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SFERA-III
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Almería (Spain)

Lecture:
Solar Thermal Cogeneration Plants

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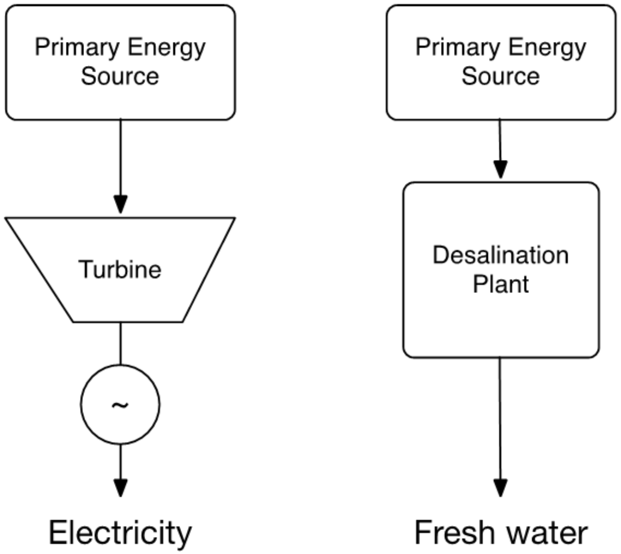
- Introduction
- Cooling systems
- CSP+D Configurations
- Worldwide experiences

Introduction

- An increase in demand for desalinated water goes hand in hand with an increase in demand for power.

- Both processes require a primary energy source

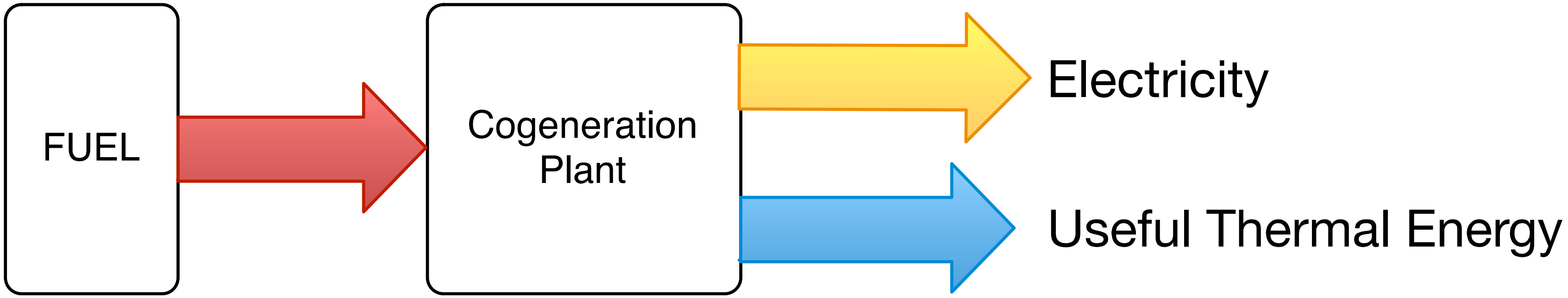


- An attractive option to meet both needs in a more efficient way is the concept of cogeneration plants for the simultaneous production of fresh water and electricity.

Introduction

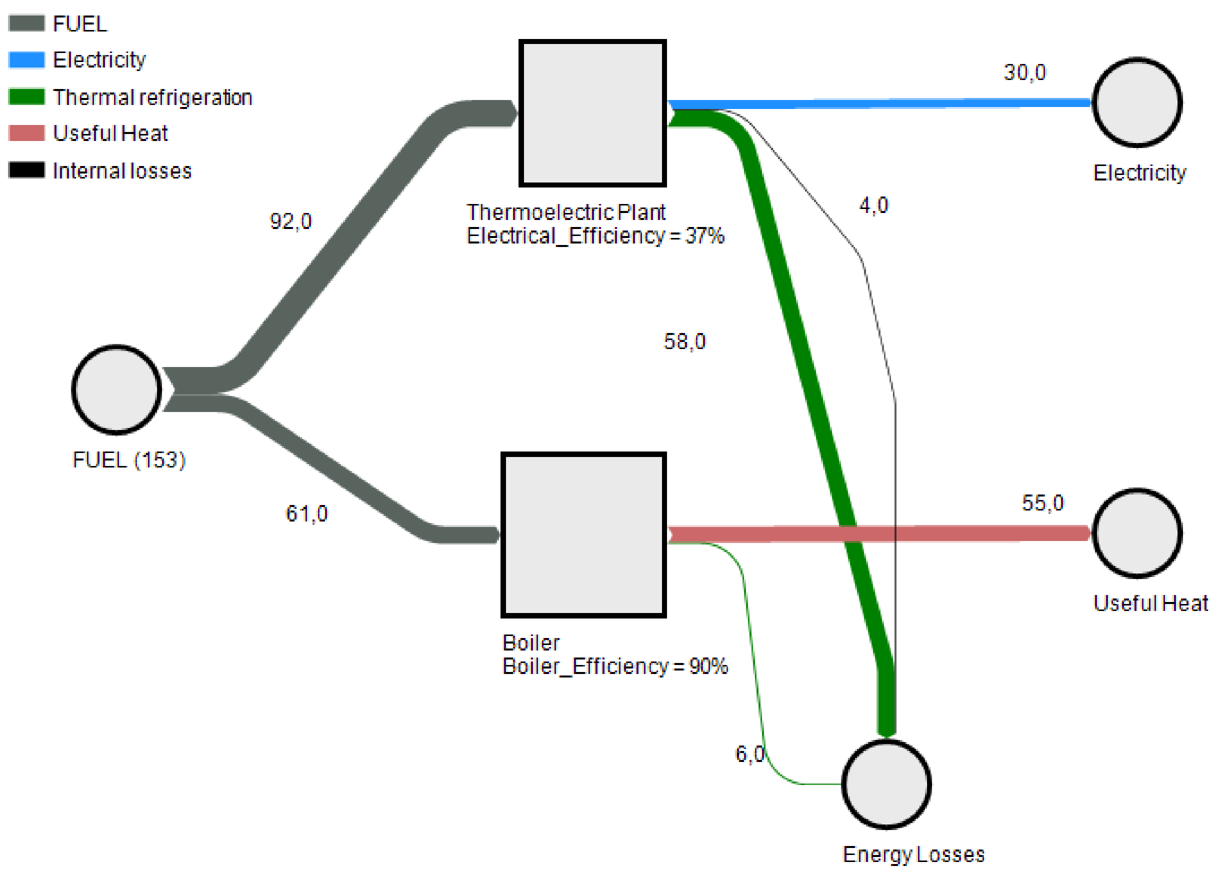
What is cogeneration?

