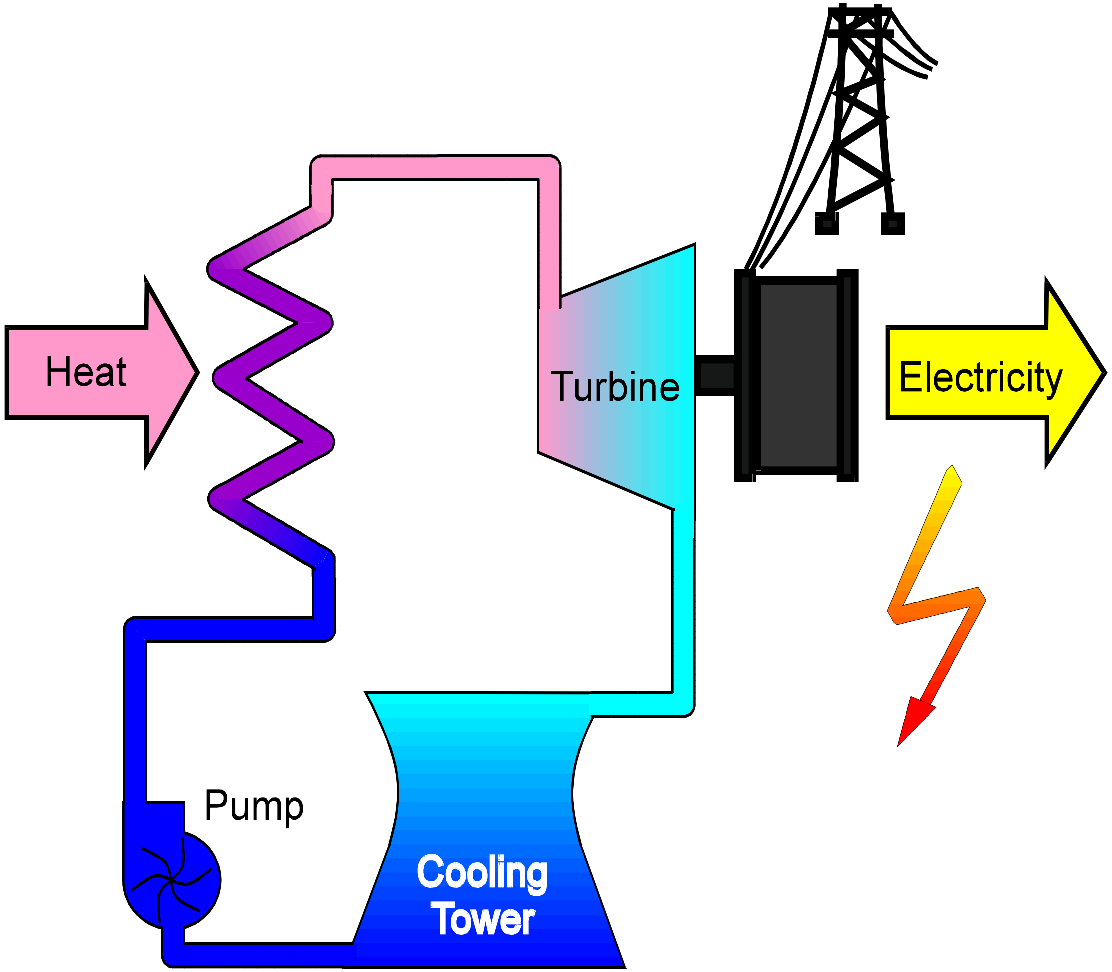
# Konzepte zur Kostensenkung solarthermischer Kraftwerke

DPG Jahrestagung 2015, 16. März 2015, Berlin

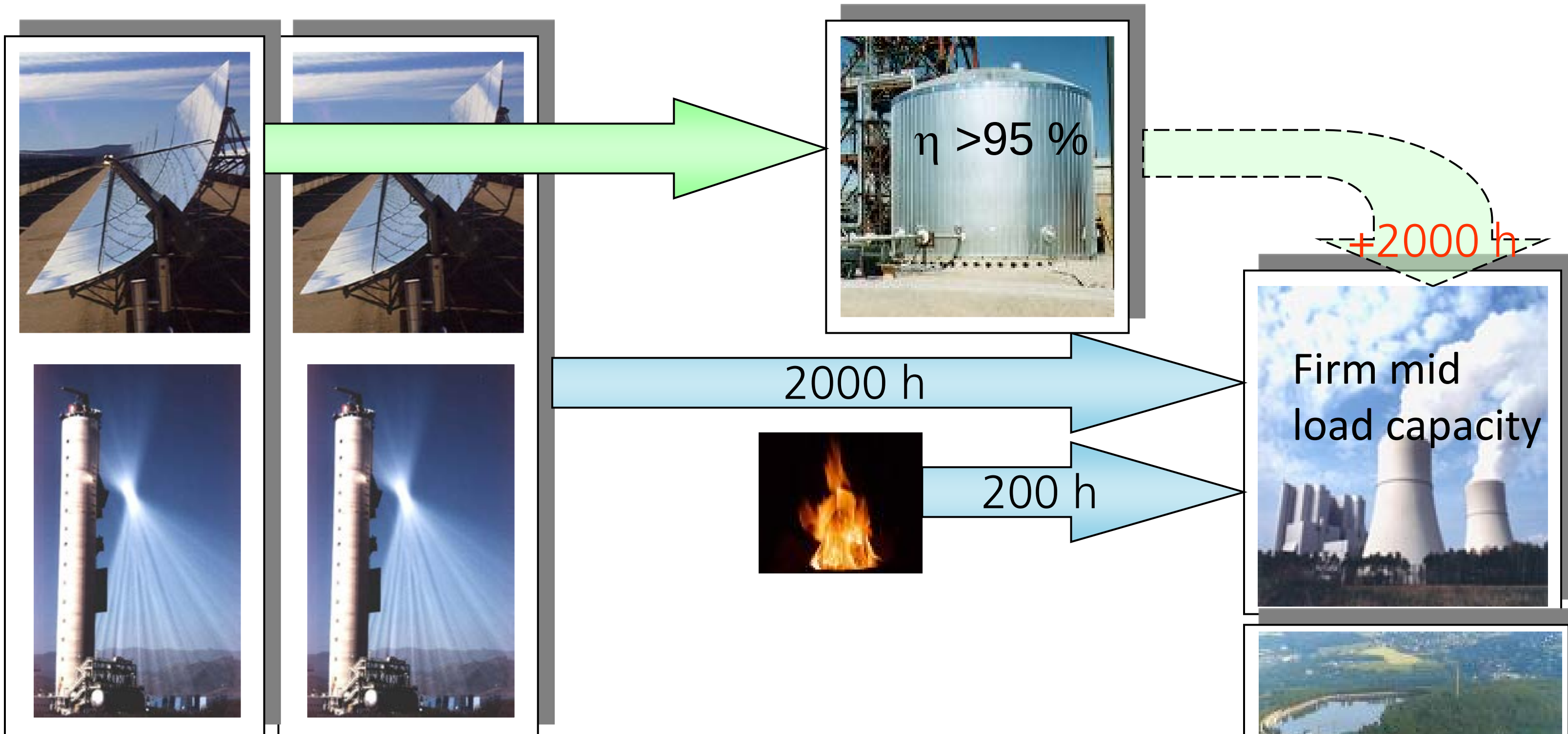
Robert Pitz-Paal, DLR Institut für Solarforschung

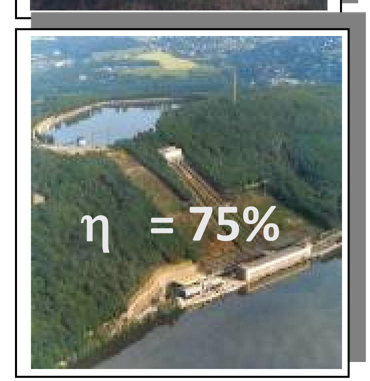
# What is CSP ?

