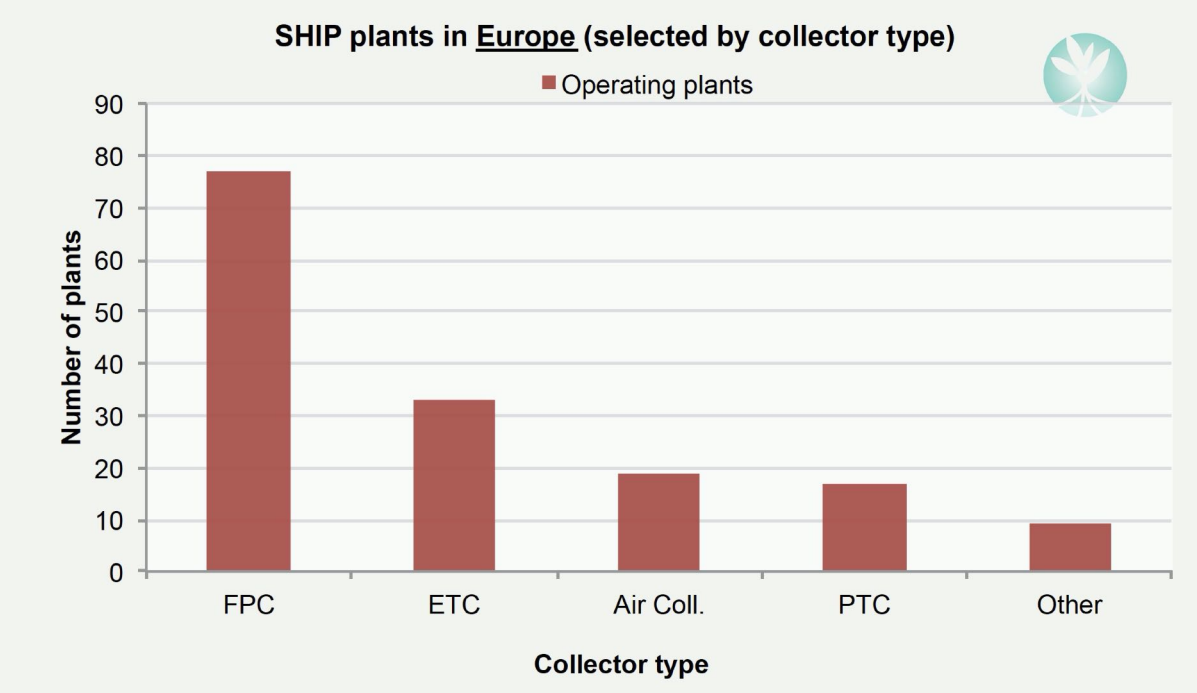
Kollektortypen für solare Prozesswärme in Europa (2015)