Cogeneration is defined as the procedure by which electrical energy and useful thermal energy (heat) are obtained simultaneously from the same fuel.



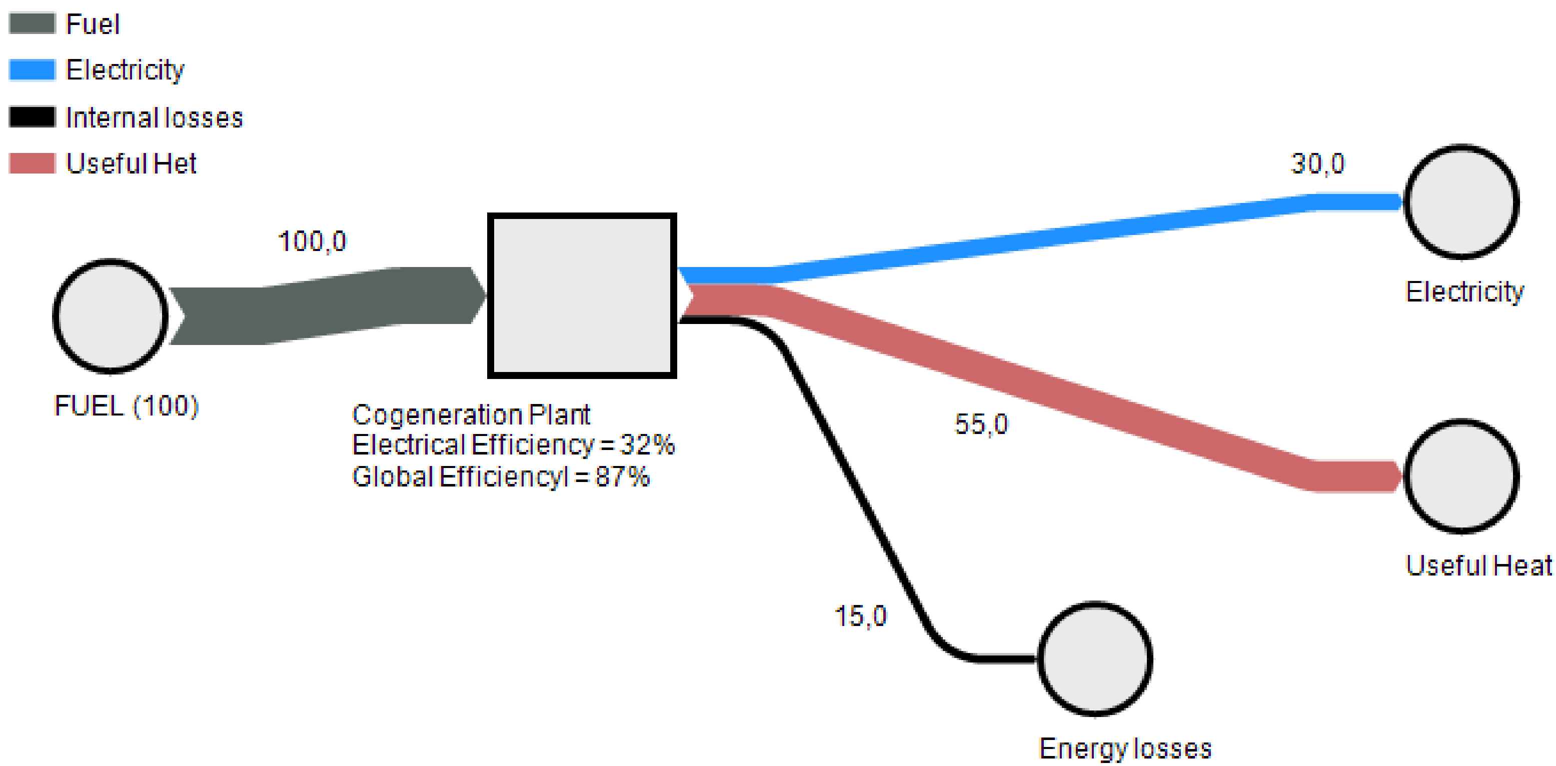
Introduction

Conventional System



Introduction

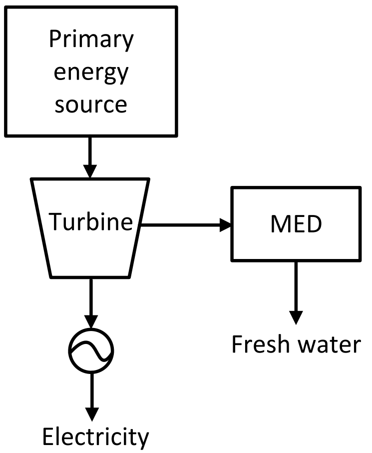
Cogeneration system



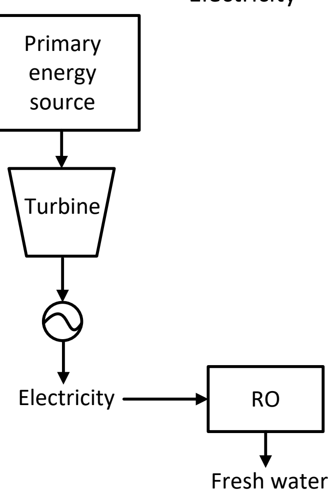
Introduction

- There are two alternatives for the simultaneous generation of fresh water and electricity, depending on the form of energy required in the desalination process

- If it is a thermal desalination process (such as MED), steam from the turbine outlet is used as an energy input to the desalination process.



