Small-scale CSP and solar process heat application: case studies

Conference on Small-scale Concentrating Solar Power in Sardinia

Werner J. Platzer

Director Division
Solar Thermal and Optics

Fraunhofer Institute for
Solar Energy Systems ISE

Pula, 25th September 2015

Fraunhofer ISE – Short Profile

- Director Prof. Eicke Weber
- Founded 1981
- 12 Business areas
- Budget 2014 86 Mio €
- Revenues from industry average 40% (over last seven years)
- 1225 Employees
- 27000 m2 lab and office space
- Strong growth rate 2008-2012

Solar Thermal Technology for Heat and Electricity

Optics and Material Science	Solar Thermal Collectors	Solar Thermal Systems Engineering
PVD coatings	Collector development	DHW and heating
Surface analytics	Certified TestLab	Process heat
Vacuum technology	Heat transfer	Solar thermal power
Micro structuring	Concentrator optics	Thermal storage
Degradation	Structural mechanics	Water treatment

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Content

- Introduction
- Solar Process Heat
- Electricity Generation by CSP
- Polygeneration
- Project examples and Case studies
- Conclusion

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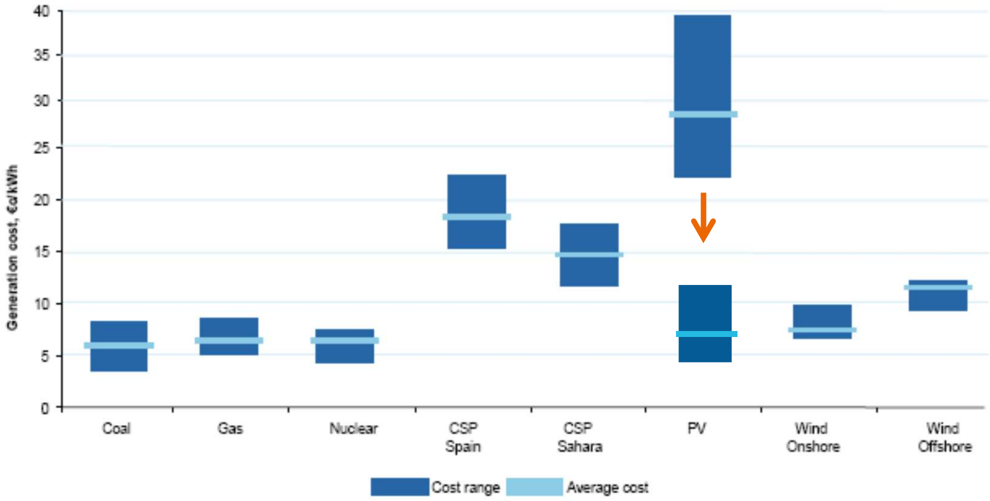
Comparison of LCOE conventional and renewable energy



Source: PWC 2010

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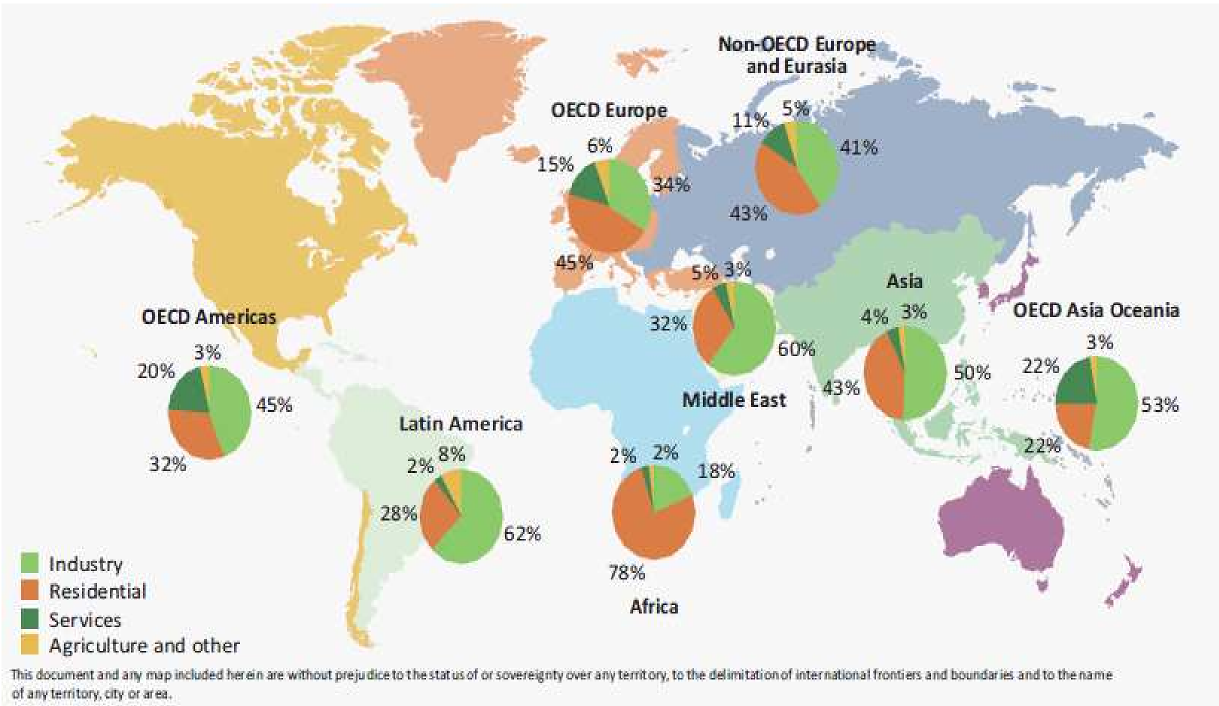
Heat plays important role worldwide



Note: Figure based on 2009 data

Source: Energy Technology Perspectives 2012

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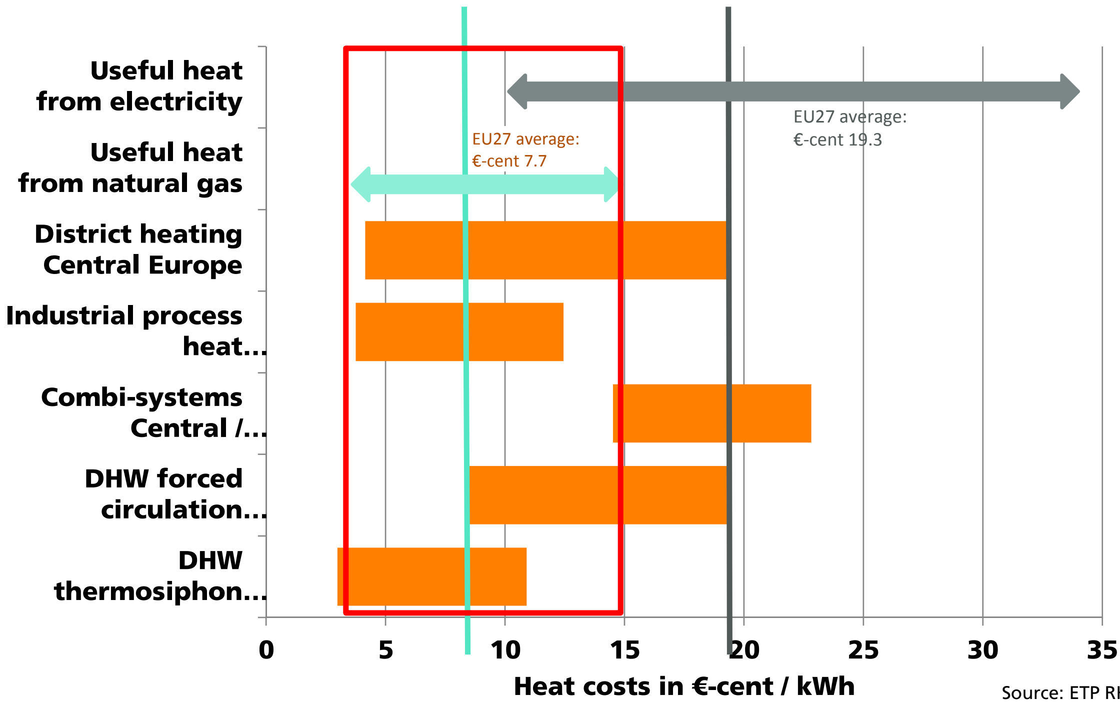
Cost of Solar Heat in Europe



Source: ETP RHC (2013)

Is the combination of CSP and process heat the solution?