Solar thermal power plants



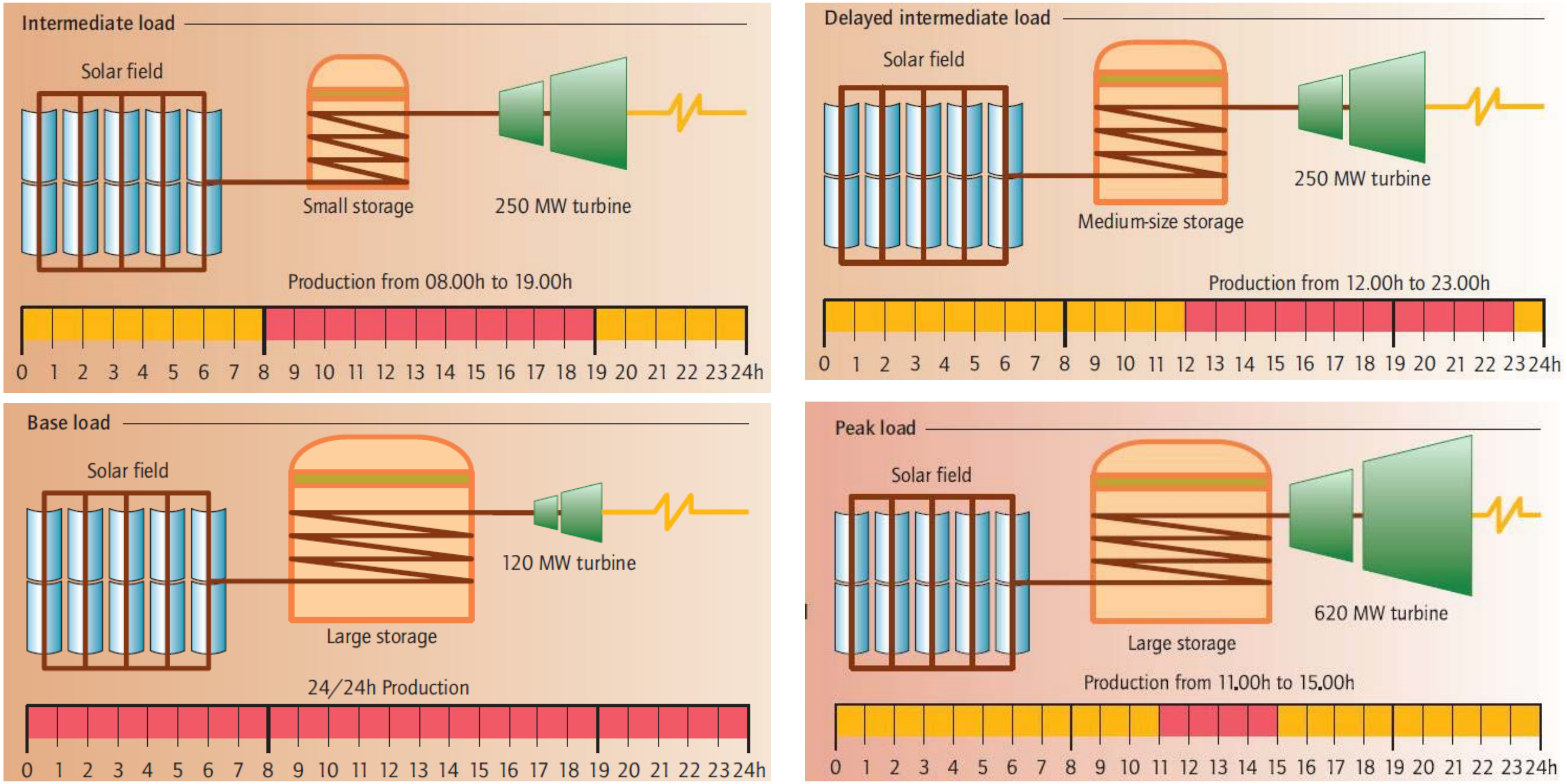
# Thermal Storage vs. Electric Storage




**CSP with storage and fossil hybridisation can provide firm capacity**
**Thermal storage economically favorable**

# Design Options for CSP with Thermal Storage

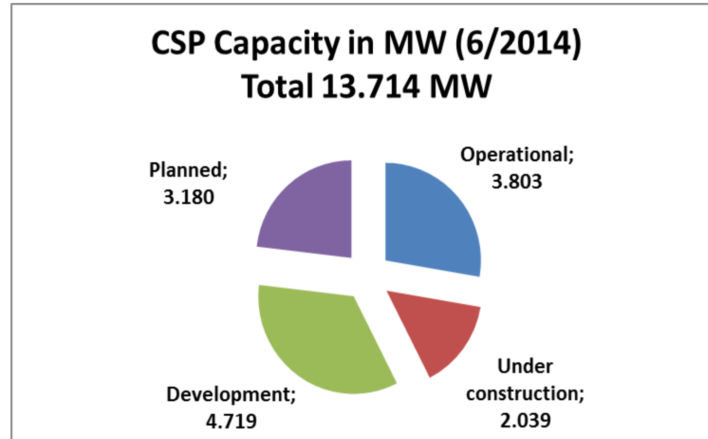


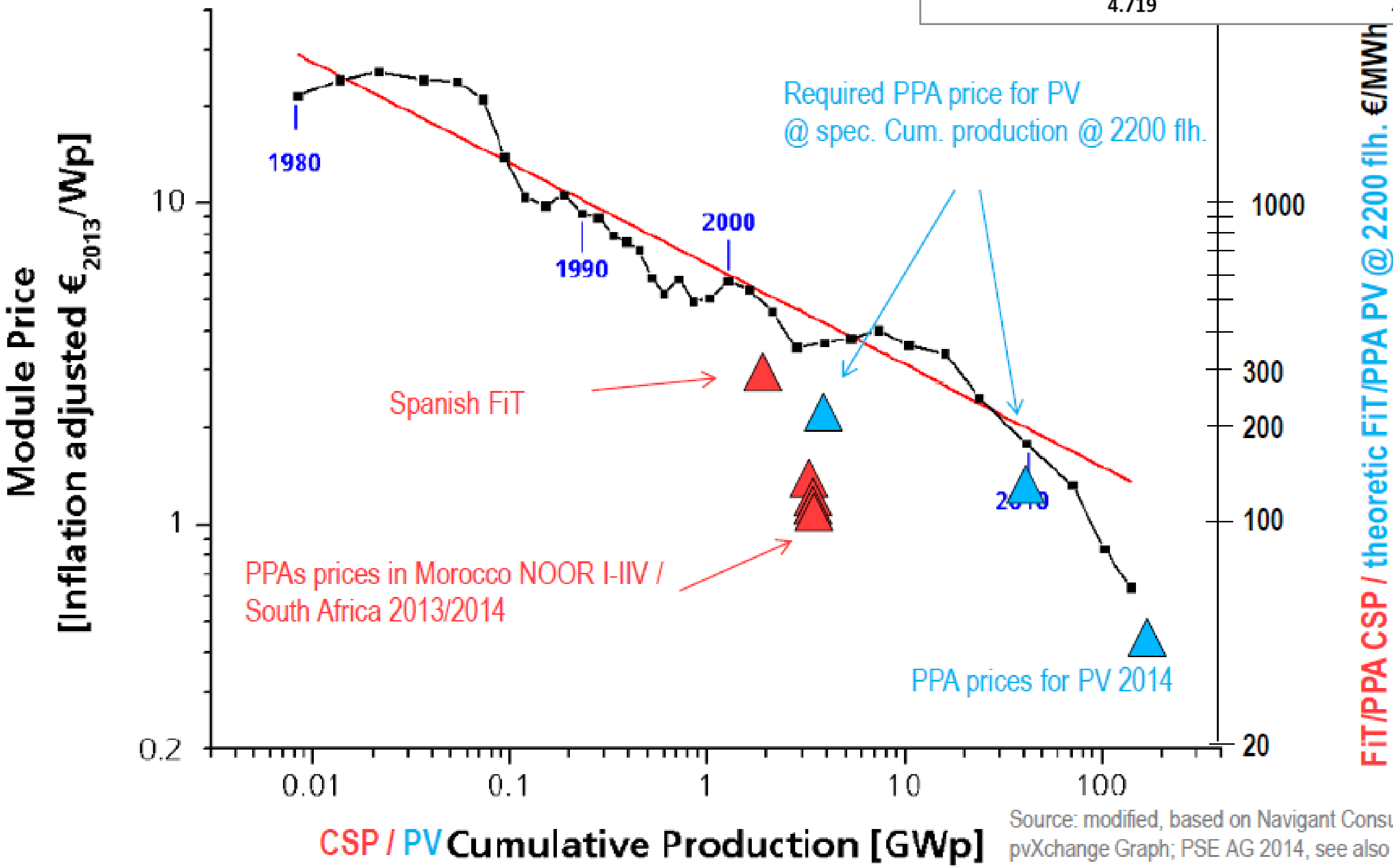

Source: IEA CSP Technlogy Roadmap 2010

# Market


**Source: CSP Today Global Tracker** www.csptoday.com/tracker

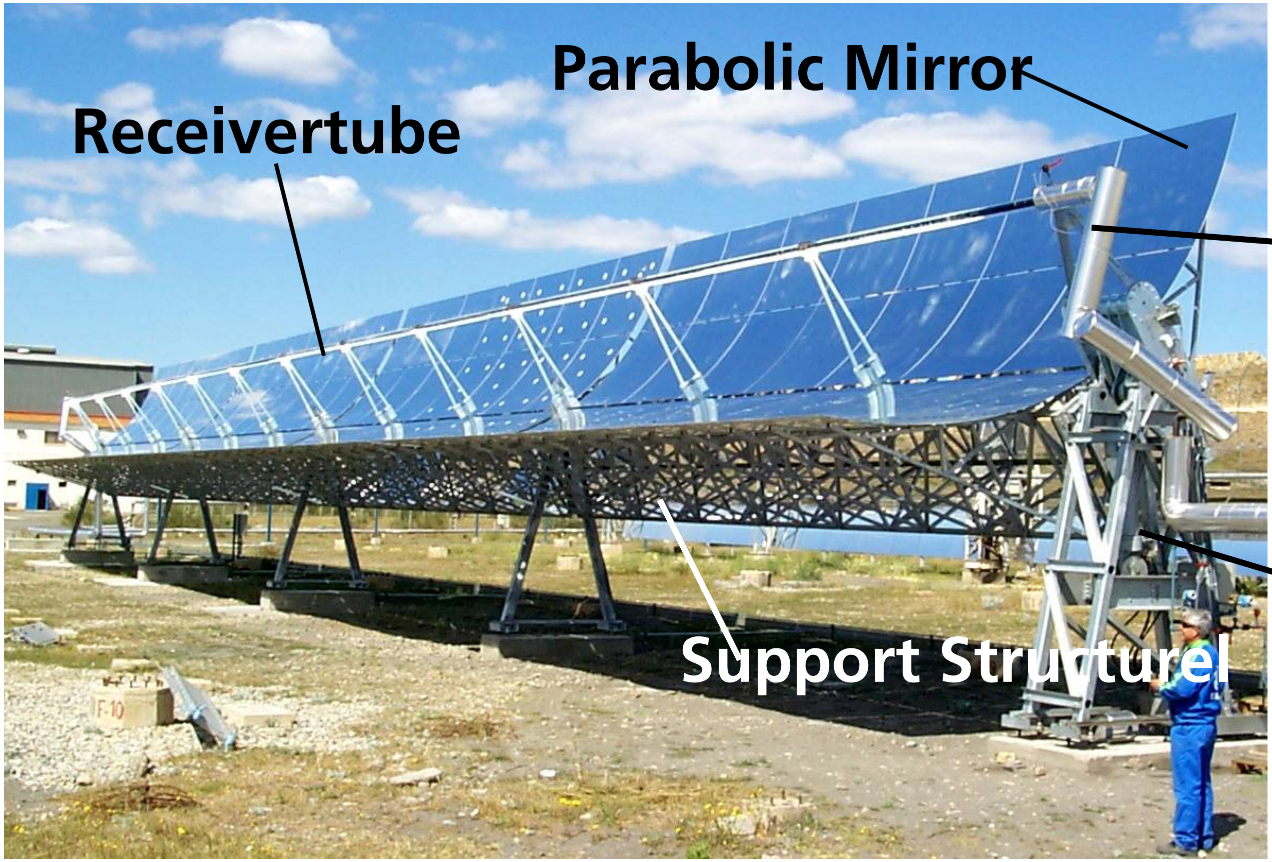
# Market Size and Cost Reduction




Source: modified, based on Navigant Consulting, EuPD, IHS, pvXchange Graph; PSE AG 2014, see also ISE 2014 S(3)/p.40