- If the desalination process is driven by mechanical energy (such as RO), the electrical energy needed to carry out the pressurization of the salt water comes from the electrical production.



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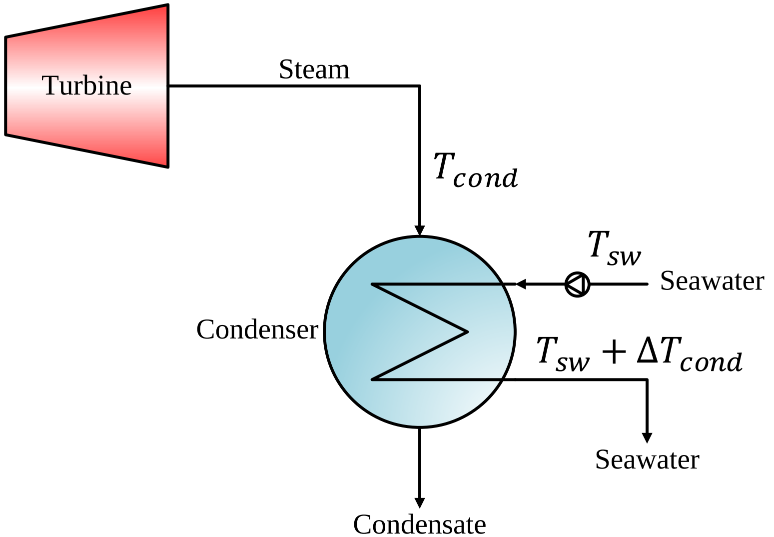
Cooling systems

- An important aspect to take into account in the case of solar thermal power plants is the selection of the most appropriate system for the cooling of the power block.
- The cooling system establishes the **steam condensation temperature (exhaust steam temperature)**, which in turn establishes the maximum thermal efficiency that can be achieved in the CSP plant (the lower the steam condensation temperature, the greater the efficiency of the CSP plant).
- This can be done by two methods: **dry cooling** system or **wet cooling** system.
- There are two types of wet cooling systems: **once-through cooling** and **evaporative cooling**.
- The steam condensation temperature is established as a function of the **dry bulb temperature** (in the case of dry cooling systems), the **wet bulb temperature** (in the case of cooling systems with an evaporative tower) and the **seawater temperature** (in the case of once-through cooling systems).

Once-through cooling

- This cooling system uses cold water, usually from the sea, which circulates through a tube condenser to remove waste heat.
- Once the water has circulated through the tube bundle, it comes out at a higher temperature and is returned back to the source (e.g. the sea) with the consequent environmental impact.



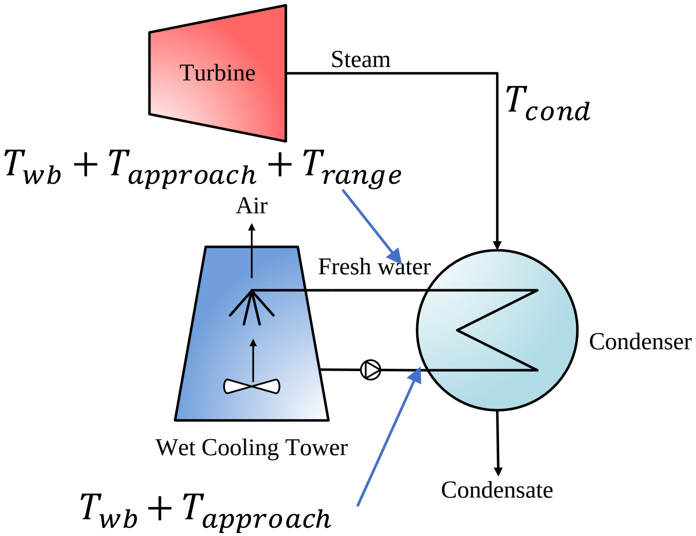
$$T_{cond} = T_{sw} + \Delta T_{cond} + TTD$$

- ΔT_{cond} is the difference between inlet and outlet seawater temperature (3-5°C)
- TTD is the difference between temperature of saturated steam and seawater outlet temperature. It varies between 3-5°C

- Since the condensing temperature is low, this type of cooling method is the most energy efficient.

Evaporative cooling

- The hot water at the outlet of the condenser is cooled as it passes through the cooling tower.
- The cooling medium is demineralized water instead of seawater, thus avoiding the problems of scale in the tower.
- The tower fans induce the flow of air through the tower where the water is pulverized, leaving the humid air at the exit of the tower.
- The cooling process is mainly achieved by latent heat of evaporation (85-90%).