Combination of CSP and solar process heat => small scale CSP
1 MW_{el} instead of 100 MW_{el}

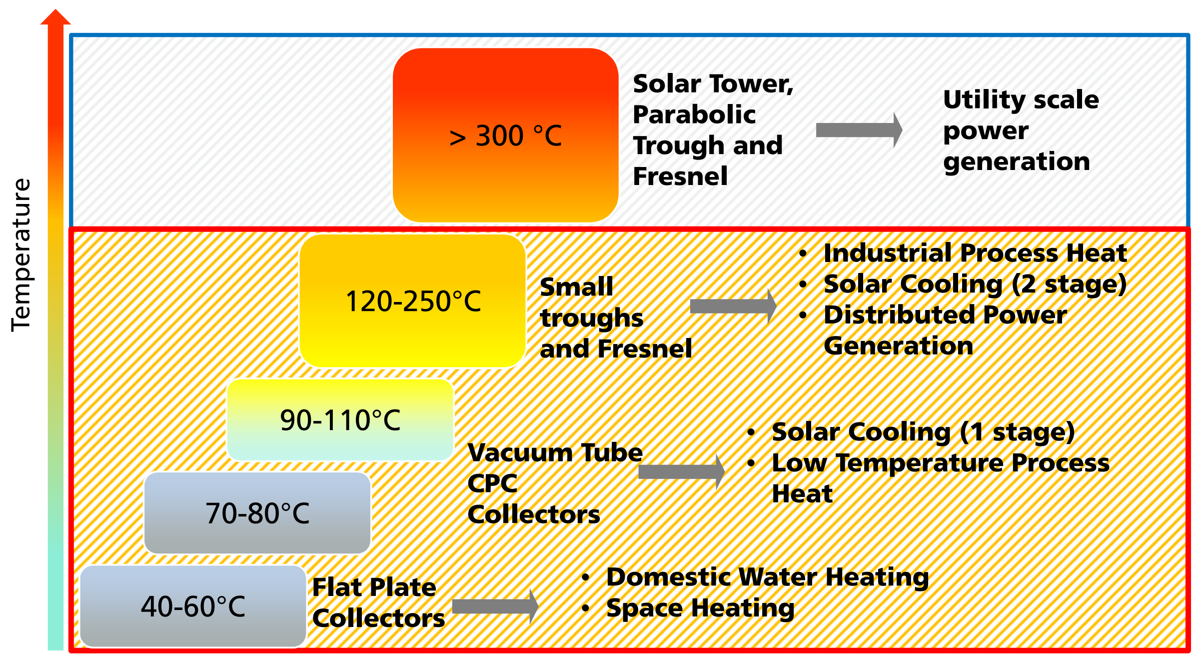
Considerations:

- Heat consumers have limited demand on heat -> industry < 10 MWth
- Area in industrial areas is usually more expensive
- Area for solar process heat often limiting factor
- Economy of scale: large plants have lower specific costs
- Additional operational complexity
- PV electricity seems better suited for smale-scale generation

Which factors can make SSCSP commercially viable?

Content

Solar Thermal Collectors – for Power, Cooling and Heat



Parabolic Throughs and Linear Fresnel Collectors

- Reduced temperature level for process heat compared to CSP
- Smaller solar field requires different installation procedures



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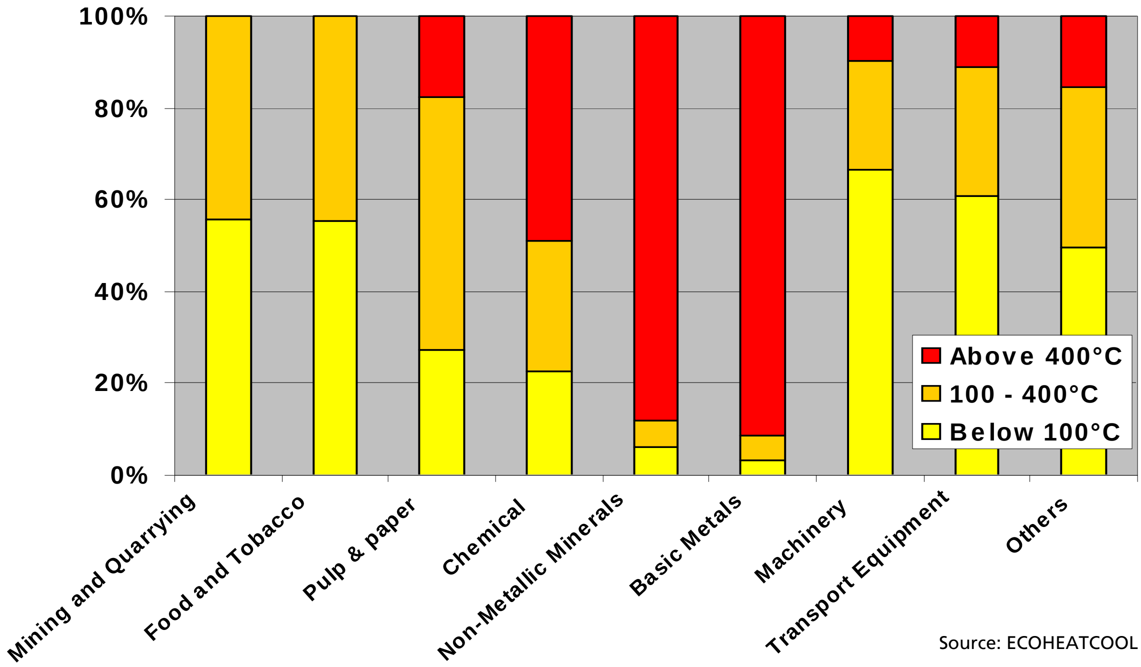
European Industrial Heat Demand by temperature level and industrial sector year 2003



Source: ECOHEATCOOL

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Temperature Levels for Industrial Heat

Industry Sector	Process	Temperature level [C]
Food and Drinks	Drying Washing Pasteurising Cooking Sterilising Heat Treatment	30 - 90 40 – 80 80 –110 95 – 105 140 – 150 40 – 60
Textile	Washing Bleaching Dying	40 – 80 60 – 100 100 – 160
Chemistry	Cooking Destilling various chem. Processes	95 –105 110 – 300 120 -180
All Sectors	Feedwater pre-heating Space Heating	30 – 100 30 – 80

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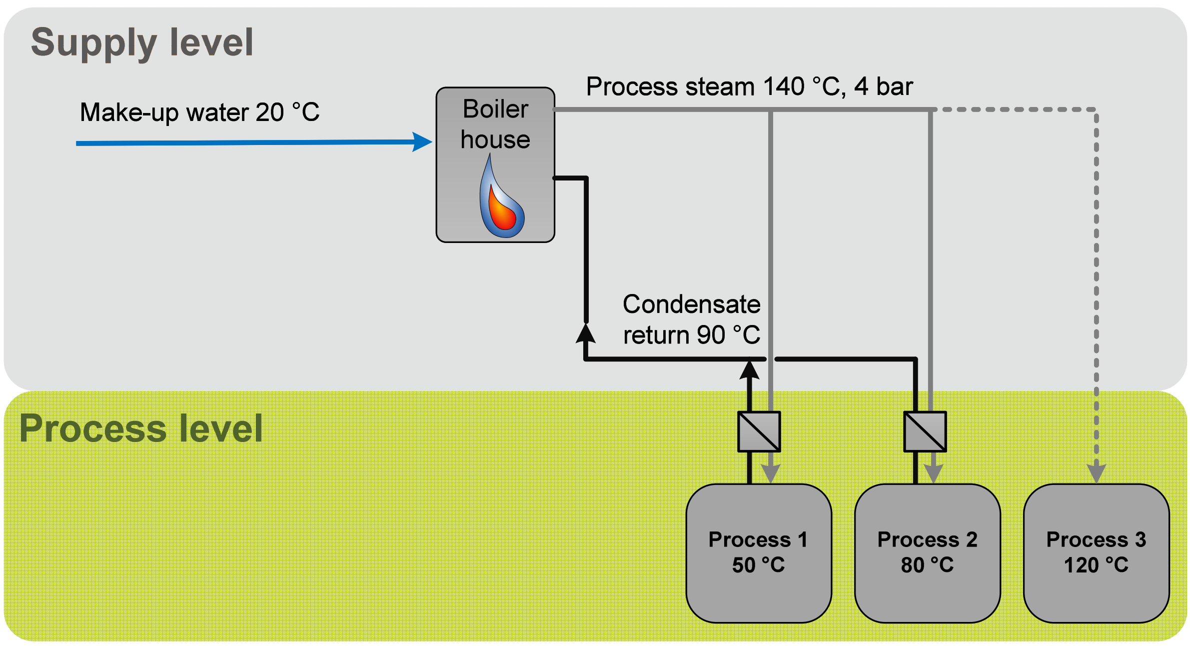
Solar Thermal Heat Integration
Process- or Supply Level?