Quelle: JER,
Daten von AEE Intec

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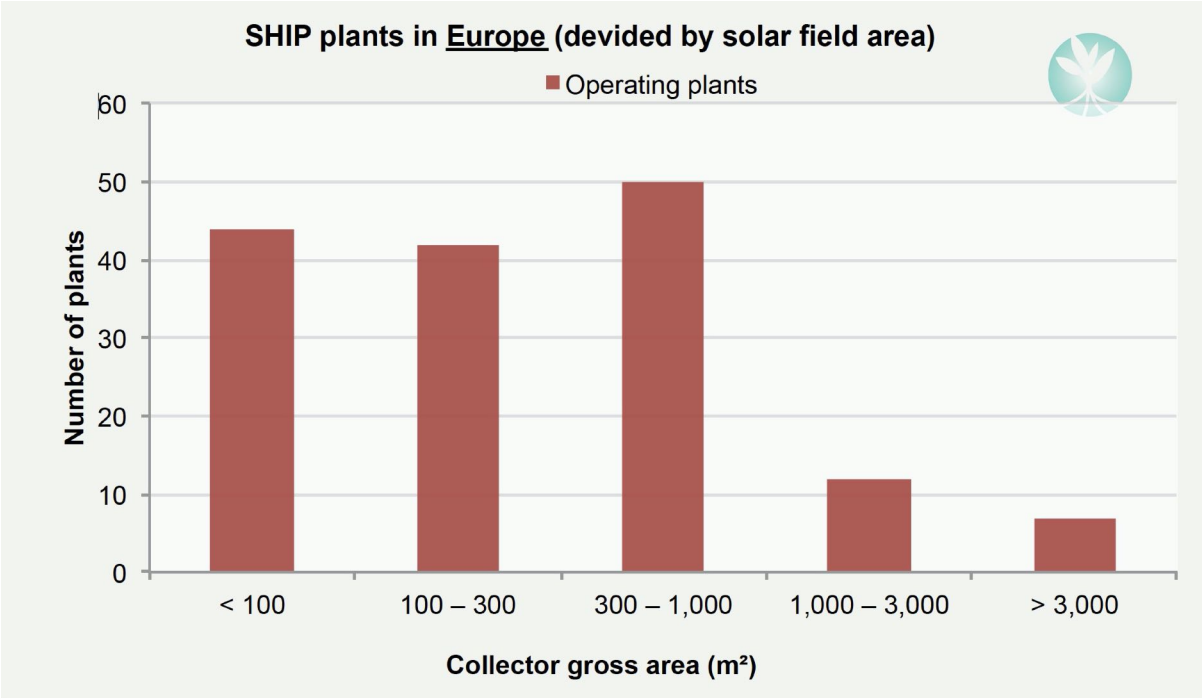
Kollektorgrößen solare Prozesswärme Anlagen in Europa (2015)