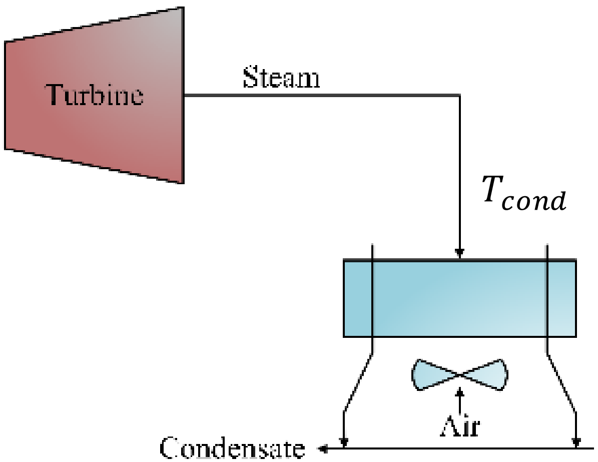
$$T_{cond} = T_{wb} + T_{approach} + T_{range} + TTD$$

- $T_{approach}$ is the difference between the cold water temperature at the exit of the tower and the wet bulb temperature
- T_{range} is the difference between the hot water temperature at the inlet and outlet of the tower
- TTD is the difference between the steam temperature at the outlet of the turbine and the hot water entering the cooling tower

- Since part of the water is evaporated, a constant water supply is required.
- The condensing temperature depends on the wet bulb temperature, which makes CSP plants with this cooling method more efficient than dry cooling.

Dry cooling

- These refrigeration systems are an alternative to wet refrigeration systems.
- Their main problem is the penalty in the power production that they cause (higher condensation temperature), the greater needs of auxiliary electricity (fans) and the high investment costs.
- There are two types: direct systems (Air Cooled Condenser) and indirect systems (Air Cooled Heat Exchanger).
- In the Air Cooled Condensers, heat transfer is mainly by means of sensible heat through the tower, which can be of natural or forced draft.



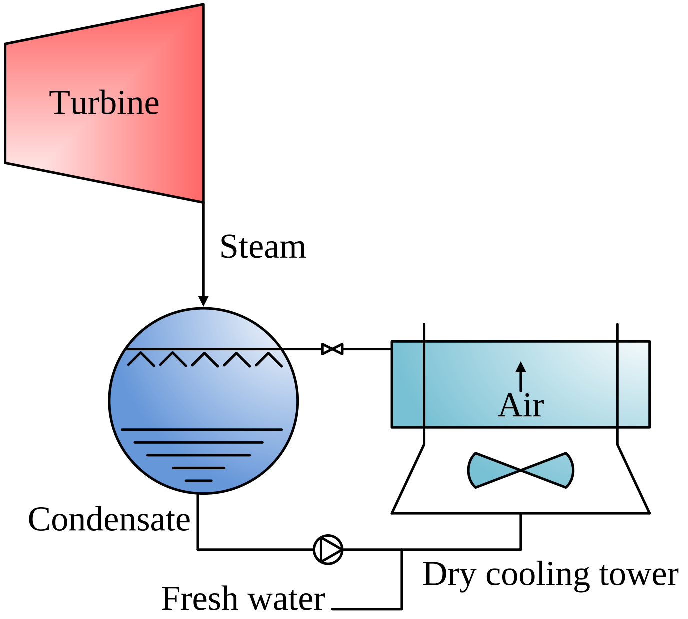
$$T_{cond} = T_{db} + \Delta T_{ACC}$$

- ΔT_{ACC} is the temperature difference in the air cooler (around 20-22°C)
- T_{db} is the dry bulb temperature

- The lowest achievable condensation temperature is the dry bulb temperature. This is why they lead to a higher electricity penalty (the higher the ambient temperature, the higher it is).

Dry cooling

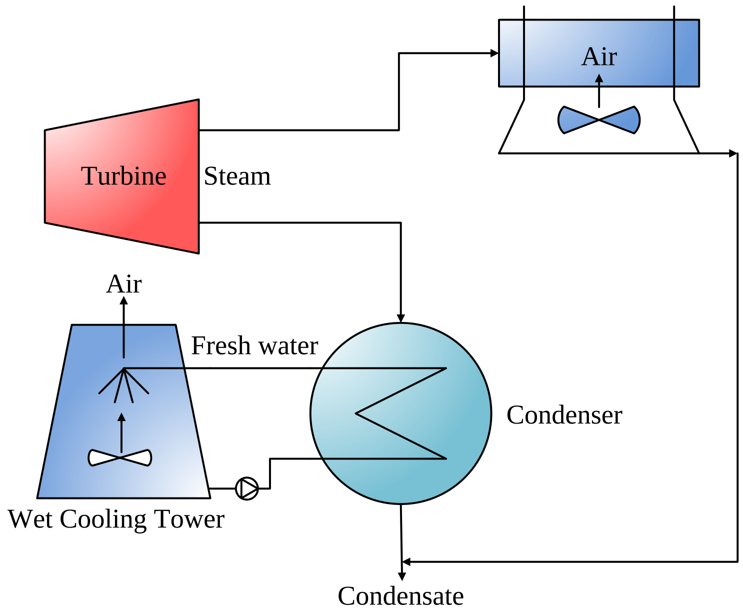
- The steam is condensed through a surface condenser and the hot water is cooled by a dry cooling tower
- The air-cooled heat exchanger has a fan system generating convective air currents



- This system offers a 1% increase in electricity production compared with ACC systems
- The main problem is the greater initial capital investment and increased operational costs

Hybrid cooling

- They reduce the water consumption compared to wet cooled plants and enhance the performance in warm weather compared to dry-cooled plants
- The turbine performance can be maintained close to design conditions, even at high ambient temperatures
- They typically involve separate dry and wet cooling units that operate in parallel (it allows to be varied depending on the ambient temperature)



- They allow saving up to 80% of the annual water consumption of a conventional water cooling system
- The main problem is the higher capital and maintenance requirements costs (an increase of roughly 5% compared with evaporative)

Cooling in CSP Plants: Summary

- A CSP plant with an **evaporative cooling system** requires about **3.5 m^3/MWh_e of water (82-94% for cycle cooling,** 2-10% for mirror cleaning, 4-8% to replace cycle losses).
- **Once-through cooling systems** require the pumping of large quantities of water (**over 87 m^3/MWh_e**) and have a serious environmental impact as a result of the death of marine fauna in the water suction process as well as severe alterations in the ecosystem caused by the return of large volumes of water at significantly higher temperatures. In addition, a large amount of energy is dissipated to the environment, which contributes to global warming and climate change.
- A CSP plant with **dry cooling** requires **0.53 m^3/MWh_e of water**. However, these cooling systems carry with them a number of disadvantages such as: reduced electricity generation **(~3% lower overall efficiency**), increased need for auxiliary power (air condenser ventilation systems have higher electricity consumption) and higher investment costs **(~3% higher**).