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Heat Integration

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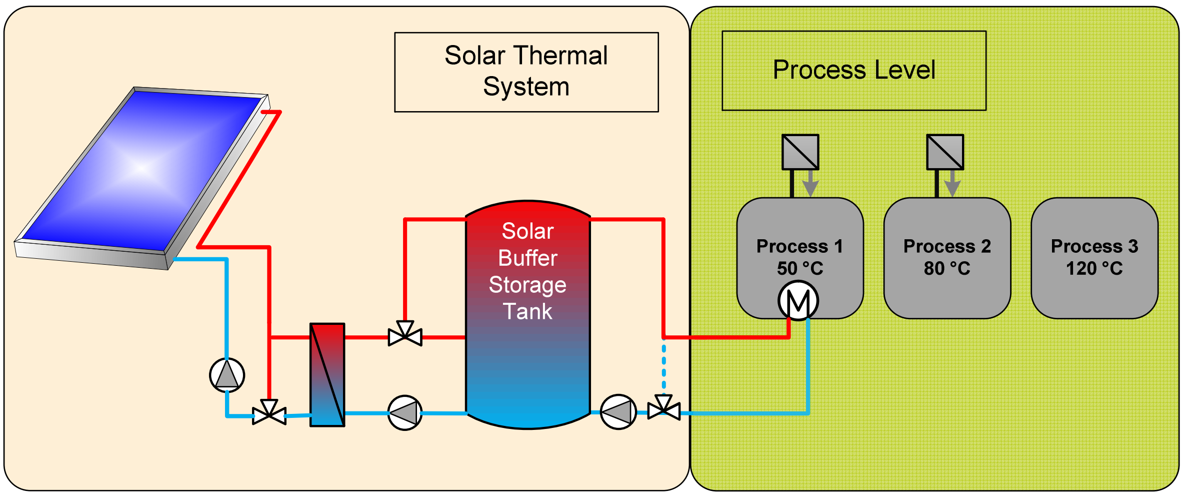
Solar Thermal Heat Integration
Process Level



Simplified system concept for direct process heating

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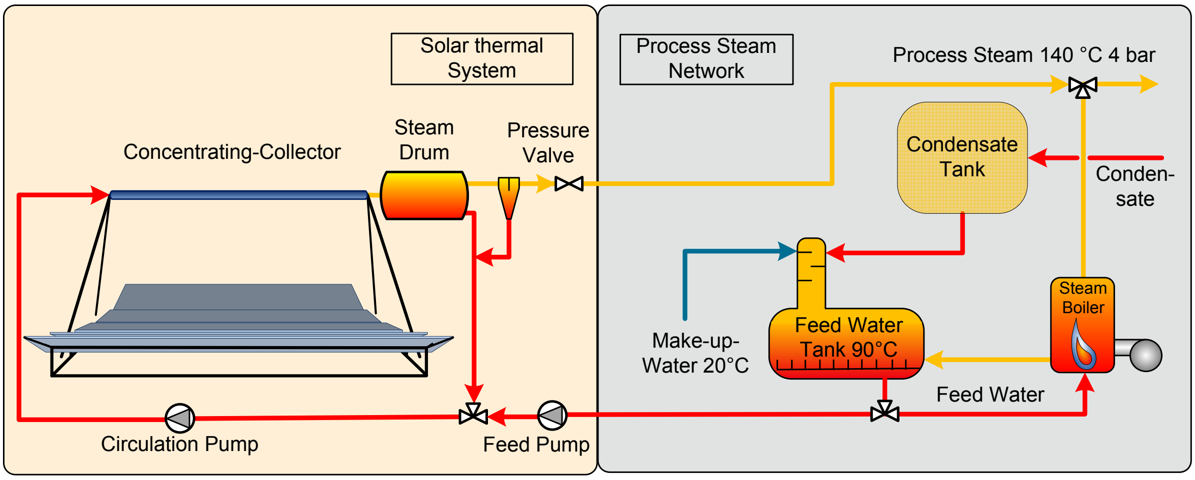
Solar Thermal Heat Integration
Supply Level Example: Direct Steam Generation



Simplified system concept for direct steam generation

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Integration concepts

- Process Level
  - Solar heat is directly supplied to the process.
  - Can be used for processes where the temperature of heat required is of low grade (until 100 °C) such as washing, cleaning, heating of industrial baths, hot air drying.
  - Is useful most when the heat requirement is restricted to one or two processes.
- Supply Level
  - Solar heat is supplied to all the processes through the heat distribution network.
  - Used in steam networks and high temperature networks where the solar thermal system may deliver pre-heated feed water or direct high-temperature steam
  - Flexible against process and demand changes!

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Four main CSP technologies today

Overview of CSP technologies

= required land use XX = worldwide installed capacity (status 2013)

Parabolic trough

- Parabolic mirrors focus sunlight onto a receiver tube
- Receiver contains fluid (oil, molten salt or water) which is heated and used to produce steam that drives turbine & generator

3.25 ha/MW

Linear Fresnel

- Series of flat / shallow-curvature mirrors focus sunlight onto receiver tube positioned above the mirrors
- Fluid (oil, molten salt or water) in receiver is heated and steam is generated that drives a turbine and generator

1.45 ha/MW

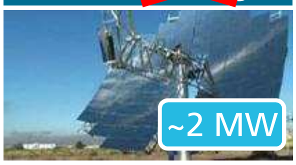
Solar tower

- Array of heliostats focus sun-light upon a single point (receiver) at the tower
- Receiver is heated up (air, oil, water, etc.) and produces steam
- Steam drives a turbine and generator

4.50 ha/MW[1)]

1.39 ha/MW[1)]

Dish / ~~Stirling~~



- Parabolic dish focuses sunlight onto a receiver above the dish
- A combustion engine (Stirling type) converts heat into kinetic energy and drives an electric generator

Falling back

3.90 ha/MW

1) Depending on tower technology

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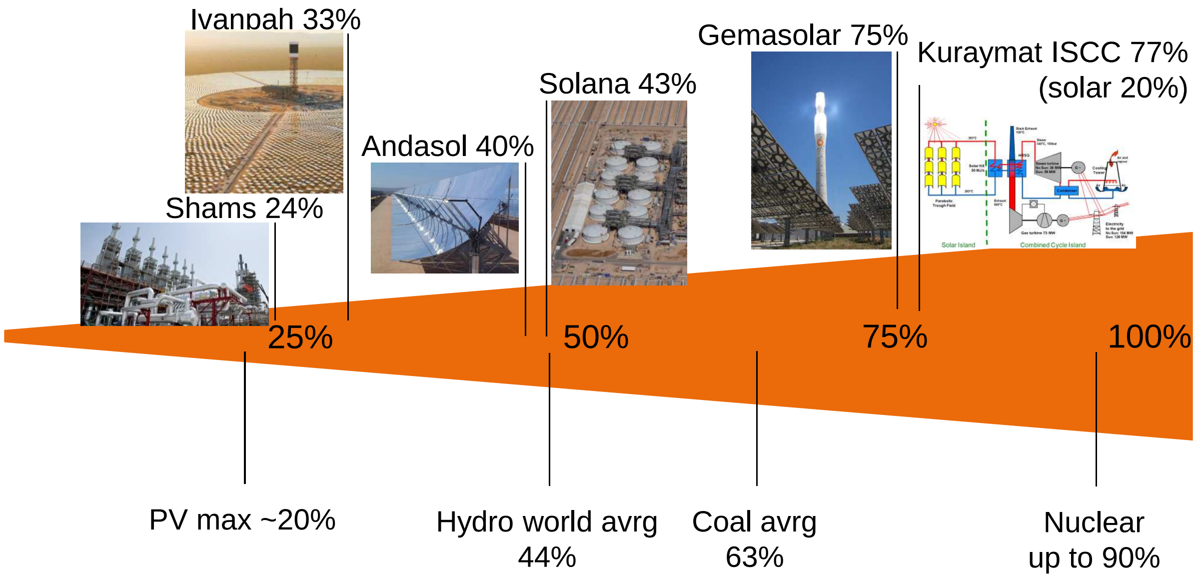
Capacity factors of CSP

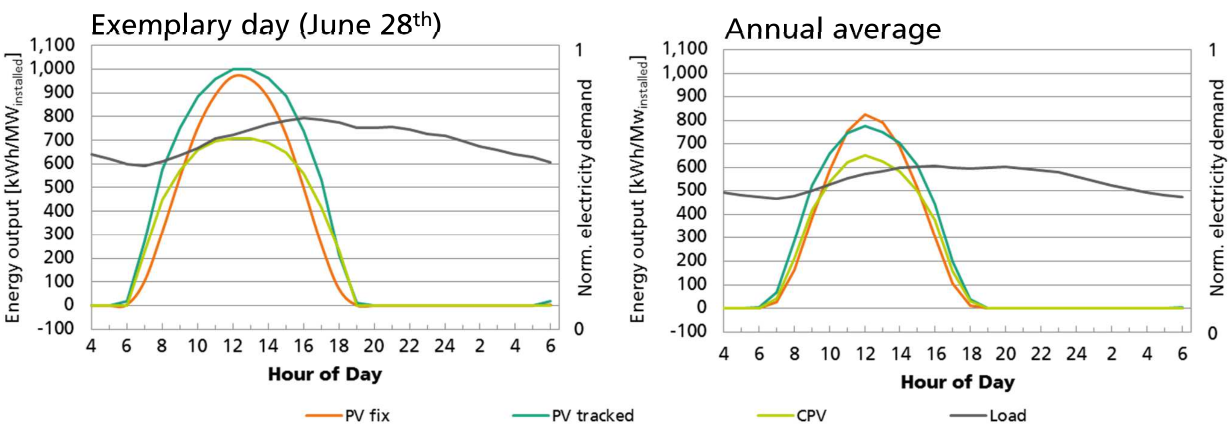
CSP provides wide range of plant types with different CF