Quelle: JER,
Daten von AEE Intec

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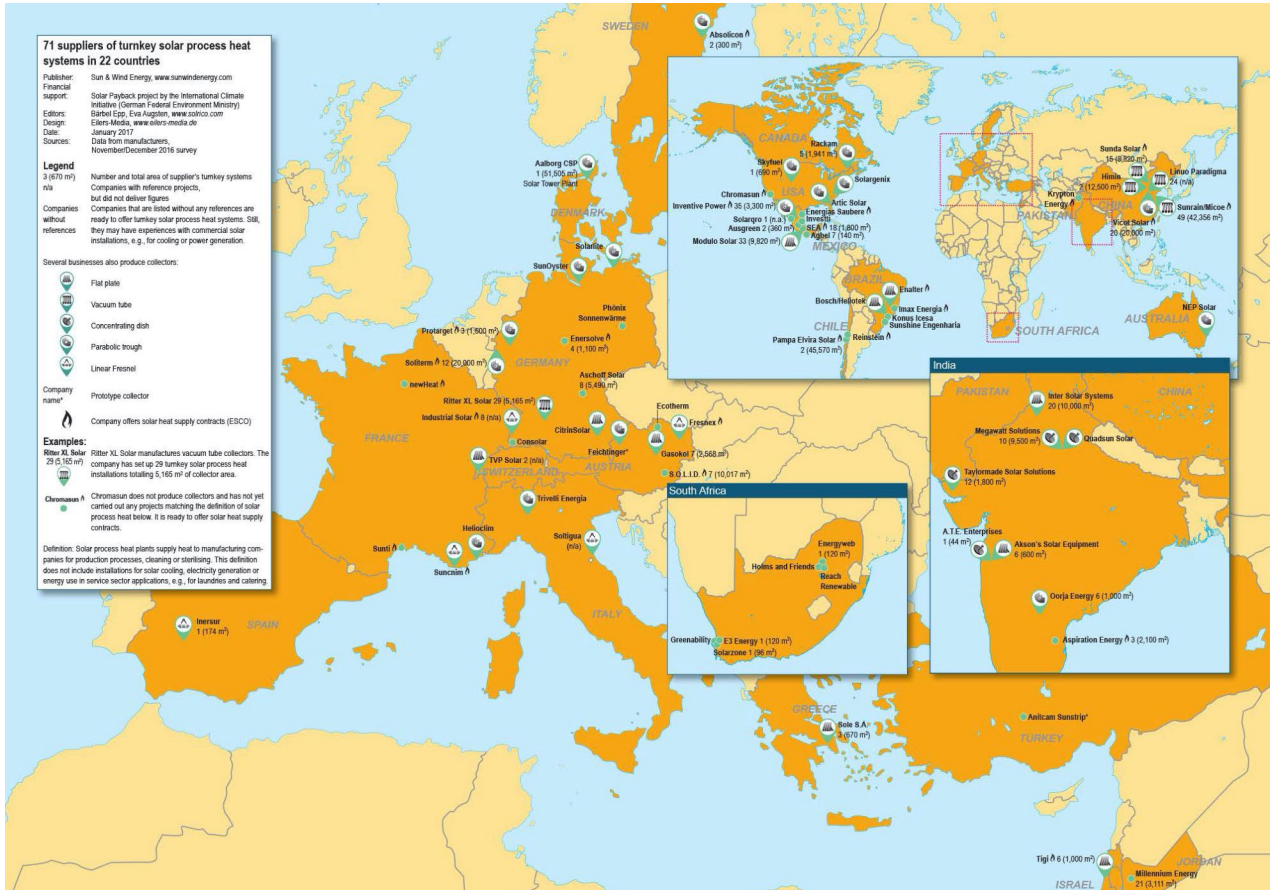
Anbieter solare Prozesswärme weltweit (2017)