# State of the Art: Parabolic Trough Collector Components



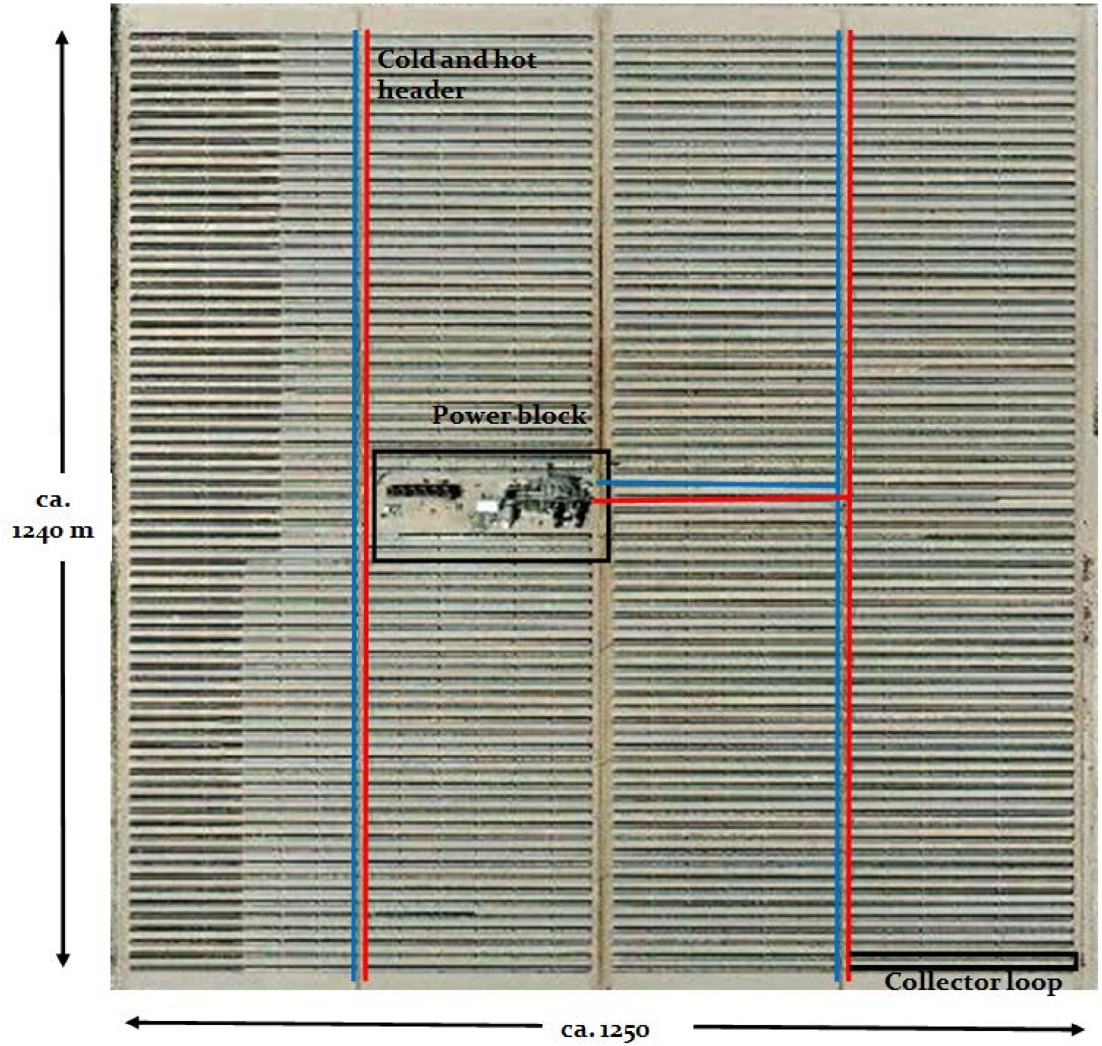

Eurotrough-Kollektor

# State of the Art: Solar field structure

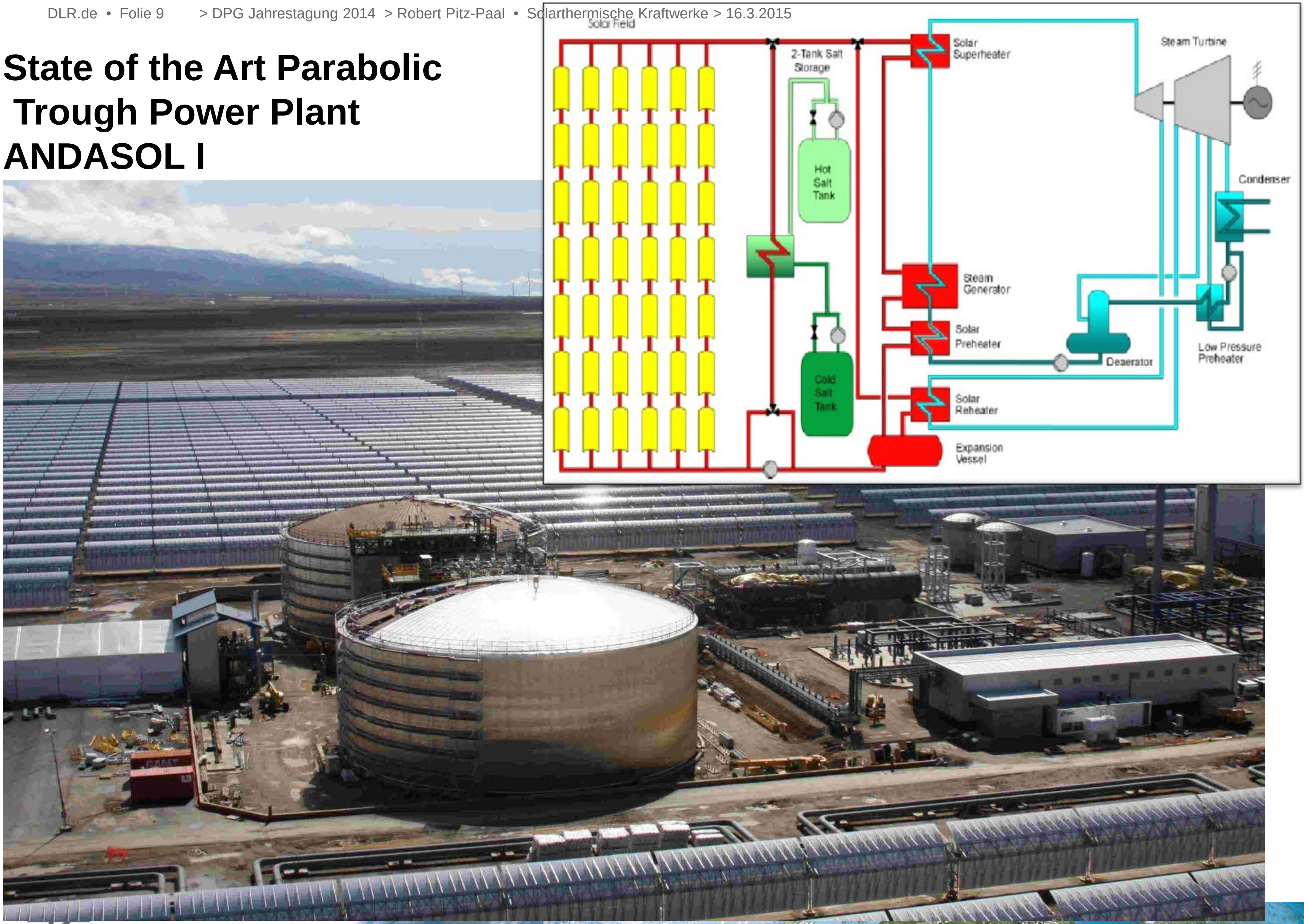
- normally rectangular, nearly square
- power block near the power plant area centre

→shorter pipes → lower thermal losses

Trough loops are connected to headers, which connect them to the power block.

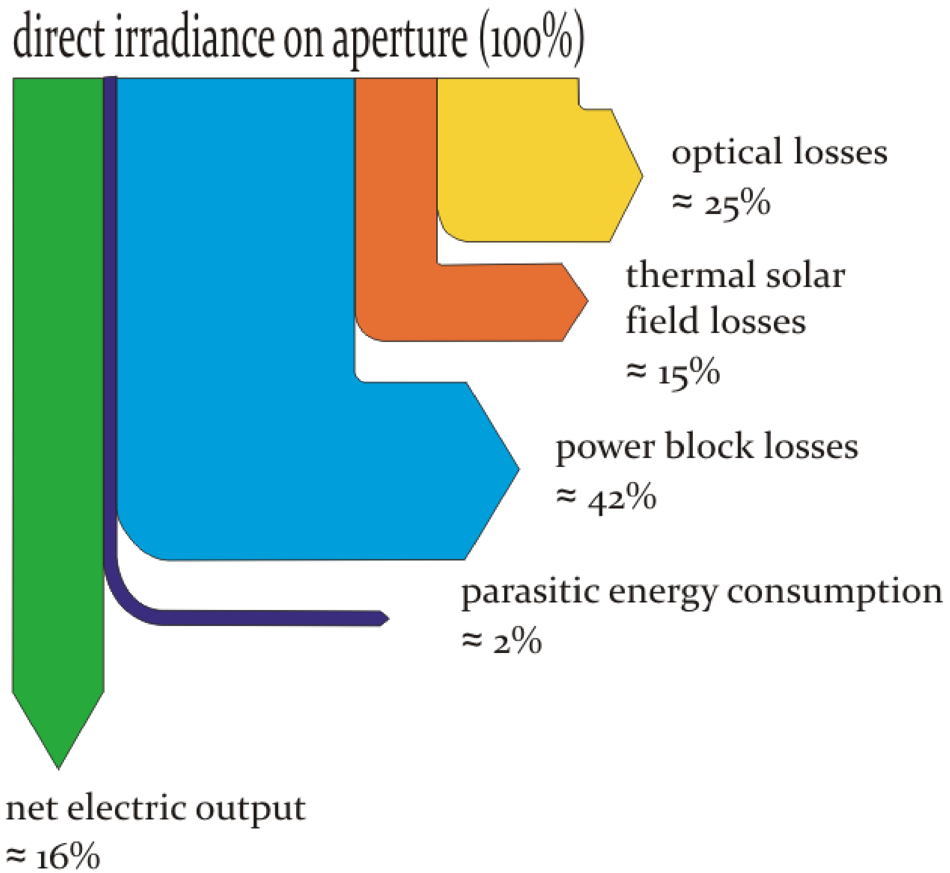


# State of the Art Parabolic Trough Power Plant ANDASOL I

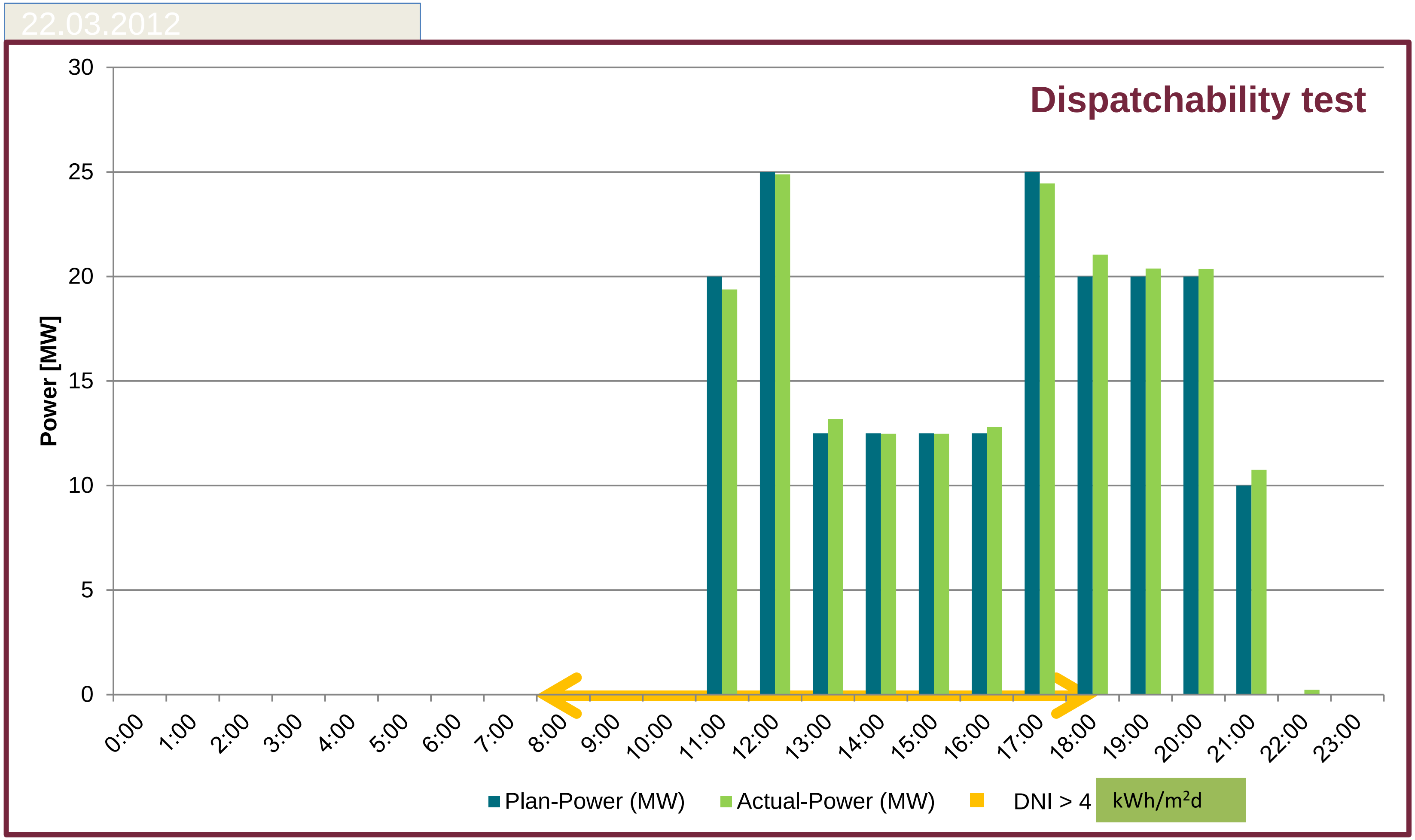


# State of the Art : Annual Power plant efficiency

Approximate average values for a current large parabolic trough power plant:

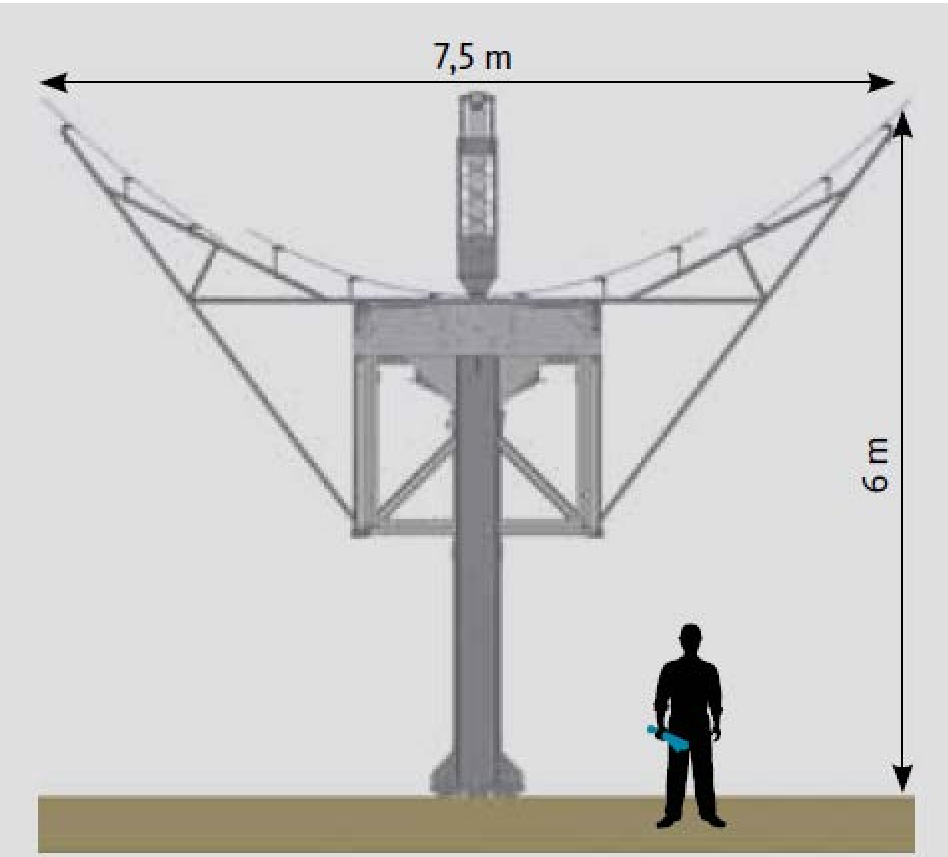


# State of the Art: Dispatchable generation

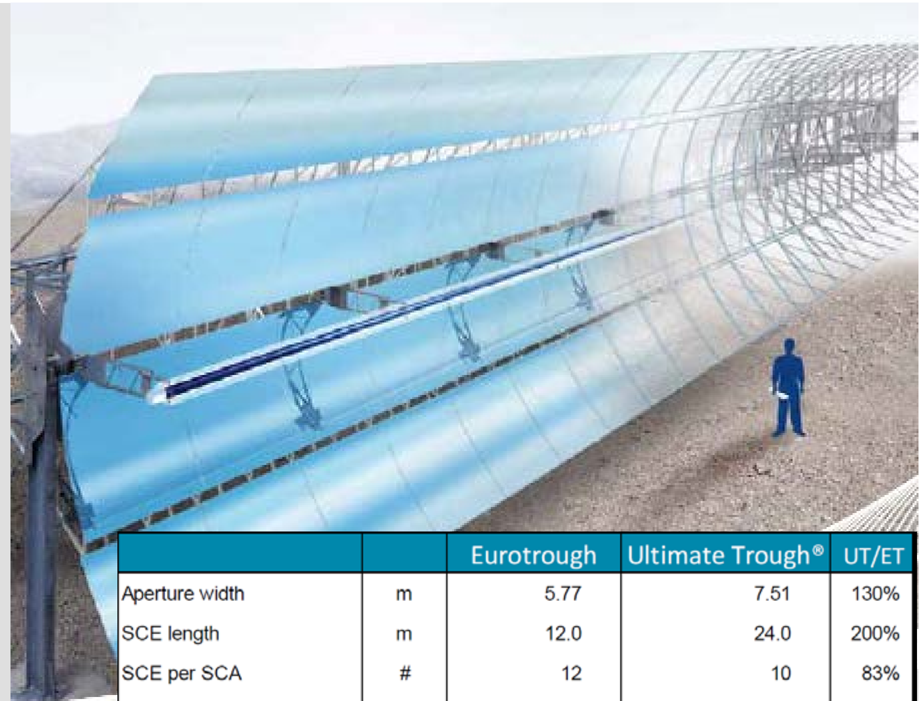



Source: RWE Innogy, F. Dinter

# State of the Art: Collector Technology

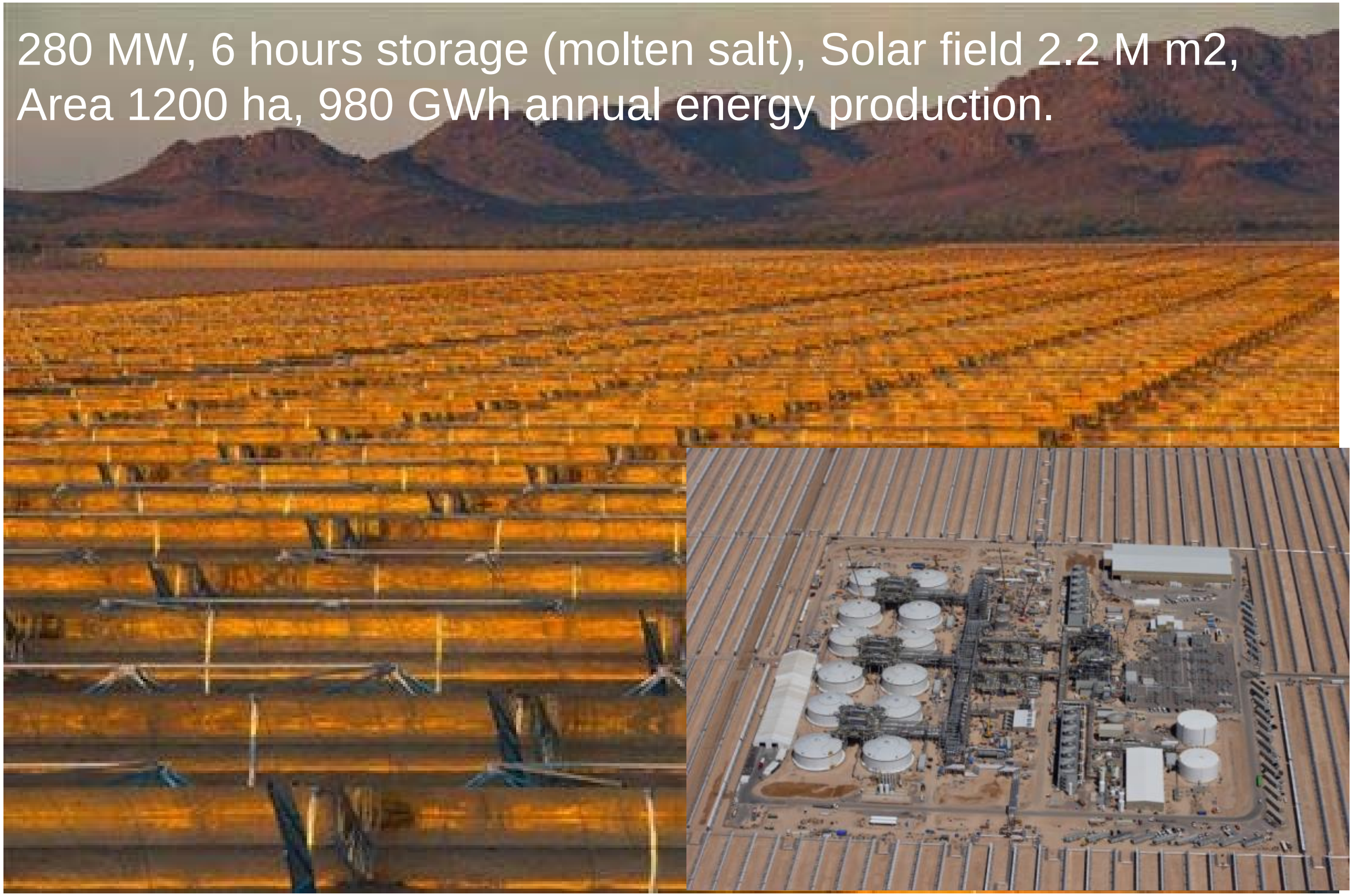



Dimensions of one Solar Collecting Element (SCE).
One Solar Collector Assembly (SCA) consists of ten SCEs.

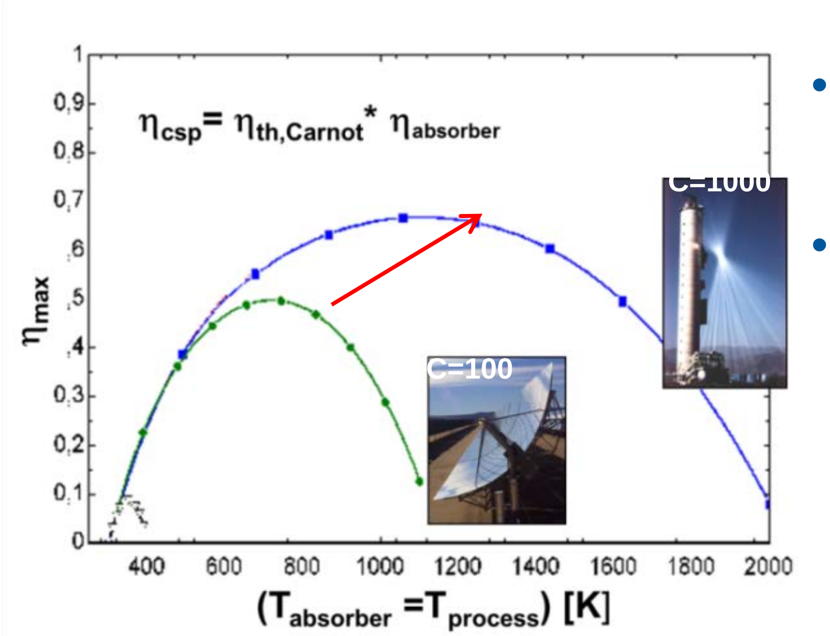


| | | Eurotrough | Ultimate Trough® | UT/ET |
|---|---|---|---|---|
| Aperture width | m | 5.77 | 7.51 | 130% |
| SCE length | m | 12.0 | 24.0 | 200% |
| SCE per SCA | # | 12 | 10 | 83% |
| SCA length | m | 147.8 | 242.2 | 164% |
| Aperture area / SCA | m² | 817.5 | 1'689 | 207% |
| Solar field | m² | 1'239'330 | 1'141'629 | 92% |
| Capacity (gross) | MW | 250 | 250 | 100% |
| Loops | # | 379 | 169 | 45% |
| SCE | # | 18'192 | 6'760 | 37% |
| Drives / Sensors / Controls | # | 1'516 | 676 | 45% |
| Pylon foundations | # | 18'950 | 7'436 | 39% |
| Swivel joints | # | 3'032 | 1'352 | 45% |
| Cross over pipes | # | 379 | 169 | 45% |

# 280 MW plant Solana (Abengoa) now in operation (10. Oct 2013)



# Strategy and Approach for Cost Reduction



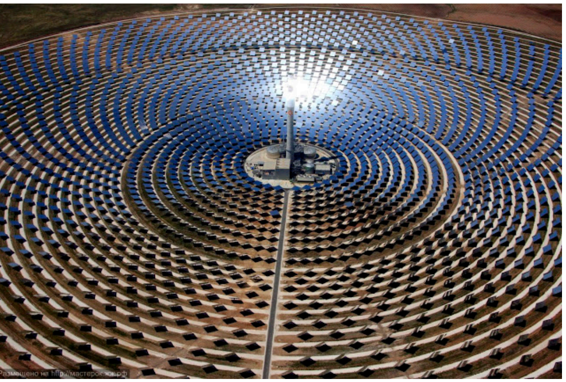

- **High Concentration + High Temperature = High Efficiency = Low Cost**
- **Advanced heat transfer media** needed for:
  - ➢ high temperature operation
  - ➢ efficient storage integration