Why CSP? Case study – RE-mix at middle east site

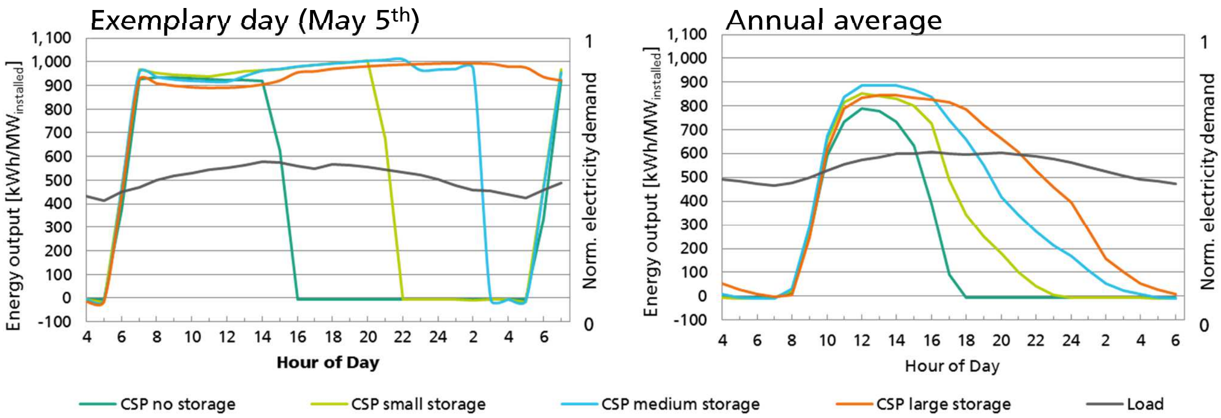
PV power production profile vs. load

- PV production follows irradiation with peak at noon
- CPV has slightly lower output because it only uses direct irradiance



Why CSP? Case study – RE-mix at middle east site
CSP production profile vs. load

- On a good solar day, CSP storages are filled and the complete period of high load can be covered
- With large thermal storage, even 24/7 operation is possible
- Also the annual average shows the positive influence of storage



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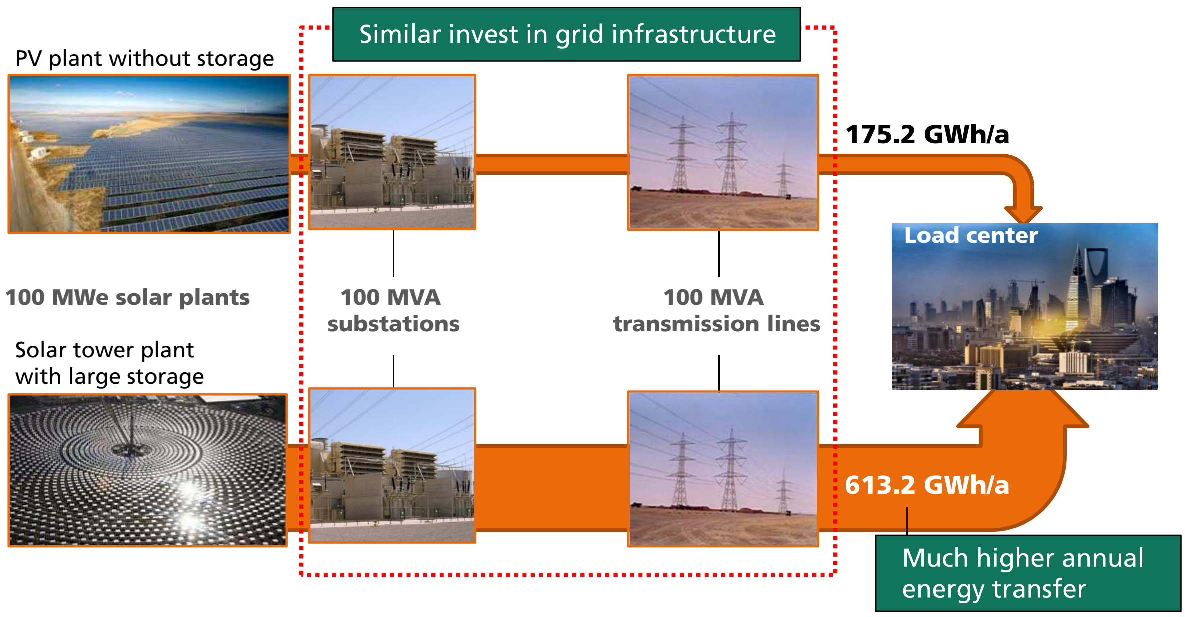
Why CSP?
Impact on grid infrastructure utilization

- Due to the higher capacity factor the **grid infrastructure is used much more effectively** with CSP than with plants without storage



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After news on low battery cost – is PV cheaper?
Comparison of Investment Cost for 100 MW Plant

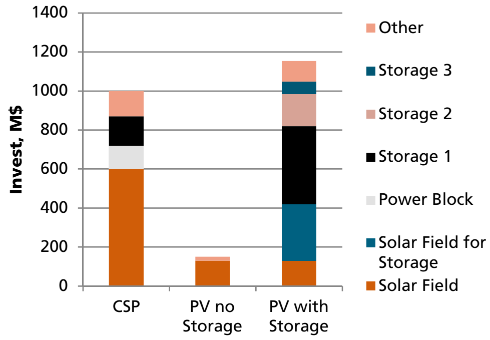
Assumptions:

- Solar Multiple of 3 sufficient for 24h operation

Important to note:

- Additional Solar field capacity is required for storage charging
- Storage efficiency is not 100 % but rather 90 % in case of batteries
- Batteries need to be replaced at least once during power plant life time
- CSP still competitive for dispatchable power

  → Detailed comparison required on case by case basis



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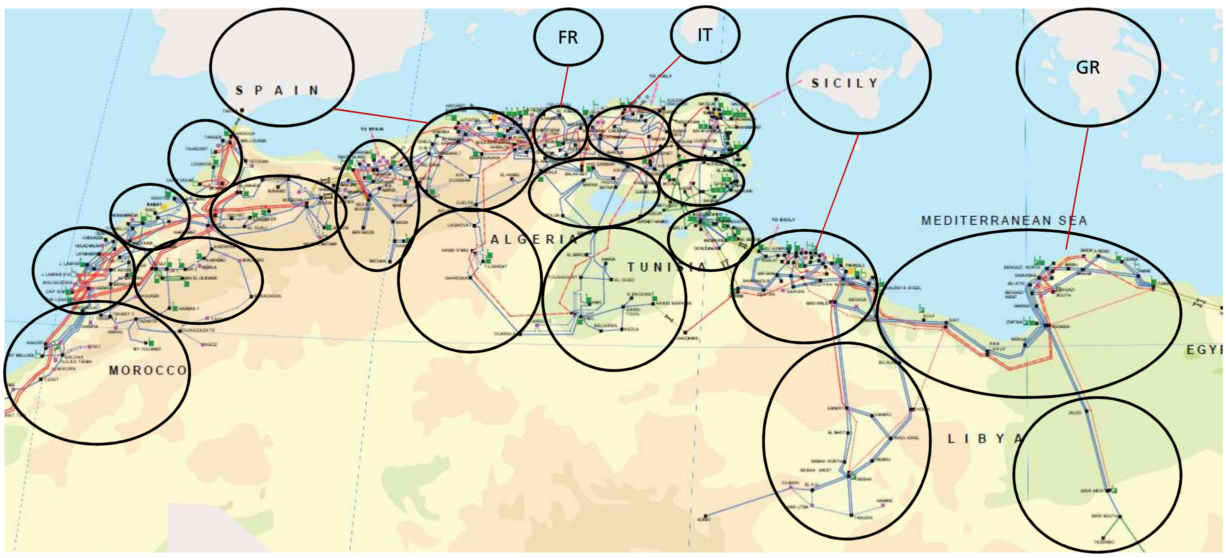
Grid Model for North Africa