Source: solrico

- 71 Turnkey Anbieter von SHIP Systemen in 22 Ländern
- Mehr als 500 Anlagen weltweit (280 MW_{th})

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Kosten solare Prozesswärme

Anlagenkomponenten:

- Solarkollektoren (Luft / Flach / Vakuum / Parabolrinne / Fresnel)
- Montagesystem
- Pufferspeicher
- Rohrleitungen, Wärmetauscher, Isolierung, etc.
- MSR-Technik
- Hydraulische Einbindung in den jeweiligen Prozess

Spezifische Kosten (netto) einer solarthermischen Prozesswärmeanlage bezogen auf Bruttokollektorfläche:

- 100 bis 1.000 m^2: 500 - 800 EUR/m^2
- > 1.000 m^2: 450 - 600 EUR/m^2

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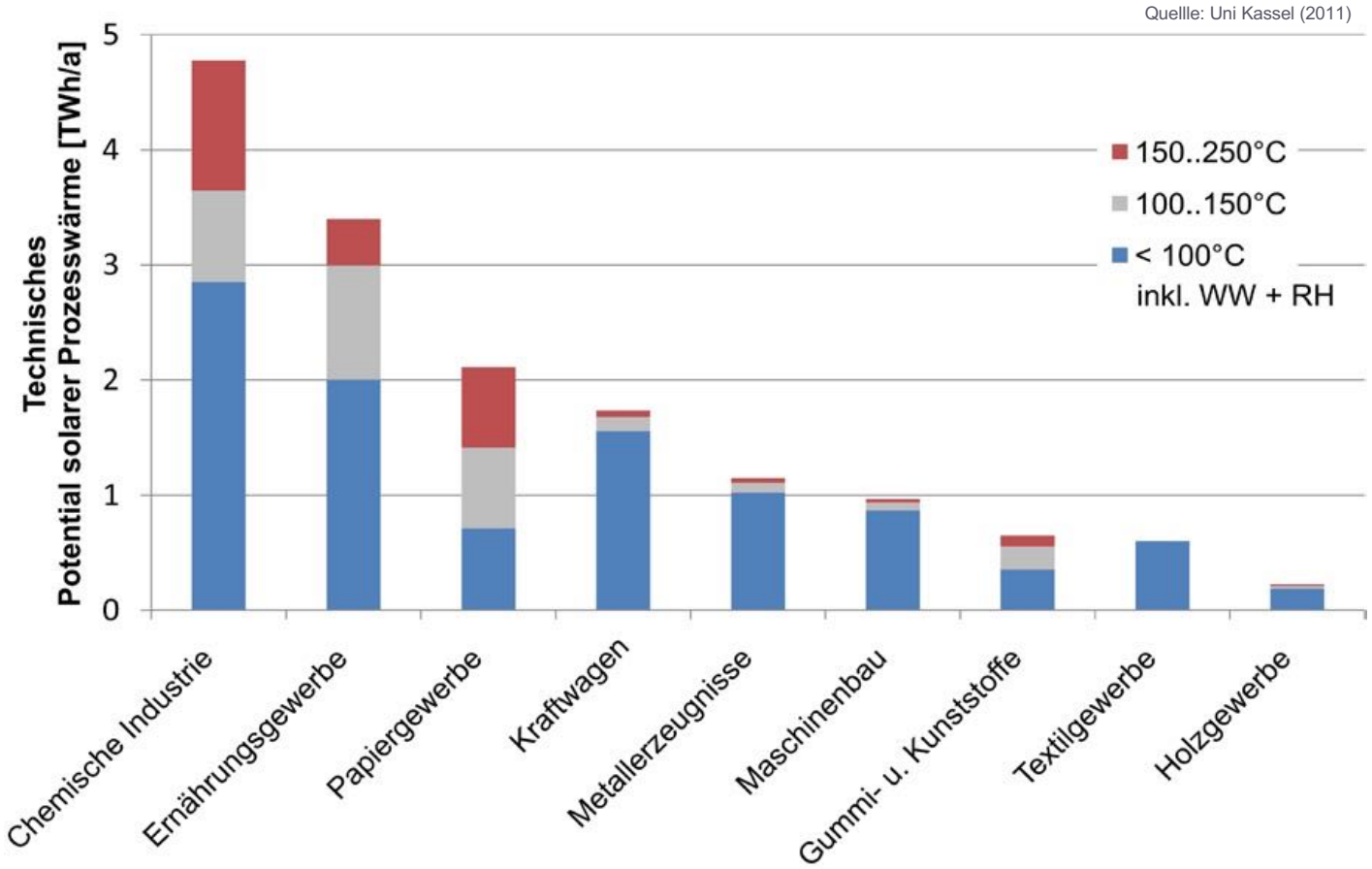
Branchenspezifisches Potential von solare Prozesswärme



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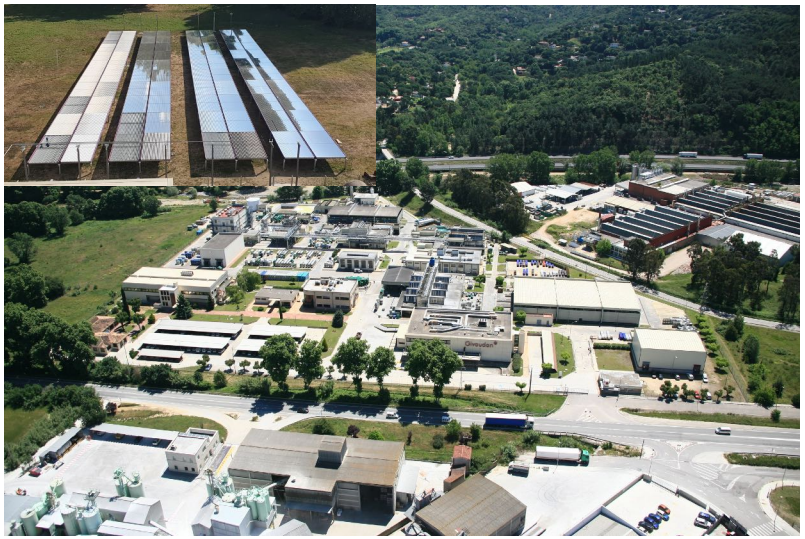
Beispiel Chemische Industrie (Spanien)