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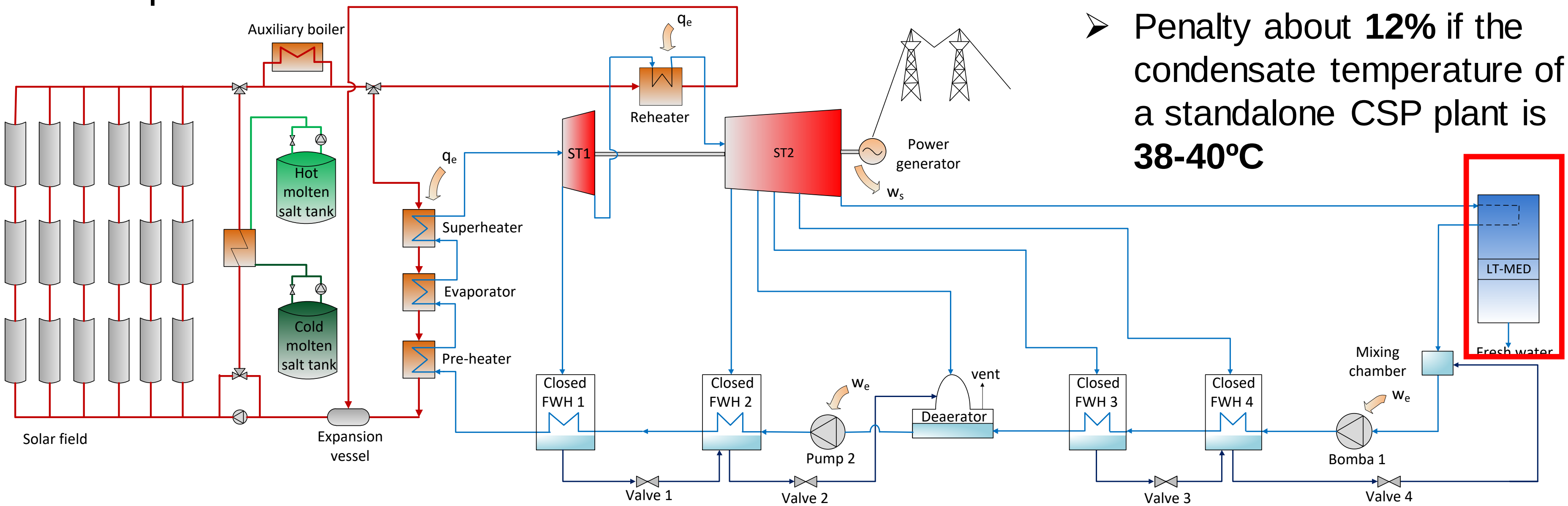
CSP+D Configurations

- Configuration 1: Low temperature multi-effect distillation plant (LT-MED) integrated into a CSP plant

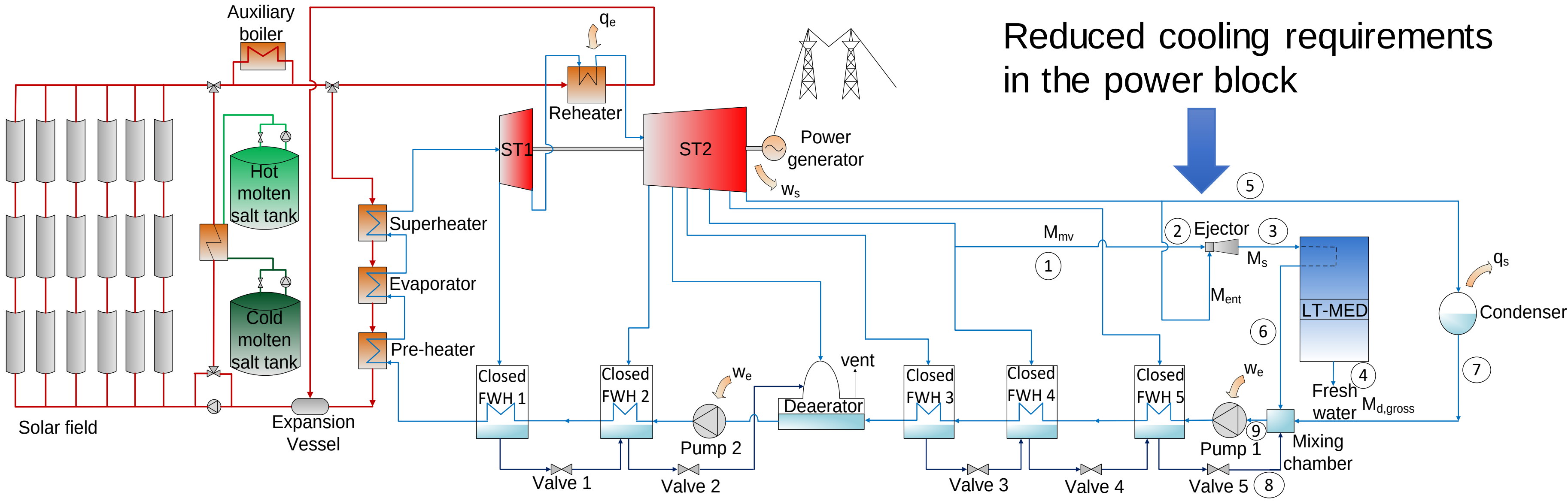


- Penalty about **12%** if the condensate temperature of a standalone CSP plant is **38-40ºC**

- The use of turbine output steam as a source of thermal energy for the desalination process allows the complete replacement of the cooling system of the power block (energy that would otherwise be dissipated to the environment is used to produce drinking water).
- Steam exits the turbine at 70°C, reducing the efficiency of the power cycle.