- Regional grid plan
- Interconnectors to Europe taken into account



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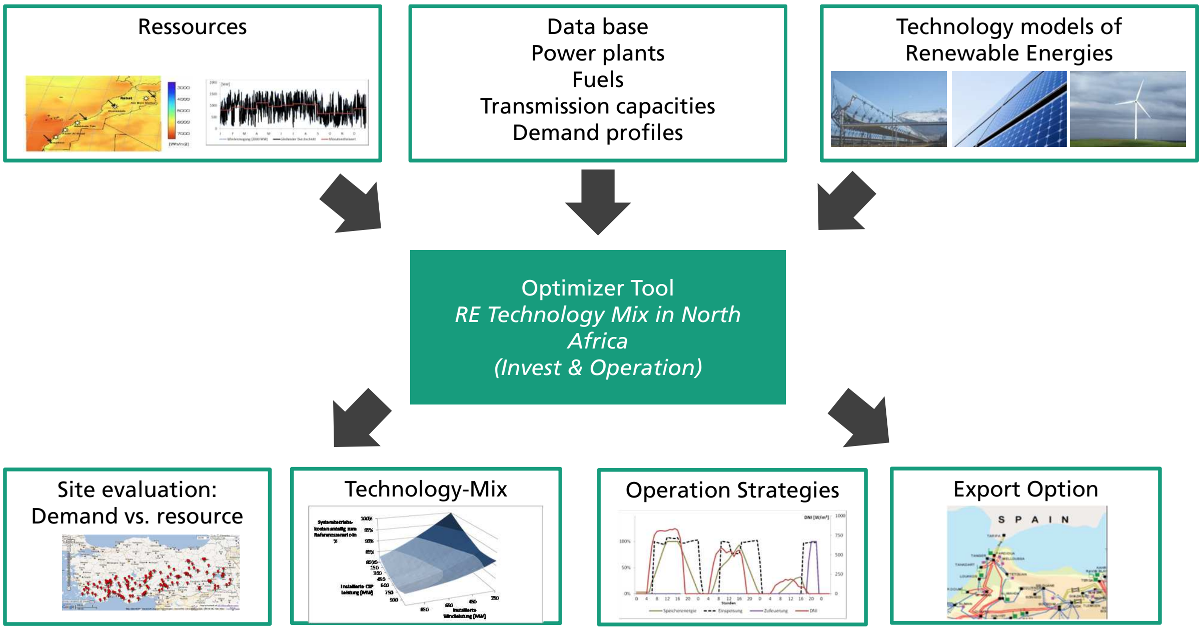
RE-Power Generation in Marocco (Example)



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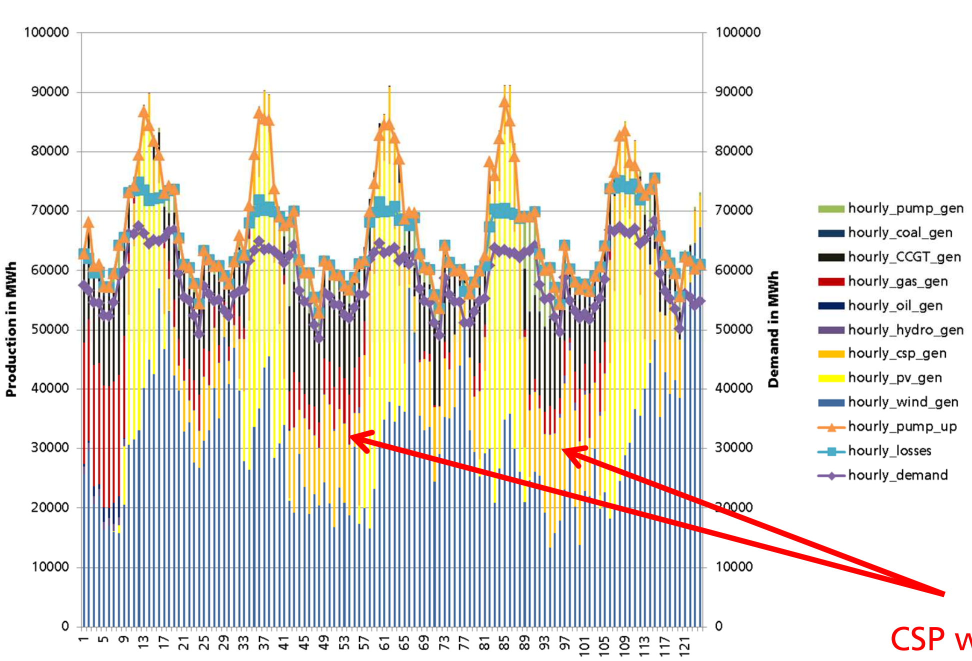
Analysis of Electricity Production over 5 days

Projection North Africa



- Fluctuating generation from RE
- Transmission losses taken into account
- Flexible Production incorporated in model

CSP with storage

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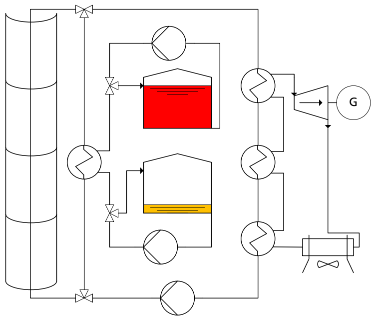
Evaluation of molten salt storages
The path to lower cost

Two-tank indirect

Temperature (T) loss due two double HX

T limited by oil

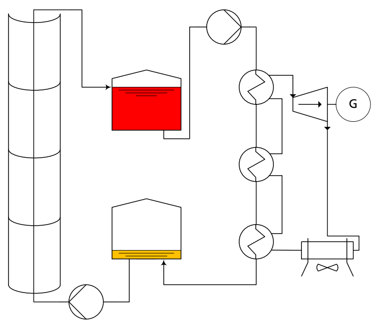
One tank always empty



Andasol

Two-tank direct

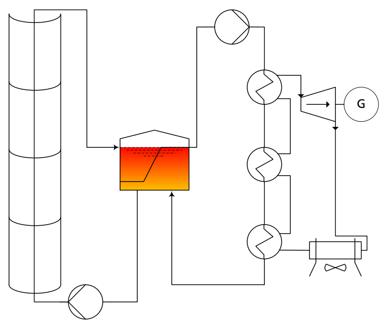
- Molten salt also in collector
- Higher T possible
- Less T loss & equipment



- Gemasolar

Single thermocline tank

- One tank less
- Possible integration of HX
- Additional use of filler material reduces amount of salt



- Testing / Pilots

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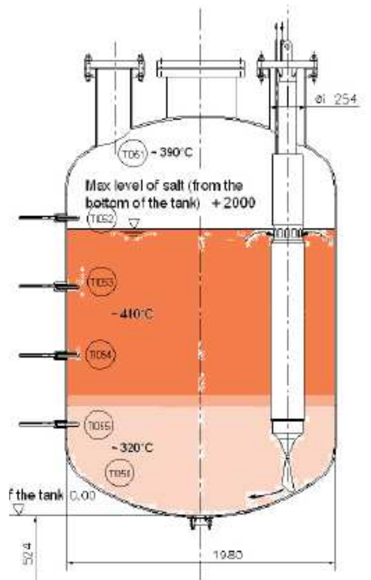
CSP – Optimization of Systems and Storage

Development of high-temperature storage, molten salt technology and further development of simulation and optimization tools

- 1 MW Solar thermal power plant using single tank storage and MED desalination in Egypt - MATS (EU FP7)
- Direct steam generator in single tnak molten salt storage - OPTS (EU FP7)
- Latent storage uisng a screw heat exchanger unit - INNOLAT (EIRI)
- Evaluation of storage concepts and innovative storage types - Supergrid (FhG)



Scheme of Single Tank molten salt storage uisng integrated steam generator

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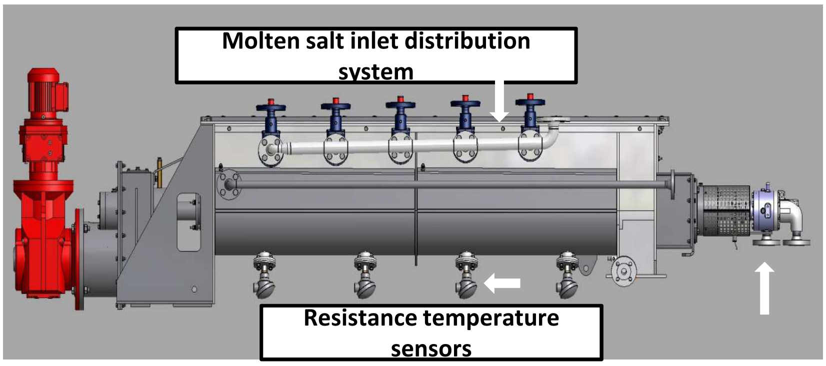
Principle of new PCM storage system

- Solid granular material and molten material are stored in separate tanks
  - Transport of PCM through screw heat exchanger (SHE)
  - Phase change inside SHE
- Size of thermal power and storage capacity are not coupled



Design of lab prototype

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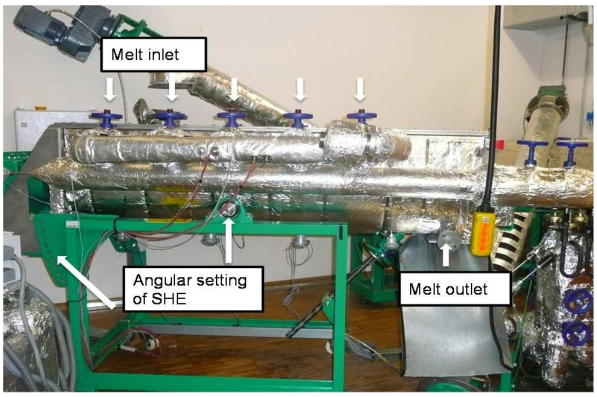
Prototype and commissioning



- Inclination for crystallization not necessary
- Crystallization of salt in SHE $\dot{m}$ = 150 kg/h
- Bulk density improved to ρ = 950 kg/m^3

=> Proof of concept has been successful
  => Heat transfer experiments with varying parameters (e.g. mass flow, rotation speed,..