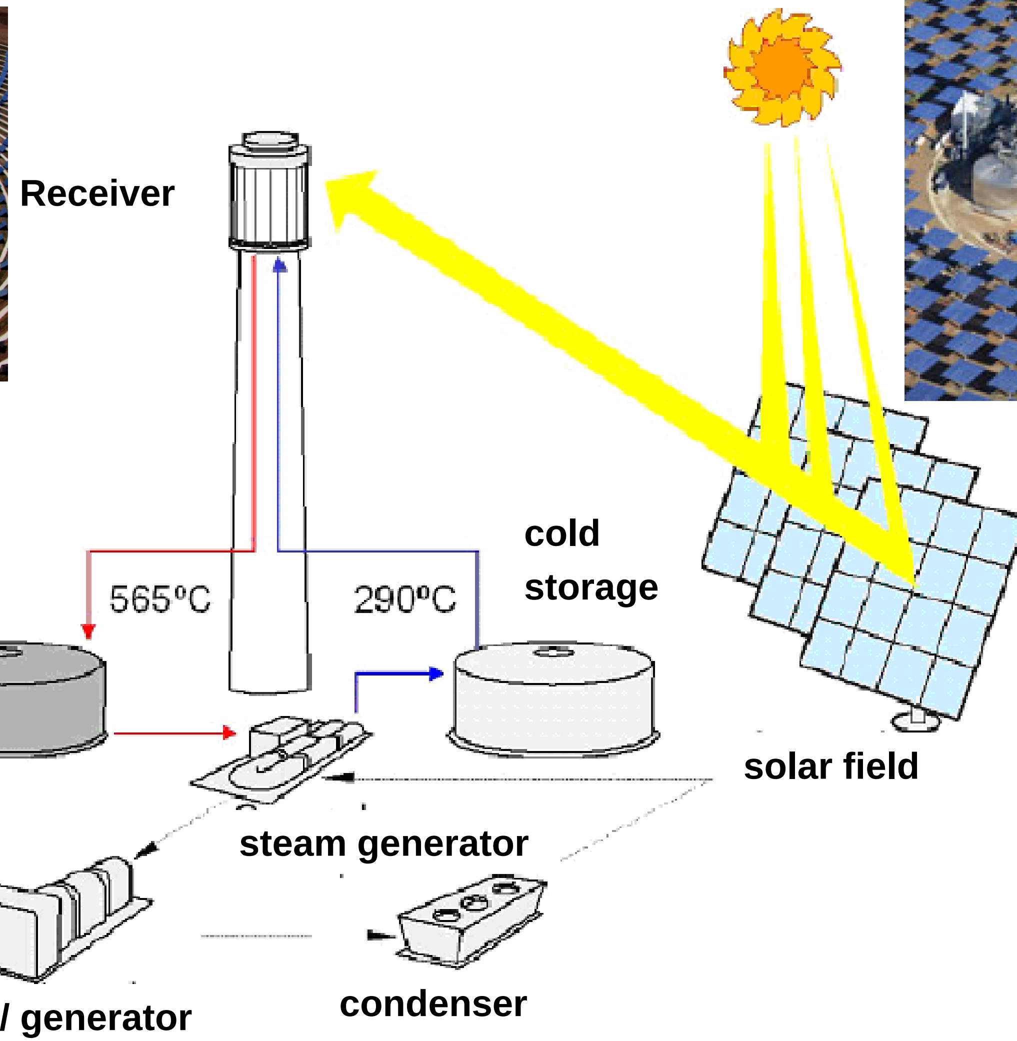
to break todays **temperature limit of 400°C**


**DLR Focus**:

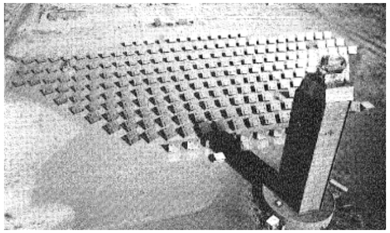
- Tower & Trough systems using advanced **salt mixtures** at **T > 500°C** with **$\eta_{sys}$ > 16%**

# Molten Salt Tower





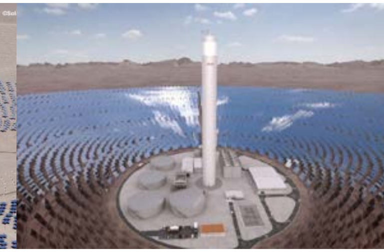
# Molten Salt Tower – Demonstration Plants



| | MSEE (1985) | Thémis (1983-1986) | Solar Two (1996-1999) |
|---|---|---|---|
| Site | Albuquerque (New Mexico) | Targasonne (Frankreich) | Daggett (California) |
| Design | Martin Marietta | CNIM | Rocketdyne |
| HTF | Solar Salt | Hitec | Solar Salt |
| Receiver type | Cavity | Cavity | External |
| Thermal power | 5 $MW_{th}$ | 9 $MW_{th}$ | 42.2 $MW_{th}$ |
| Electrical power | 0.75 $MW_{el}$ | 2 $MW_{el}$ | 10 $MW_{el}$ |

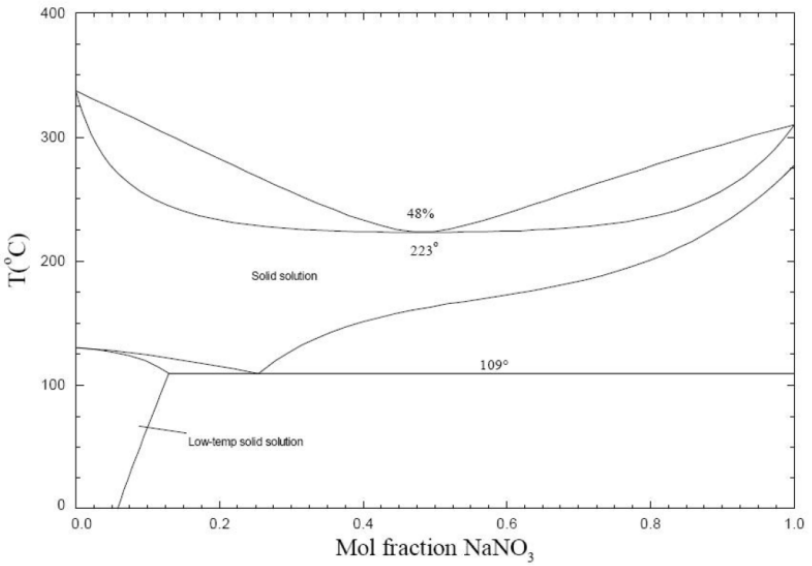
# Molten Salt Tower – Commercial Plants






| | Gemasolar | Crescent Dunes | Cerro Dominador | Supcon Solar |
|---|---|---|---|---|
| Status | In Operation | In Construction | In Construction | In Construction |
| Site | Sevilla, Spain | Tonopah, Nevada | Calama, Chile | Delingha, China |
| Design | SENER/CIEMAT | SolarReserve | Abengoa | Supcon Solar |
| HTF | Solar Salt | Solar Salt | Molten Salt | Molten Salt |
| Receiver type | External | External | External | External |
| Thermal power | 120 $MW_{th}$ | 560 $MW_{th}$ | not public | not public |
| Storage capacity | 15 h | 15 h | 18 h | 2.5 h |
| Electrical power | 20 $MW_{el}$ | 110 $MW_{el}$ | 110 $MW_{el}$ | 50 $MW_{el}$ |

# Salt Mixtures




- The more components in the mixtures the higher is the potential for lowering the freezing temperature.
- The lowest freezing temperature is achieved at the eutectic mixture
- The weakest component will determine the decomposition temperature of the full mixture

**Possible Options**;

A. NaK-$NO_3$ (aka. SolarSalt) has a high decomposition (>550 °C) and a high freezing temperature (~238 °C @ 60/40)

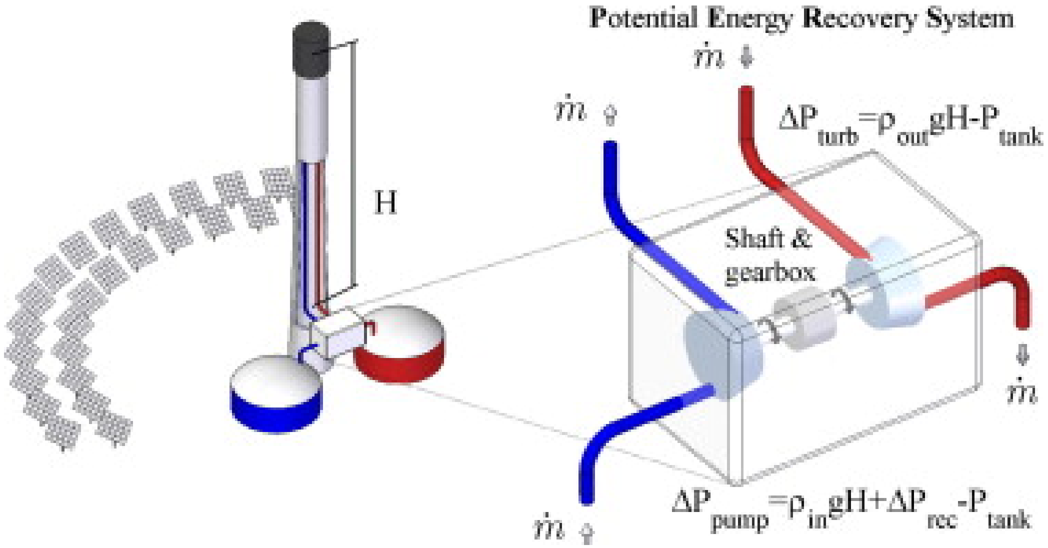
B. NaKCa-$NO_3$: decomposition <500 °C, freezing temperature ~150 °C

C. NaKLi-$NO_3$: decomposition ~530 °C, freezing temperature ~140 °C

# Pumping losses on molten salt tower systems

- HTF is pumped from cold tank to the top of the tower and through receiver
- In receiver outlet the HTF has high kinetic + potential energy (tower height)
  → high pressure at the hot tank inlet → laminate flow
  → avoid overpressure in the hot tank and possible damages
- The losses are currently in the range of 2-5% of gross electricity yields

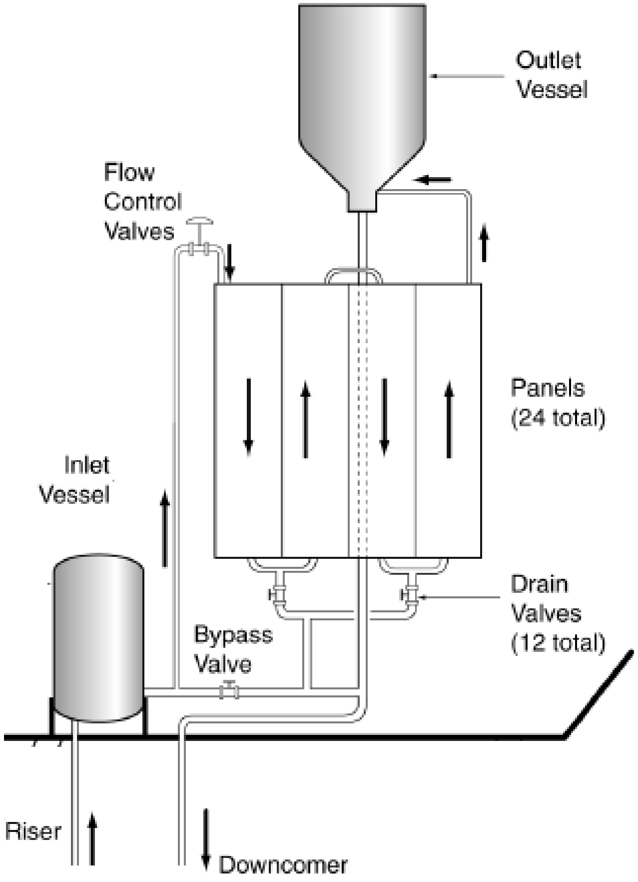
- Recovery and saving of the pumping energy is possible with a Potential Energy Recovery System (PERS)
- Depending on tower height and system setup up to 75%.




M.R. Rodriguez-Sanchez, et al. (2014). Saving assessment using the PERS in solar power towers. Energy Conversion and Management, Volume 87, November 2014, Pages 810–819.