CSP+D Configurations

- Configuration 2: Low temperature multi-effect distillation plant fed by the output steam of a thermocompressor (LT-MED-TVC) integrated into a CSP plant.

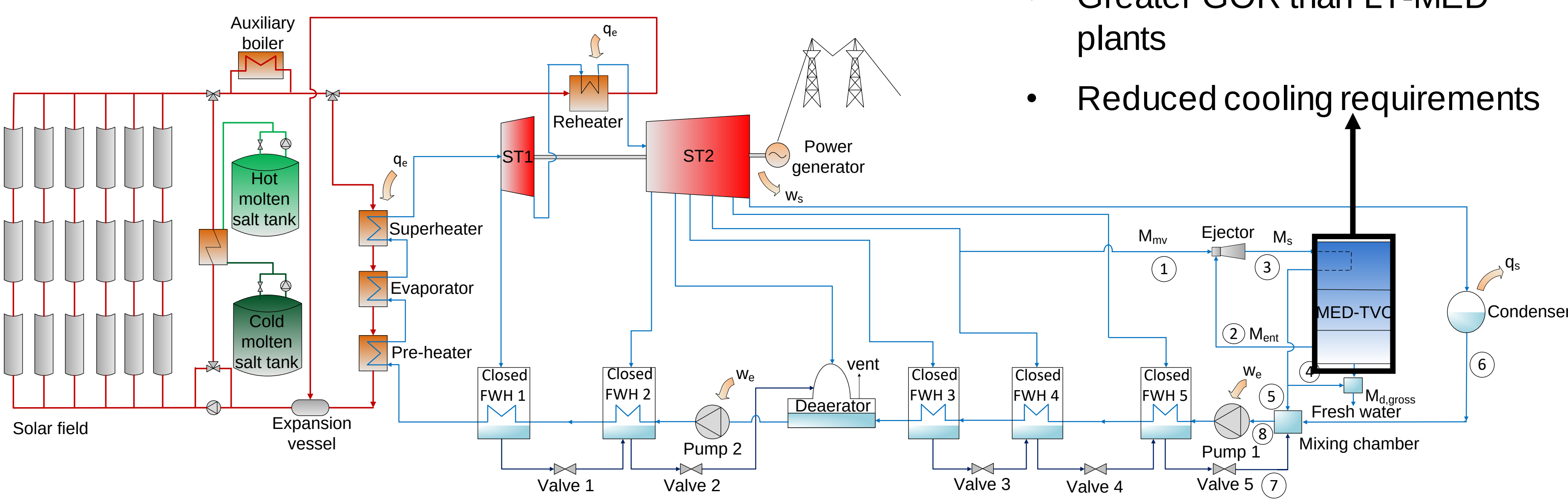


Reduced cooling requirements in the power block

- The steam ejector uses high-pressure steam from the turbine, which results in a penalty of the overall electricity production.
- Full steam expansion through the turbine
- Any thermal desalination process can be coupled to the power cycle (and not just MED).
- The desalination process does not have to follow the load of the power cycle
- The condensation of the exhausted steam does not depend on the operation of the desalination plant.

CSP+D Configurations

- Configuration 3: Multi-effect distillation plant with thermocompression (MED-TVC) integrated into a CSP plant

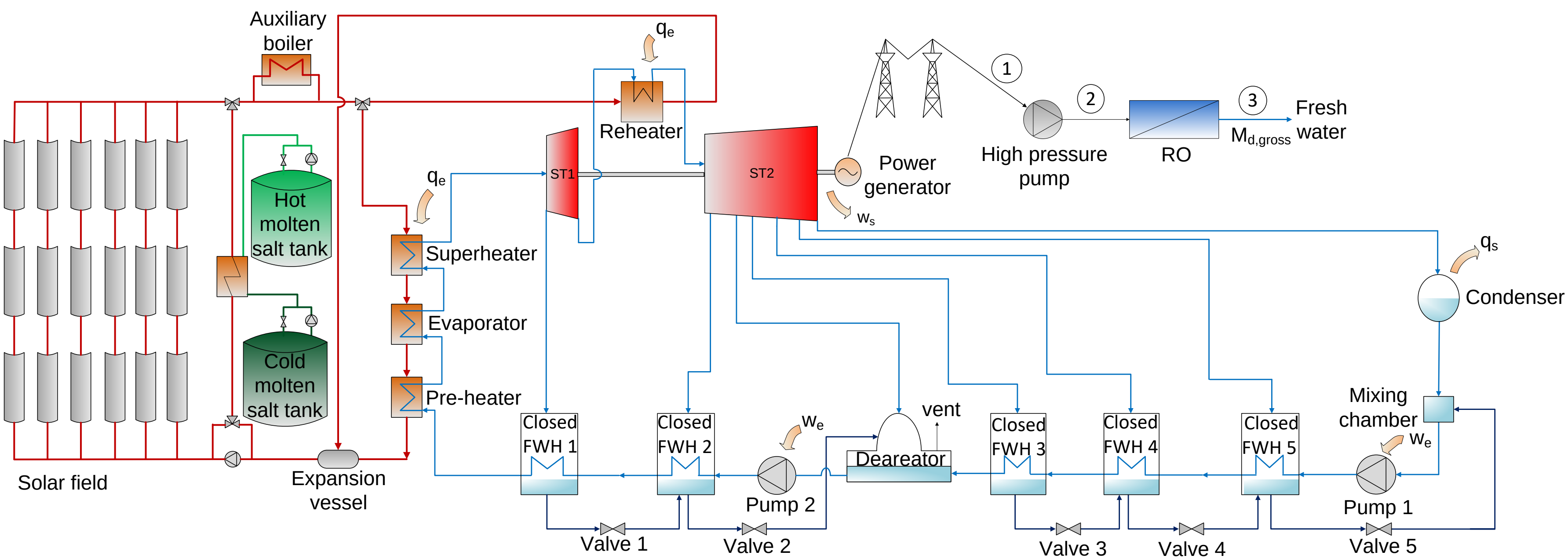


- Greater GOR than LT-MED plants
- Reduced cooling requirements

- The steam ejector uses steam extracted from the turbine as live steam, resulting in a reduction in electricity production efficiency.
- Full expansion of exhaust steam through the turbine
- The steam condenses through the power block condenser, so it is not replaced.