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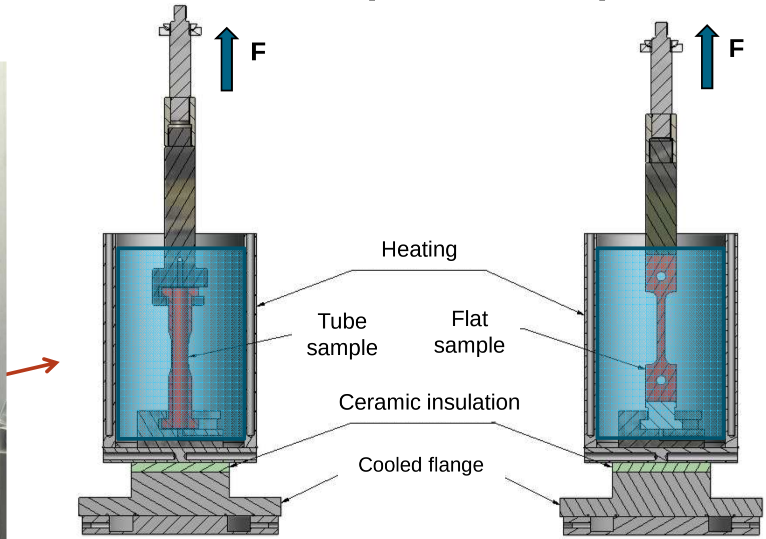
Materials Testing
Slow Strain Rate Test in molten salt (CERT –Test)



- Maximum Load: 150 kN
- Test Speed: 0,25 µm/h up to 25 mm/h

correspond > $3,5*10^{-9}$ strain rate for a sample length of 20mm

What is the future of CSP?

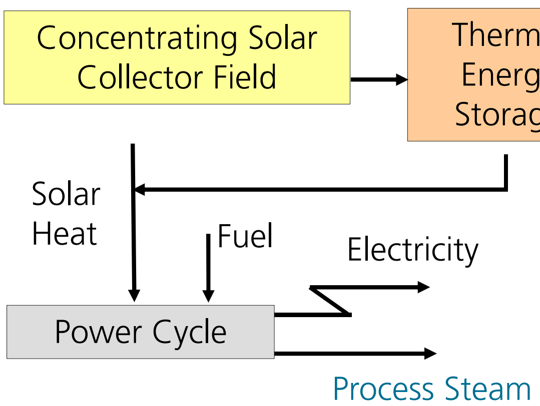
- Dispatchability of Solar Thermal Power is a unique selling point compared to PV (and allows higher LCOE to some extent); two options:
  - Thermal Energy Storage (TES) between 3h and 15h capacity
  - Hybridization with natural gas / biomass boiler
- Depending on the level of fluctuating generation (PV, Wind) in a grid the dispatchability may allow 2-4 €ct/kWh higher LCOE for CSP
- CSP may play a significant role in a regional and national energy mix, when PV and Wind have already considerable shares in the grid

- Efficiency considerations and storage capacity leads to higher operations temperatures
- Dry cooling is less detrimental for high steam temperatures

=> HTF molten salt with increased operation temperatures in future ?

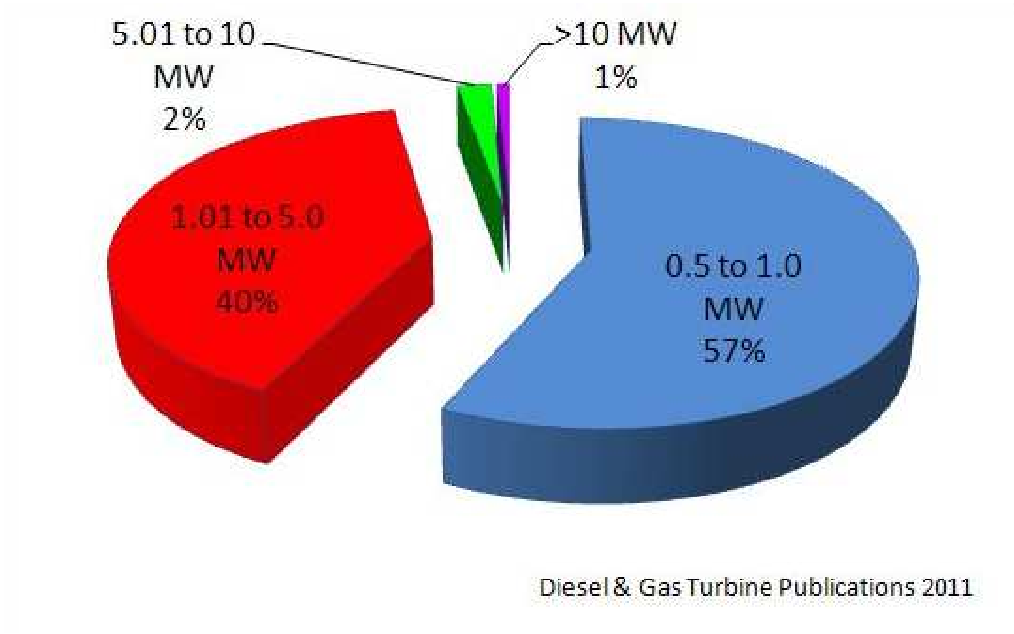
Content

Solar Polygeneration - Combined Heat & Power -> Small projects Grid-connected and Off-Grid!

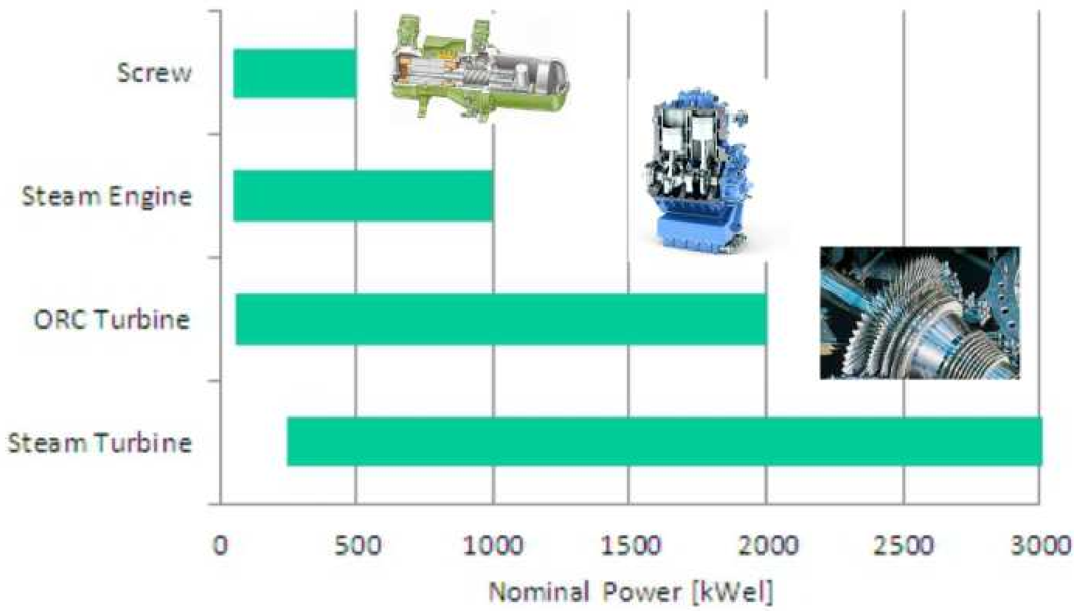


- solar electricity
- integrated fossil fuel backup capacity, power on demand
- increased solar operating hours, reduced fuel input
- additional process steam for heat, cooling, drying, seawater desalination, etc.

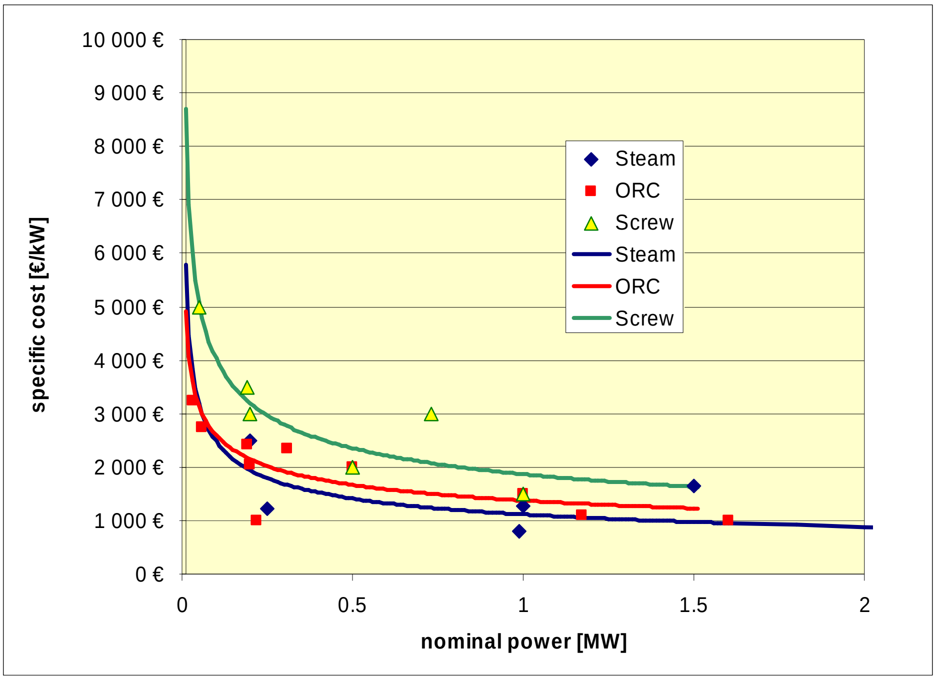
Annual Sale of Diesel Generators for Continous Operation (16 GW/ 14 000 Units)