# Components of Receiver-System (example Solar Two)

| Component | Function |
|---|---|
| Receiver pump | • supply cold salt to the receiver inlet vessel |
| Inlet Vessel (pressurized) | • Balance mass flow gradients<br>• Absorber cooling in case of pump or power loss |
| Receiver Absorber Panels | • Heat molten salt |
| Flow control valves | • Receiver Mass flow control |
| Outlet vessel | • Balance mass flow gradients |
| Drain system | • Draining an filling of receiver |
| Heat Tracing System | • Prevent salt freezing<br>• Reduce thermal stresses |



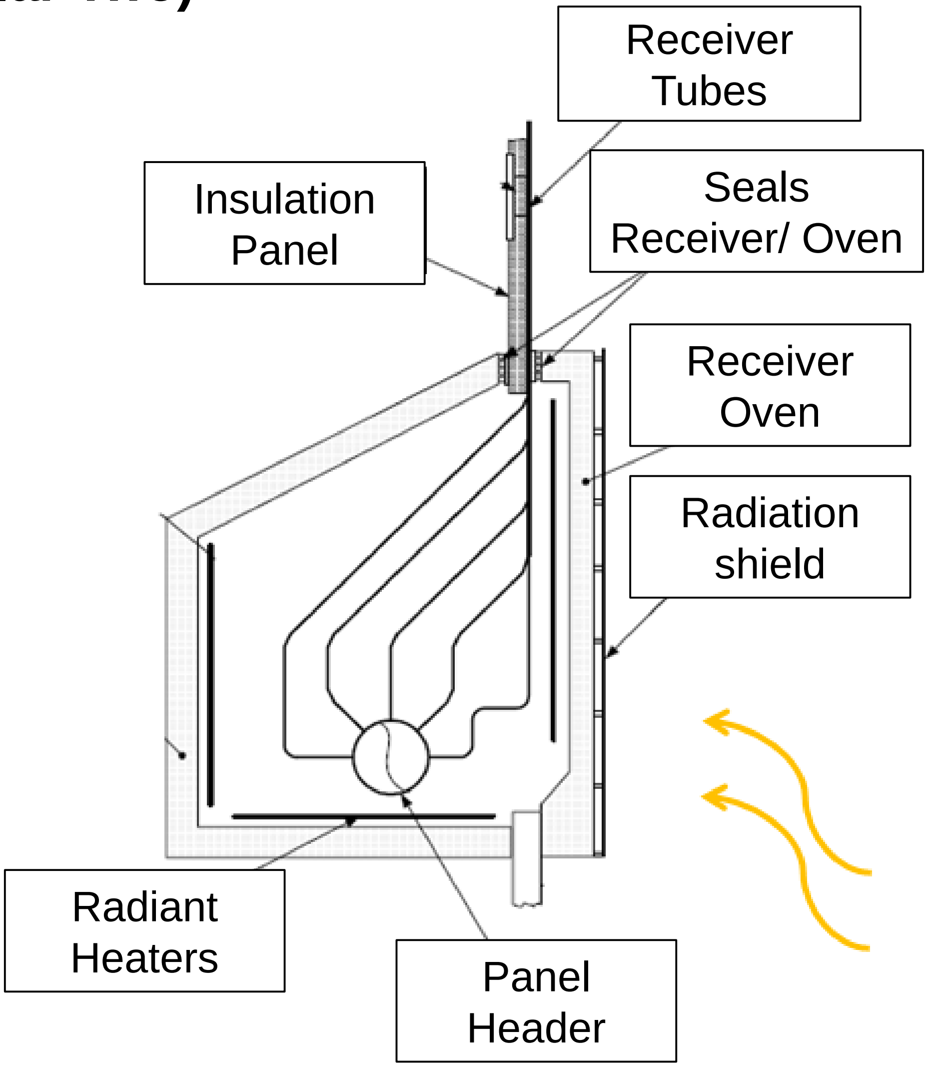
# Heat Tracing System (example Solar Two)

System:
- Receiver Oven
- Electrical heat tracing

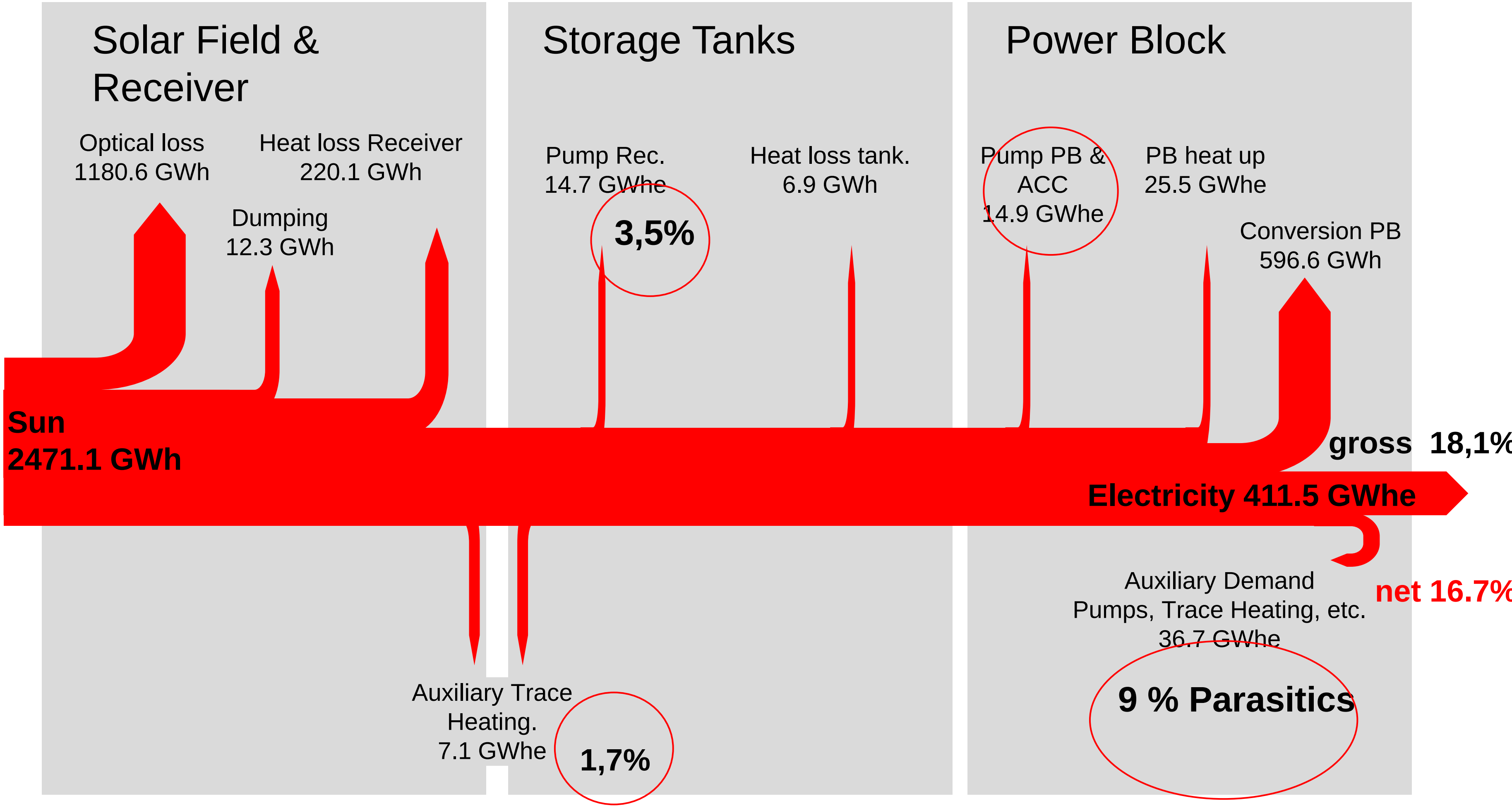
Heat Tracing causes :
- 20 % (in operation)
- 60% (in stand-by)

of auxiliary demand of overall system

A failure of the Heat Tracing system can cause major damages



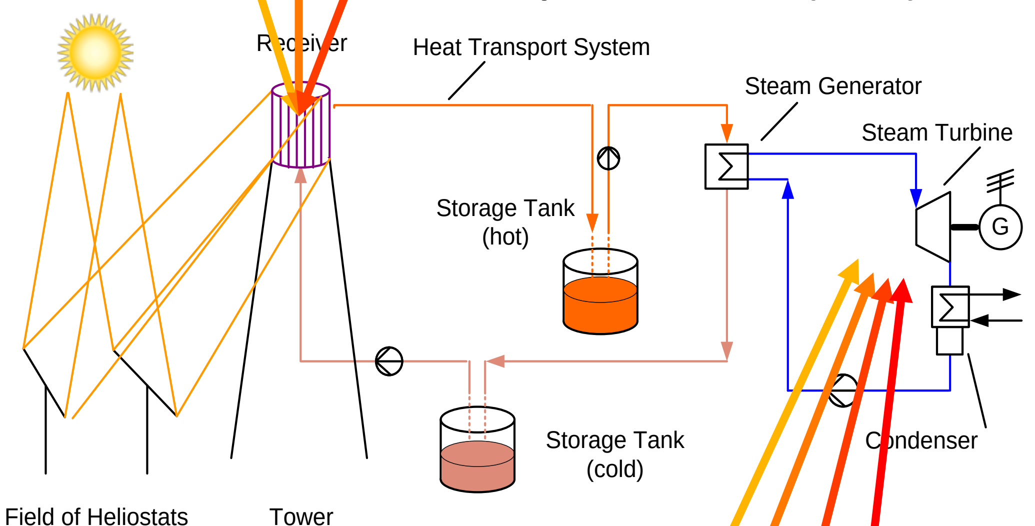
# Energy flow diagram of state of the art molten salt tower system

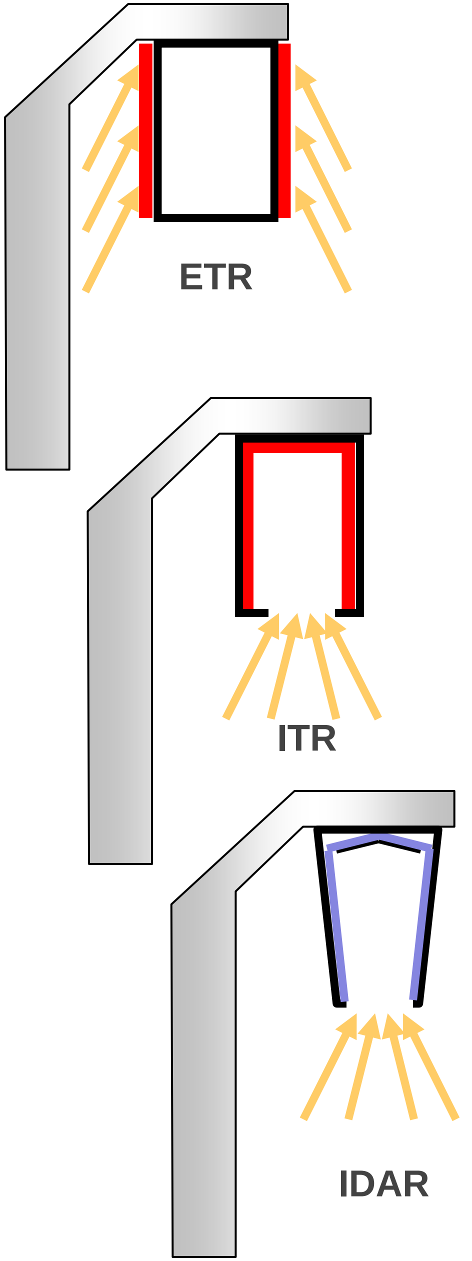


# Study on improved molten salt tower plants

**Variation of Receiver Type**

**Reference:** External Tubular Receiver (ETR)
**Innovation 1:** Internal Tubular Receiver (ITR)
**Innovation 2:** Internal Direct Absorption Receiver (IDAR)