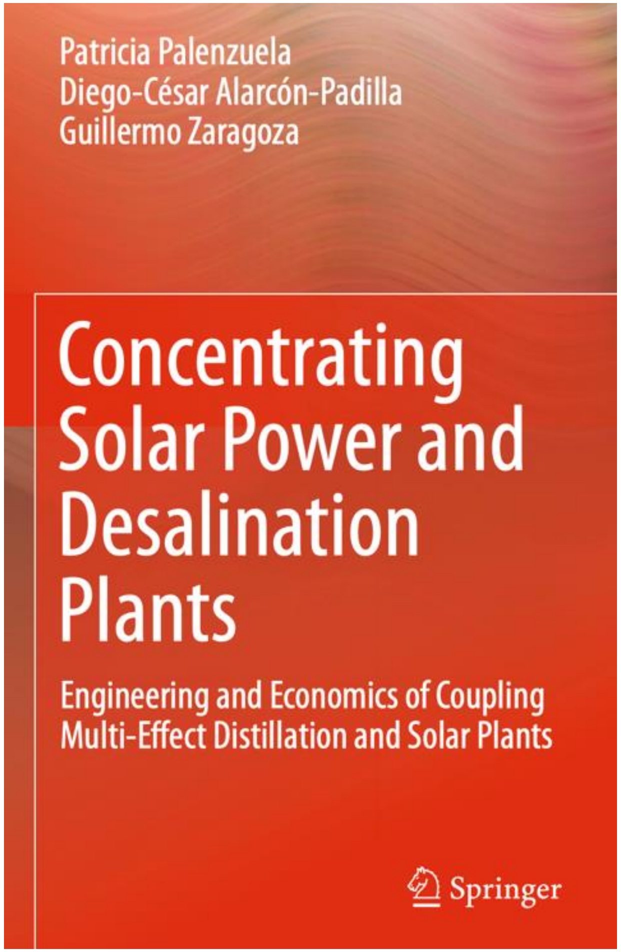
CSP+D Configurations

- Configuration 4: Reverse Osmosis plant connected to a CSP plant



- Allows the desalination process to be completely separated from the electricity production process (even geographically)
- No losses in electricity production due to changes in the power cycle
- Cooling requirements are higher than in other configurations

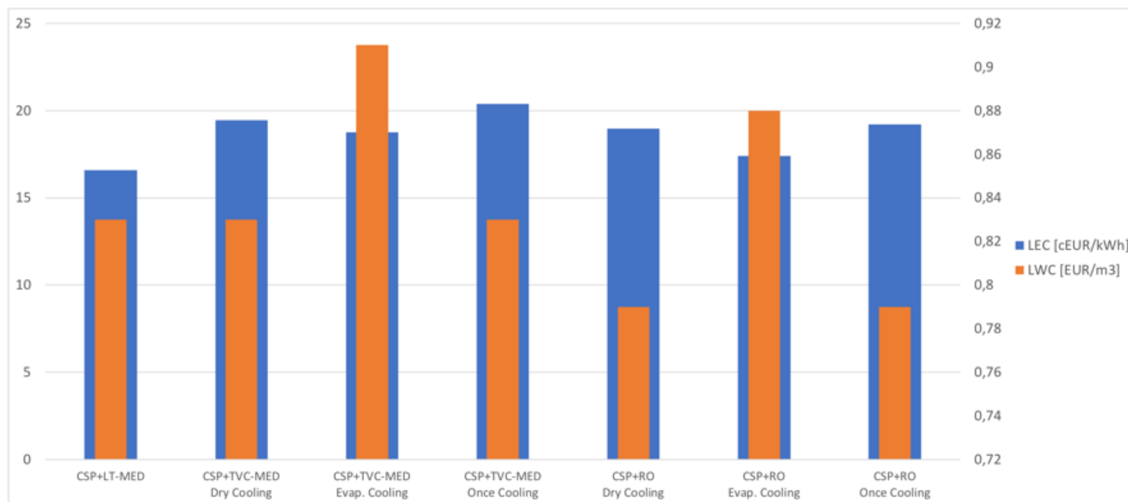
CSP+D Configurations



Published in 2015

Table 6.2 Overall efficiencies of the systems PT-CSP + LT-MED and PT-CSP + RO at an exhaust steam temperature of 37 °C, considering dry cooling as the cooling method

	SEC RO (kWh/m^3)									
	3.5		4		4.5		5		5.5	
SEC LT-MED (kWh/m^3)	LT-MED	RO	LT-MED	RO	LT-MED	RO	LT-MED	RO	LT-MED	RO
1.4	31.5	31.9	**31.5**	**31.4**	**31.5**	**30.9**	**31.5**	**30.5**	**31.5**	**30.0**
1.6	31.3	31.9	31.3	31.4	**31.3**	**30.9**	**31.3**	**30.5**	**31.3**	**30.0**
1.8	31.1	31.9	31.1	31.4	**31.1**	**30.9**	**31.1**	**30.4**	**31.1**	**30.0**
2.0	30.9	31.8	30.9	31.3	30.9	30.9	**30.9**	**30.4**	**30.9**	**30.0**
2.2	30.7	31.8	30.7	31.3	30.7	30.8	**30.7**	**30.4**	**30.7**	**29.9**
2.4	30.5	31.8	30.5	31.3	30.5	30.8	**30.5**	**30.3**	**30.5**	**29.9**