Expansionmachines for Electricity Generation



Cost function for heat engines



MEDIFRES, 2011, Fraunhofer ISE

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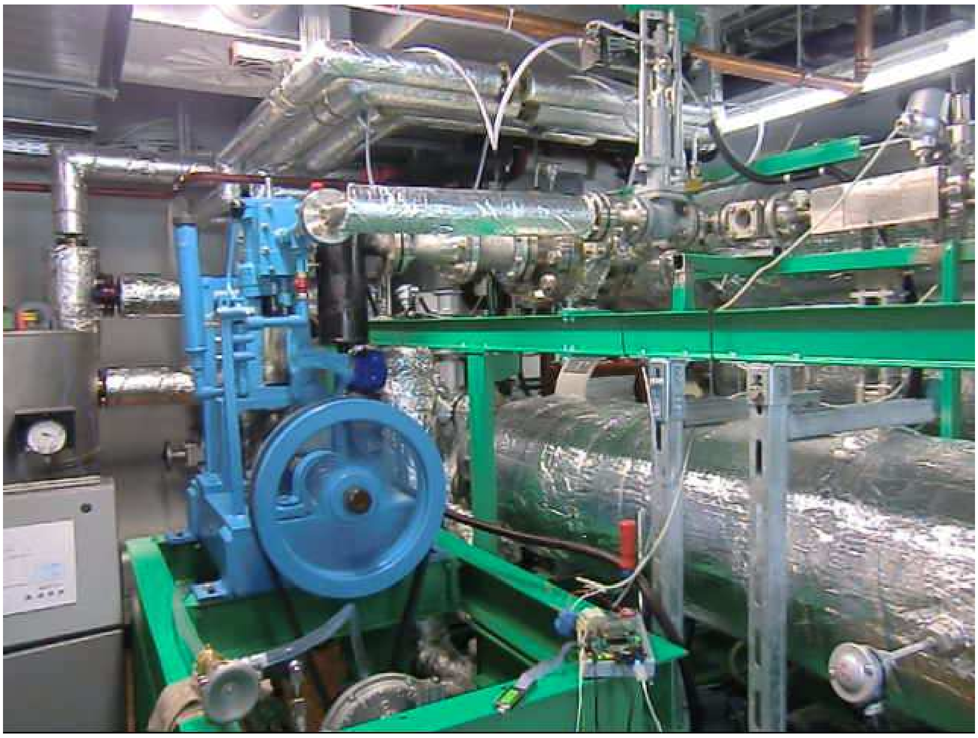
Very Simple Steam Engine for Commissioning



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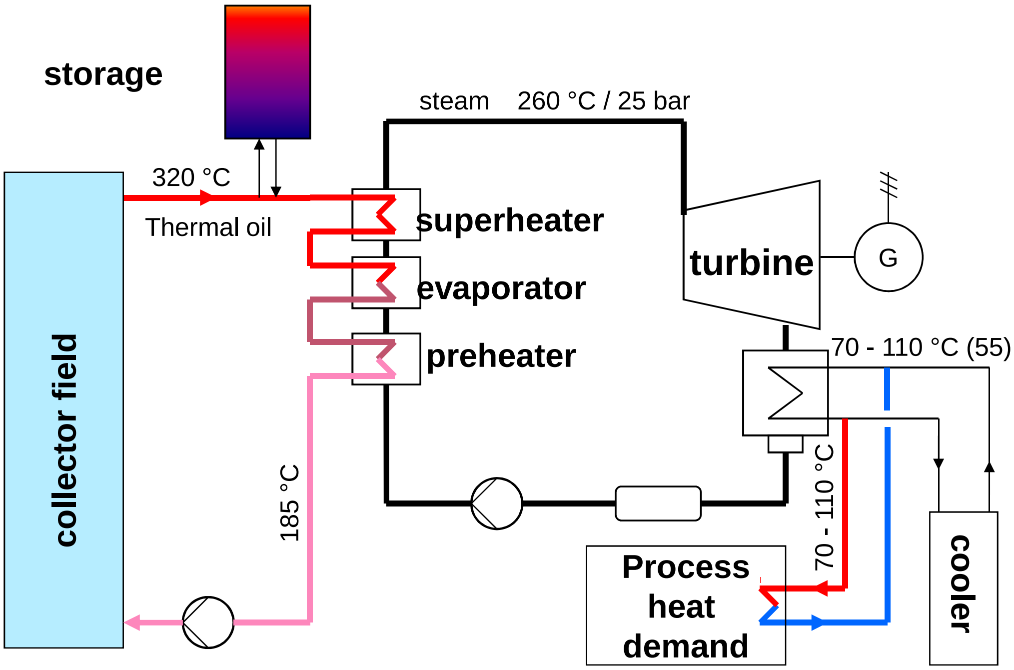
Polygeneration – Waste heat concept



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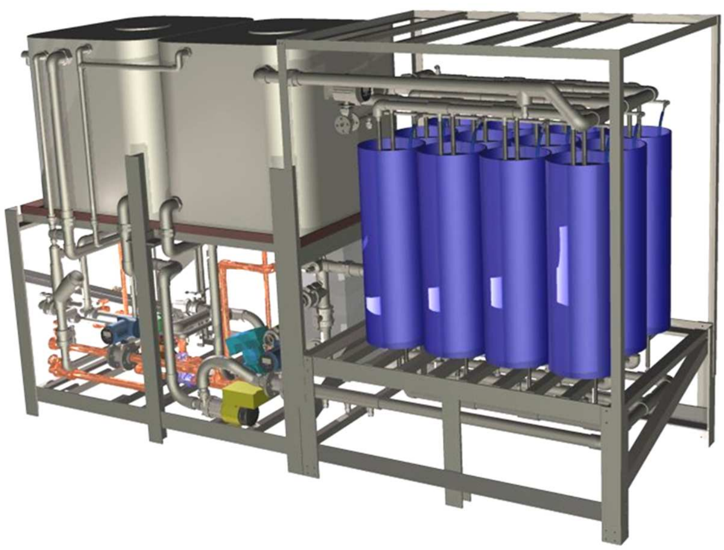
MD pilot plants in operation

Waste- and solar heat powered pilot plant in Pantelleria

In operation since October 2010

- Waste - and solar heat
- Target capacity 5m³/day
- No thermal storage
- 24h-operation
- 12 MD modules in operation
- Total membrane area 120m²



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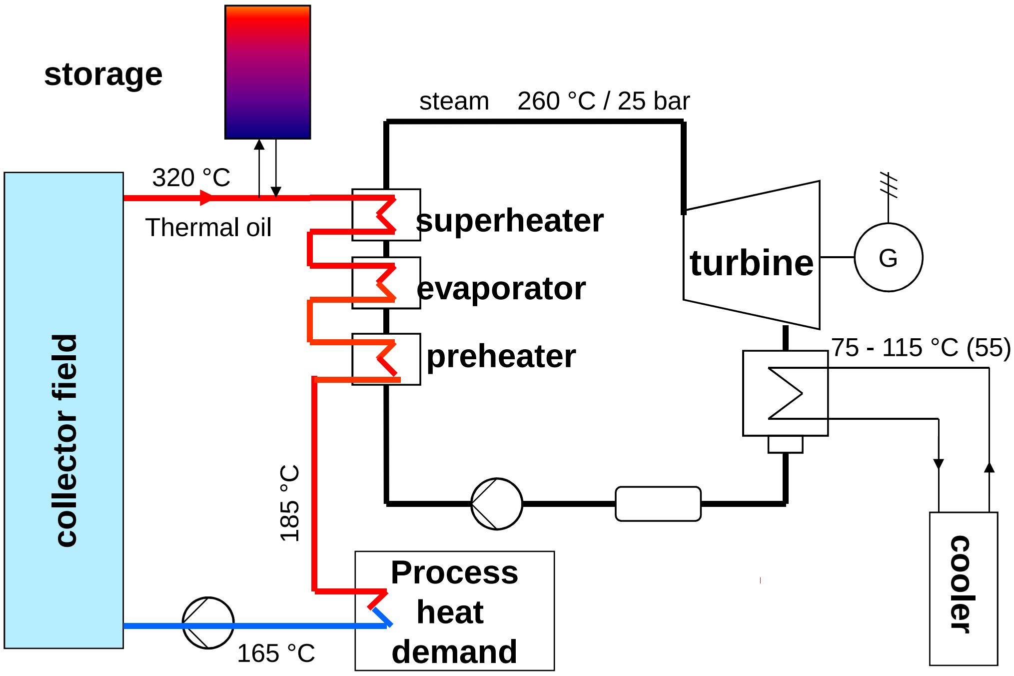
Polygeneration – process steam production