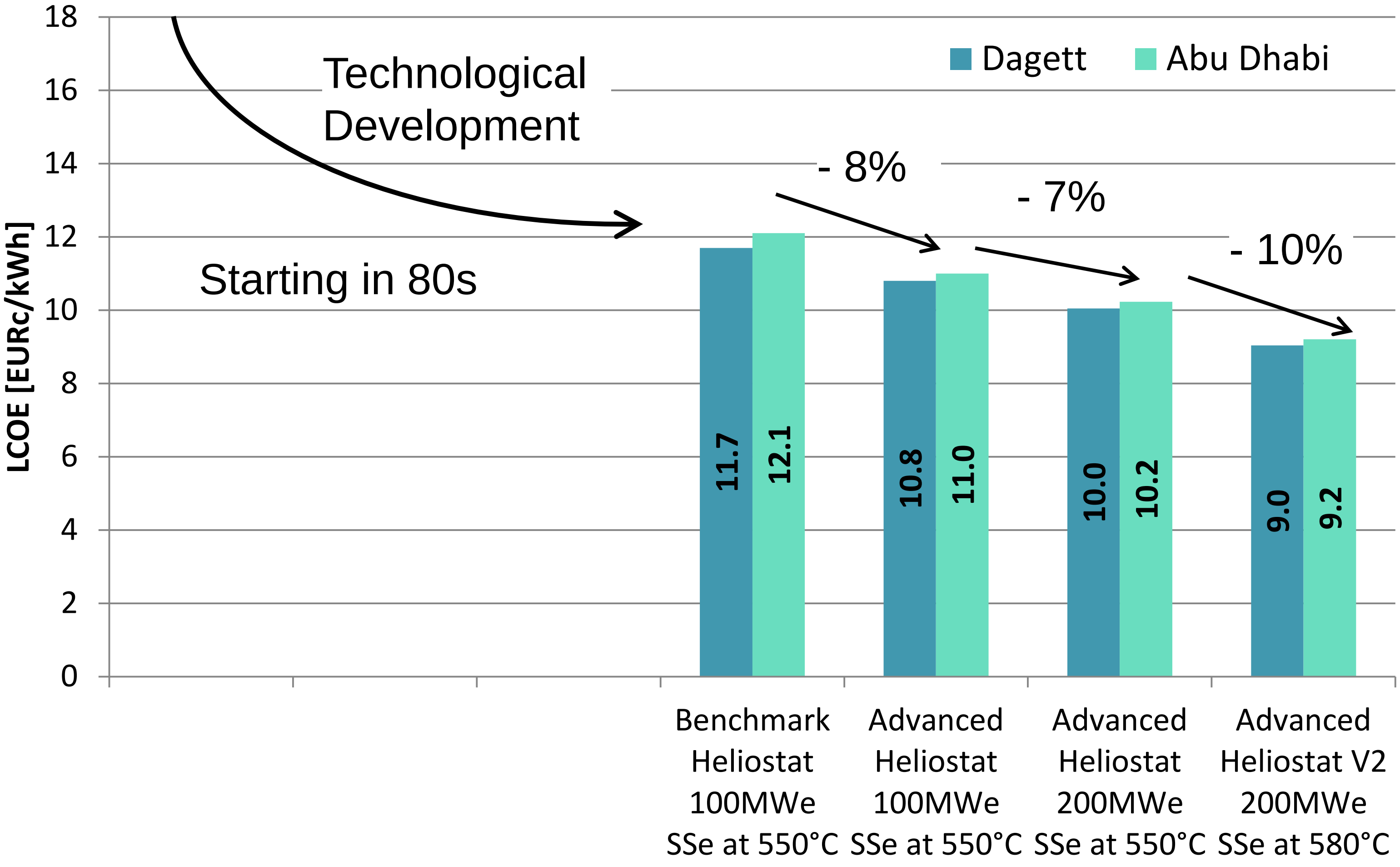




**Variation of Steam Parameters**

**Reference:** 162 bar / 550 C / 550 C (subcritical, $T_{R\_out}$ = 565 C)
**Innovation 1:** 250 bar / 550 C / 550 C (supercritical, $T_{R\_out}$ = 565 C)
**Innovation 2:** 162 bar / 620 C / 620 C (subcritical, $T_{R\_out}$ = 635 C)
**Innovation 3:** 250 bar / 620 C / 620 C (supercritical, $T_{R\_out}$ = 635 C)

DLR

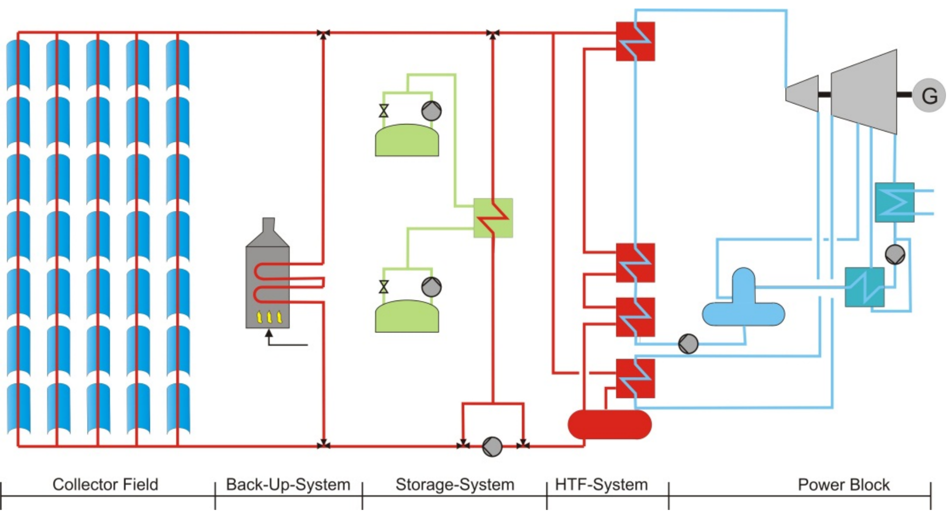
# Road map of Cost reductions for molten salt tower plants



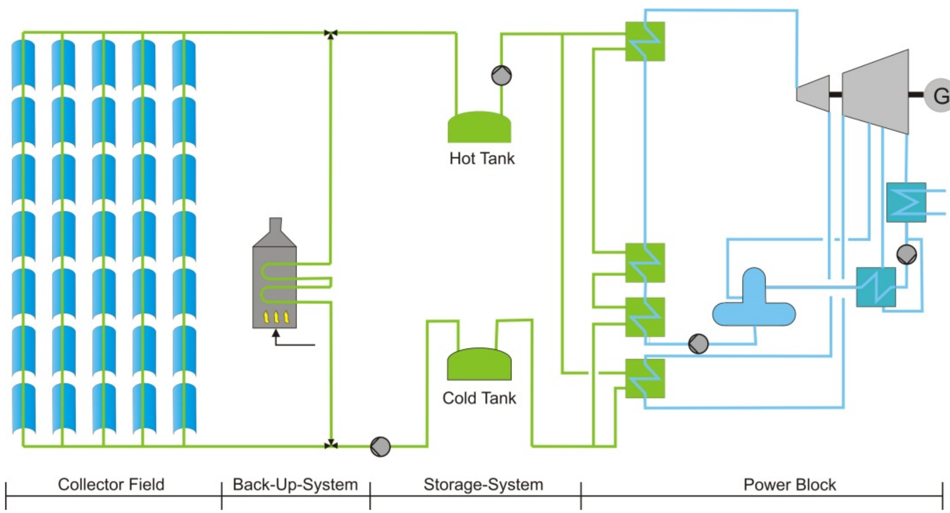

**Further Cost-reduction:**

- **Improved component efficiency**
- **Mass production (learning curve)**
- **Multi Tower**
- **Higher temperatures**

# Molten Salt in Parabolic Trough Power Plants




Thermal oil (TO) based plant



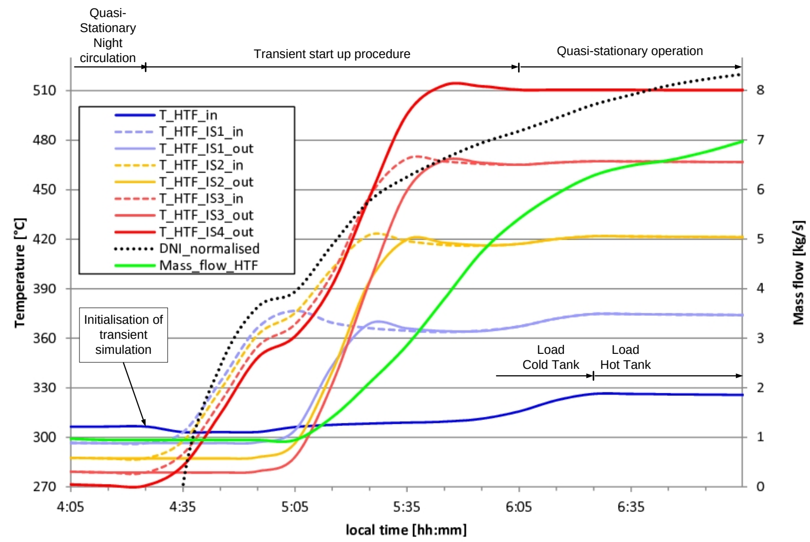

Molten salt (MS) based plant

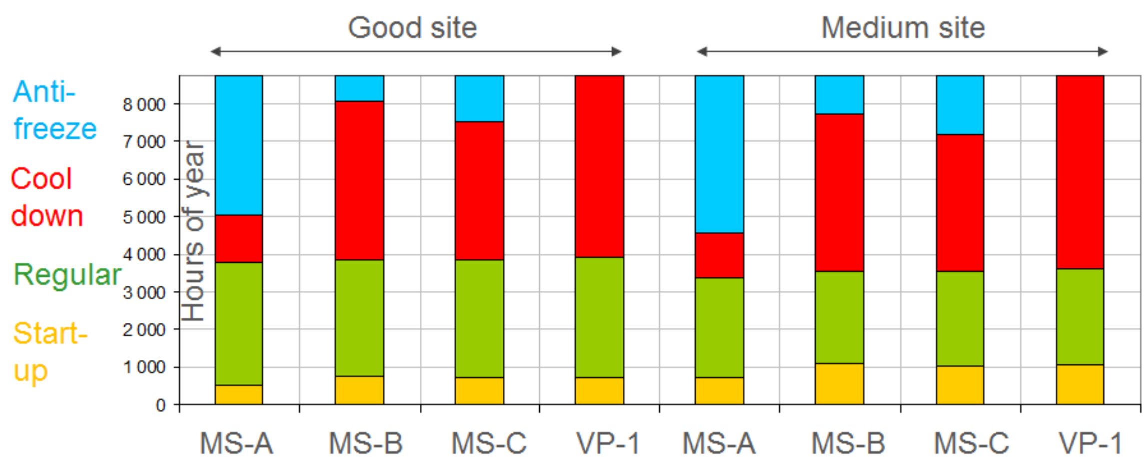
## Advantages of the Molten Salt System

- Higher overall system efficiencies due to higher working temperature
- Full decoupling of solar heat generation and power production
- Lower price for heat transfer fluid (HTF), no need of heat exchangers and additional pumps since no 2nd fluid circuit for the storage system is needed
- Non soil-permeable HTF means no environmental threat for ground water