Quellen: Givaudan, Ecotherm, Fahrenheit

Sant Celonie, Spain – steam for steam network and cooling

800 m²	Fresnel collectors
200 kWh	PCM storage
200 kW	cooling capacity, hybrid chiller (2x adsorption + 4x propane vapour compression chillers)

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Beispiel Lebensmittelindustrie (Österreich)

Quellen: Fleischwaren Berger, Solera

Sieghartskirchen, Austria – pre-heating of feed water for food processing

1,068 m²	flat plate collectors
122 m^2	parabolic trough collectors
60 m^3	hot water storage
145 tons	CO_2 avoided per year

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Beispiel Lebensmittelindustrie (USA)

Quellen: Frito Lay

Frito Lay, USA – steam for food processing (SunChips®)

5,016 m² parabolic trough collectors (20 bar steam at 240°C)
717 tons CO_2 avoided per year

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Beispiel Lebensmittelindustrie (Spanien)

Quellen: SoPro

Montesano, Spain – hot water for food processing (Iberic ham)

252 m² flat plate collectors
30 m³ hot water storage
Pay-back of about 7 years

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Beispiel Brauerei (Österreich)

Quellle: AEE Intec

Brewery Neuwirth, Austria – hot water for brew process

20 m²	flat plate collectors (heating temperature of 95°C)
1,000 l	hot water storage

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Beispiel Metallverarbeitende Industrie (Deutschland)

Quellen: Ritter XL Solar

Huster Galvanik, Germany – hot water for electroplating (galvanizing)

221 m² vacuum tube collectors
Solar fraction of 40%

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Beispiel Kunststoffverarbeitende Industrie (Deutschland)

Quellen: zafh.net

HC Mayer, Germany – hot air for space cooling and heating

100 m²	solar air collectors and boiler Back-up
45 kW	heat recovery from casting machines
100 kW	cooling capacity, DEC system

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Beispiel Betonfertigteilindustrie (Österreich)

Quelle: energiestar.at

Quelle: NAU

Leitl Beton, Austria – hot water for fabrication of prefabricated concrete walls and ceilings

315 m² flat plate collectors
36 m^3 hot water storage
Solar fraction of 30%
422 tons CO_2 avoided per year

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Beispiel LKW Waschanlage (Spanien)

Quellen: SoPro

Vaporizados Palencia, Spain – hot water for washing tuck vessels

140 m² flat plate collectors
10 m³ hot water storage
Pay-back time of 5 years

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Beispiel Autowaschanlage (Deutschland)

Quelle: Cleanpark

Cleanpark, Germany – hot water for car washing

24 m²	flat plate collectors
1 m^3	hot water storage

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Links

- BMU gefördertes **“Solar Payback”** Projekt – Solar Heat for Industry
  involvierte Länder: Brasilien, Mexiko, Indien und Südafrika
  (https://www.solar-payback.com)

- **SHIP plant database** (www.ship-plants.info)

- EU geförderte SHIP Projekte **InSun, FRESH NRG, REEMAIN, HyCool, SHIP2FAIR, FRIENDSHIP und ASTEP**
  (http://www.fp7-insun.eu, http://fresh-nrg.eu, http://www.reemain.eu, http://hycool-project.eu, http://ship2fair-h2020.eu, https://friendship-project.eu, https://astepproject.eu)

- **IEA SHC Task 49** und **IEA SHC Task 64** on Solar Process Heat
  (http://task49.iea-shc.org, http://task64.iea-shc.org)

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Vielen Dank für Ihre Aufmerksamkeit!

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