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Brewery Göss, Austria

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Integration into the mashing process

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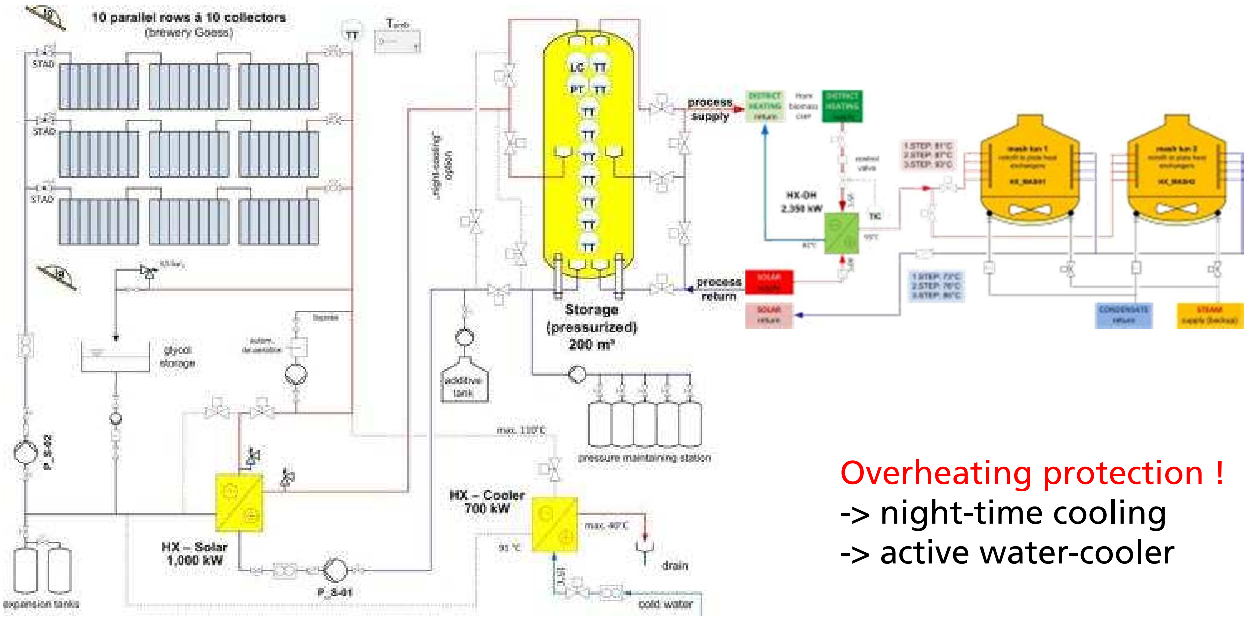
Integration into the mashing process



Overheating protection !
-> night-time cooling
-> active water-cooler

Source: AEE Intec

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Co-generation of Electricity and Heat

Solar dish-based CPV system using MIM cells developed at Fraunhofer ISE, Zenith Solar launched the first system at Kibbuz Yavne, Israel. April 2009

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ZENITHSOLAR

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Scheffler Reflector

Main technical data:

770 Scheffler dishes with fix focus (60 m2 each)

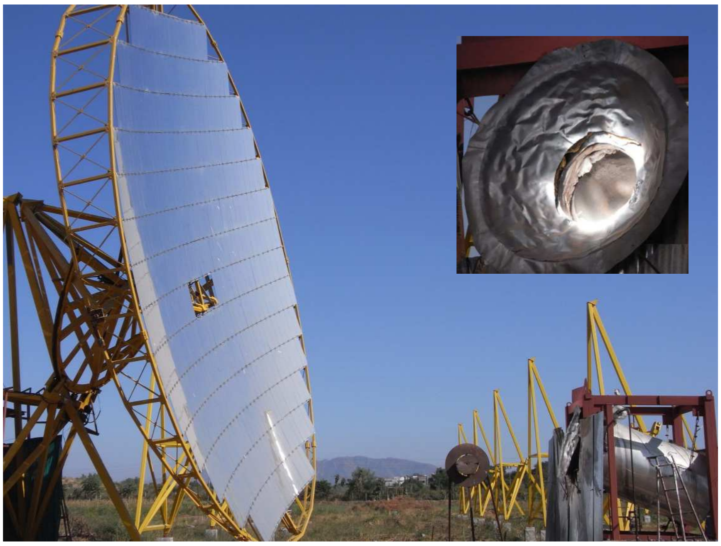
Reflector area: 45.000 m2

1 MWel (Siemens turbine,

255 °C, 41 bar)

3.5 MWth (hot water grid)

Metal core storage for continuous operation



Supported by MNRE and BMU (Germany)

Consultant: Fraunhofer ISE

www.india-one.net

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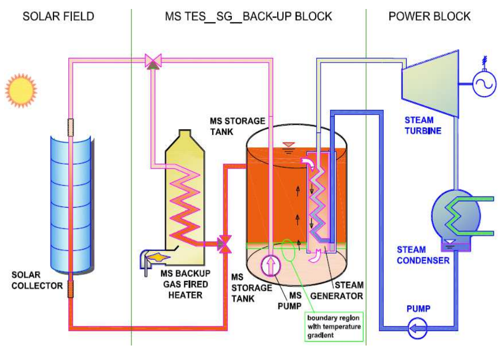
EU-Project MATS
Multiple Application Thermodynamic Solar

- Demonstration in Egypt
- Molten salt as HTF and storage medium
- 1 MWe, 100 m^3/d water desalination, 100 kW cooling



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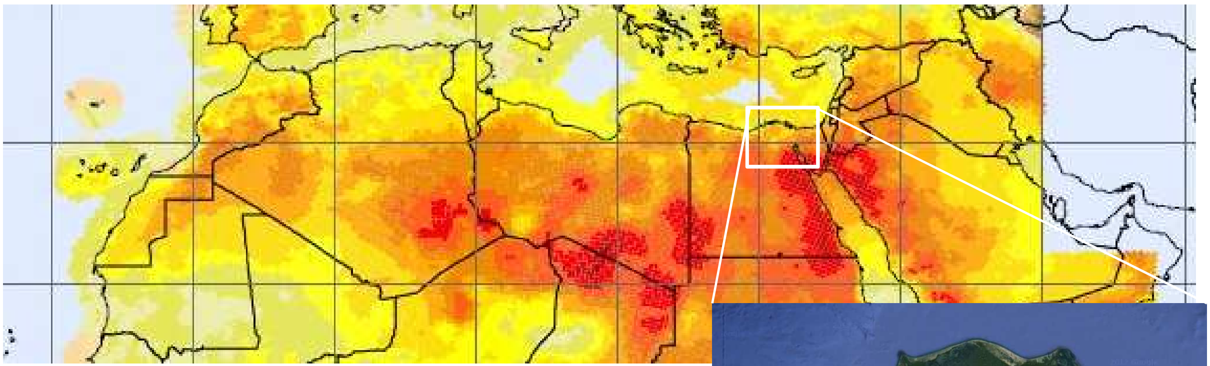
MATS - Site



NREL, Global Environment Facility, UNEP, Nov. 2005, Africa Direct Normal Solar Radiation Annual

Borg Al Arab
City of
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Research

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Conclusion

- SSCSP may be interesting when reliable and highly efficient heat engines in range 0.5 – 5 MW_{el} are available and proven
- A combination with low temperature process heat (use of reject heat < 80°C) is most interesting (e.g. desalination or industrial waste water cleaning with membrane destillation)
- Parallel use of high-temperature heat may be interesting in cases where electricity and heat demand are not parallel
- Dispatchable and reliable heat and electricity production is key:
  - Cost effecive storage technology (partly in development)
  - Hybridization with biomass
- Off-grid situations or weak-grid situations are benefical as diesel gensets produce expensive electricity
- Regional or national requirements (jobs, local value creation, grid stability) may support solar thermal power

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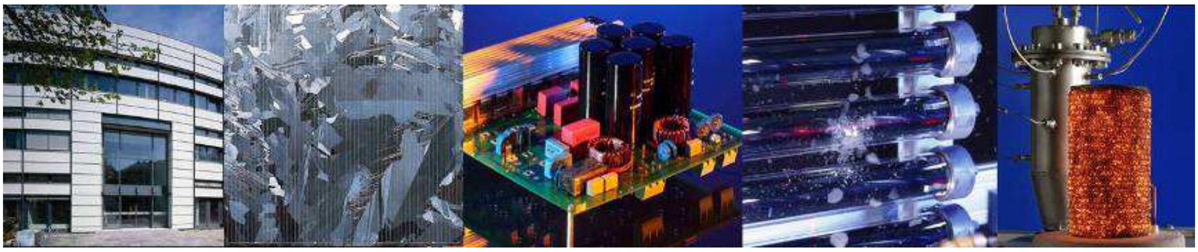
Thank you for listening!



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