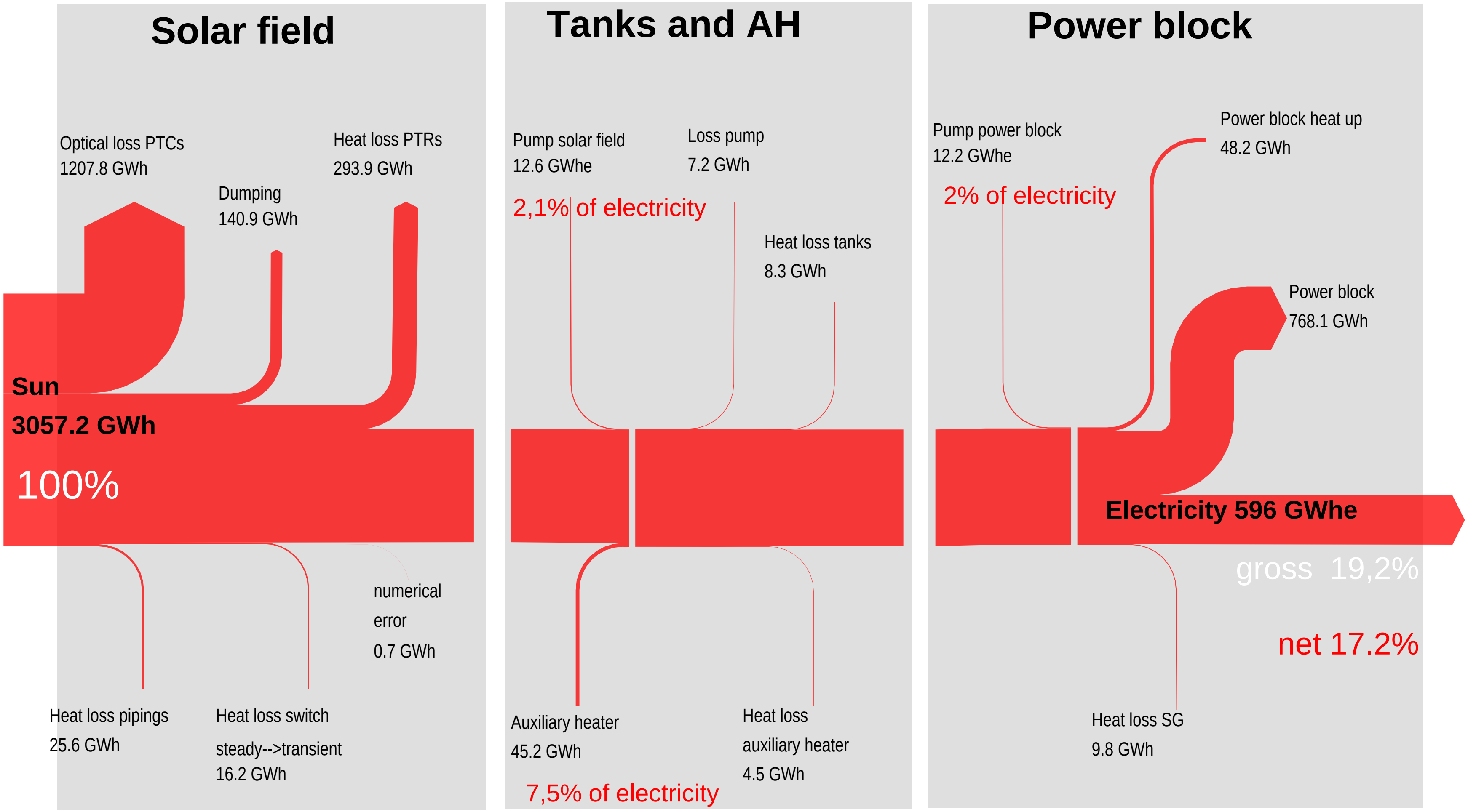
# Parabolic Trough Night operation /w molten salt

- Minimum temperature in solar field must not drop to solidification temperature of the salt
- Choice of salt defines hours of so called anti-freeze operation of a cooled down solar field, e.g. during night and overcast times

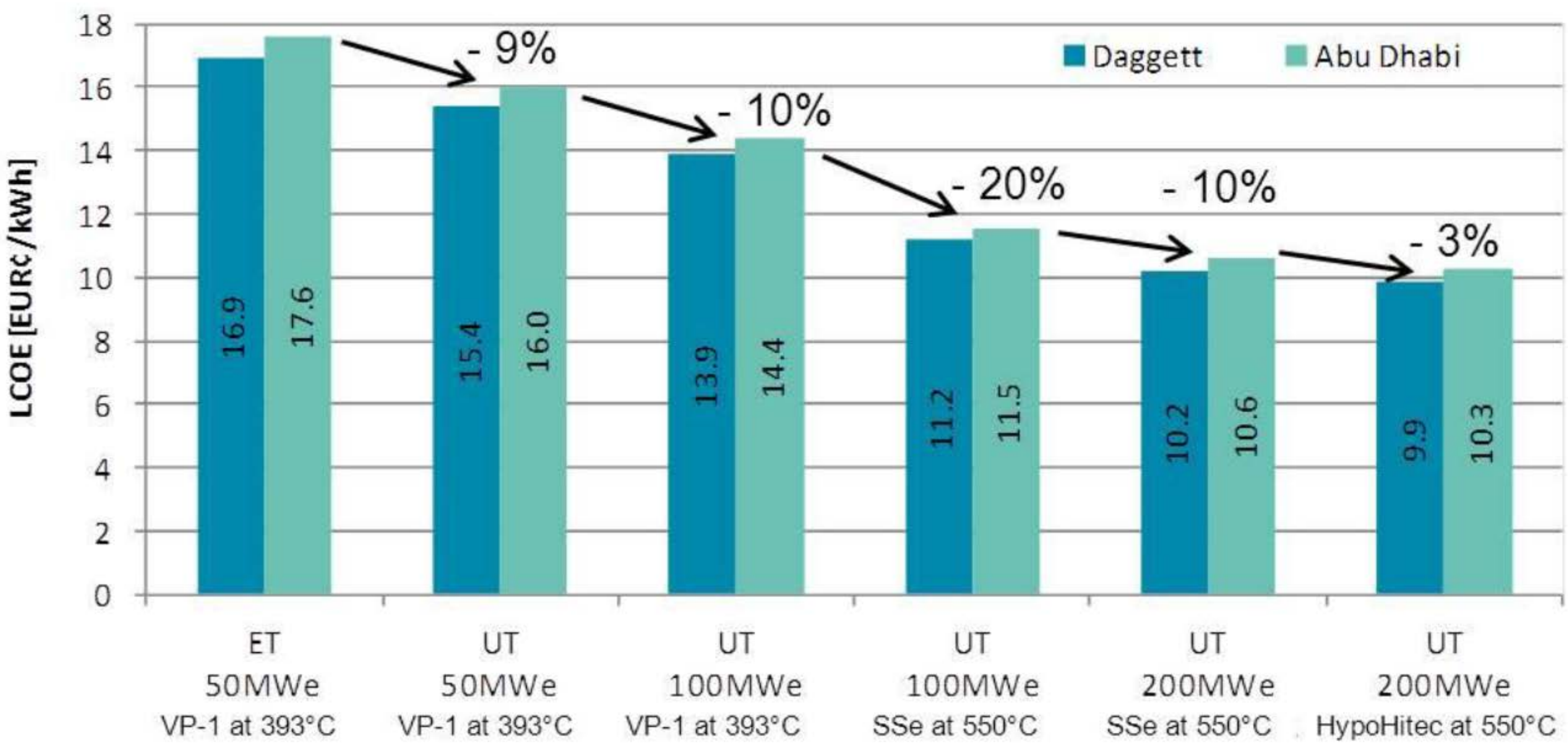


# Energy flow diagram of molten salt parabolic trough system



# Road map of Cost reductions for molten salt parabolic trough plants

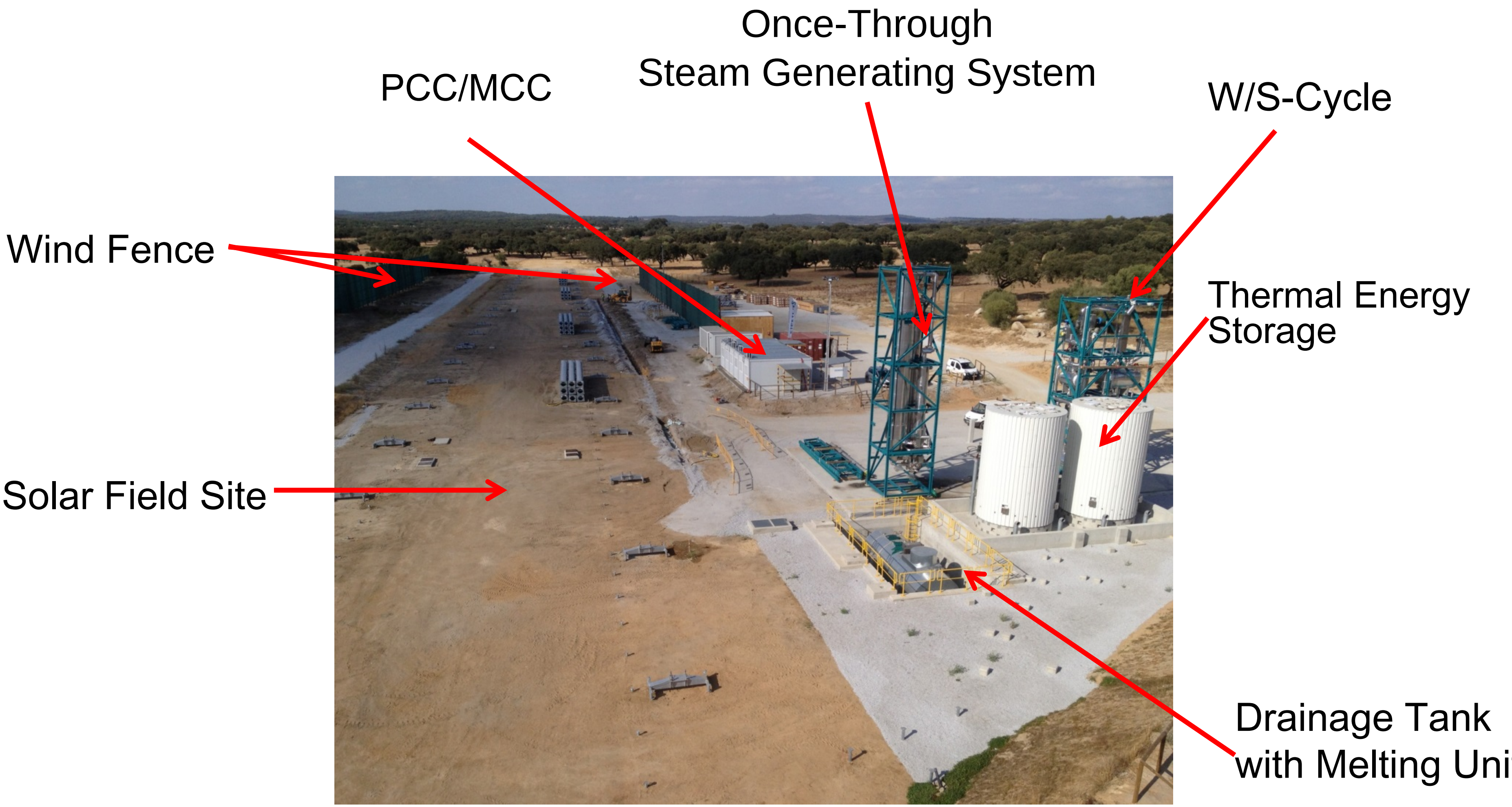



Rügamer, T., H. Kamp, et al. (2013). Molten Salt for Parabolic Trough Applications: System Simulation and Scale Effects. 19th SolarPACES Conference, Las Vegas.

# Major Concerns against molten salt systems inn troughs

1. Filling and draining of the plant
2. High thermal effort during anti-freeze operational mode (high parasitic load, added costs for the required heating through the year)
3. Danger of freezing during various operation modes (reliability of impedance heating, failure current of impedance heating, valve heating, …)
4. Blackout scenarios
5. Material requirements (high corrosion)
6. Performance of the SCA (receiver performance, behavior of receiver with collector) a. thermal performance, b. optical performance, c. mechanical properties
7. Flexible connection: Proof of functionality and tightness
8. Steam Generating System: danger of internal leakage due to defect of heat exchanger tubes
9. Maintenance procedures, Handling of disturbances (complete draining and re-filling, treating of blockages)
10. Stability of salt mixtures (time stability, thermal stability)

# DLR‘s plans in Évora, Portugal to confute the concerns




Civil Works, Site power and Water Treatment
Plant fully completed


Vielen Dank für Ihre Aufmerksamkeit!
Thank you very much for your attention!