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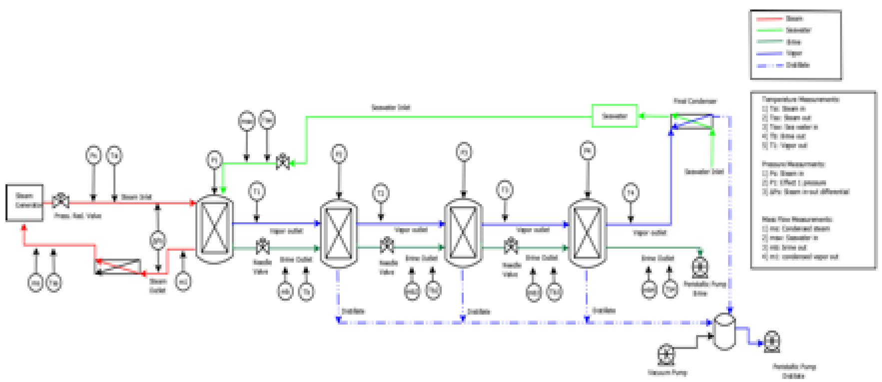
Worldwide experiences

PROTEAS Solar Field Facility of the Cyprus Institute

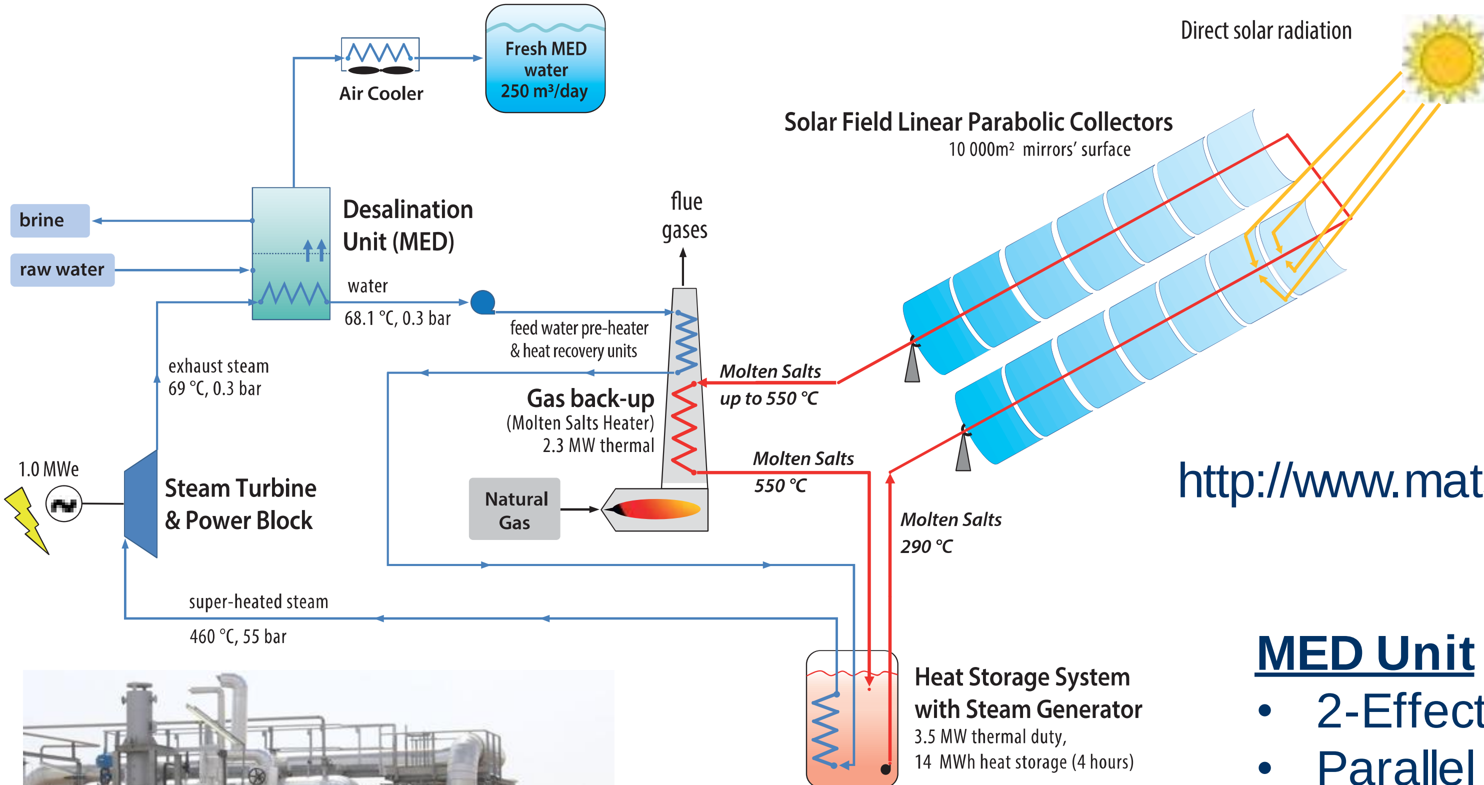
Worldwide experiences



- **Forward feed configuration (FFC)**
- **Plate Heat Exchangers (PHE)**
- **10 kW_{th} input heat load**
- **1 m^3 distillate product per day**
- **Performance Ratio (PR) max value: 2.7**

Worldwide experiences

MATS Project



http://www.mats.enea.it

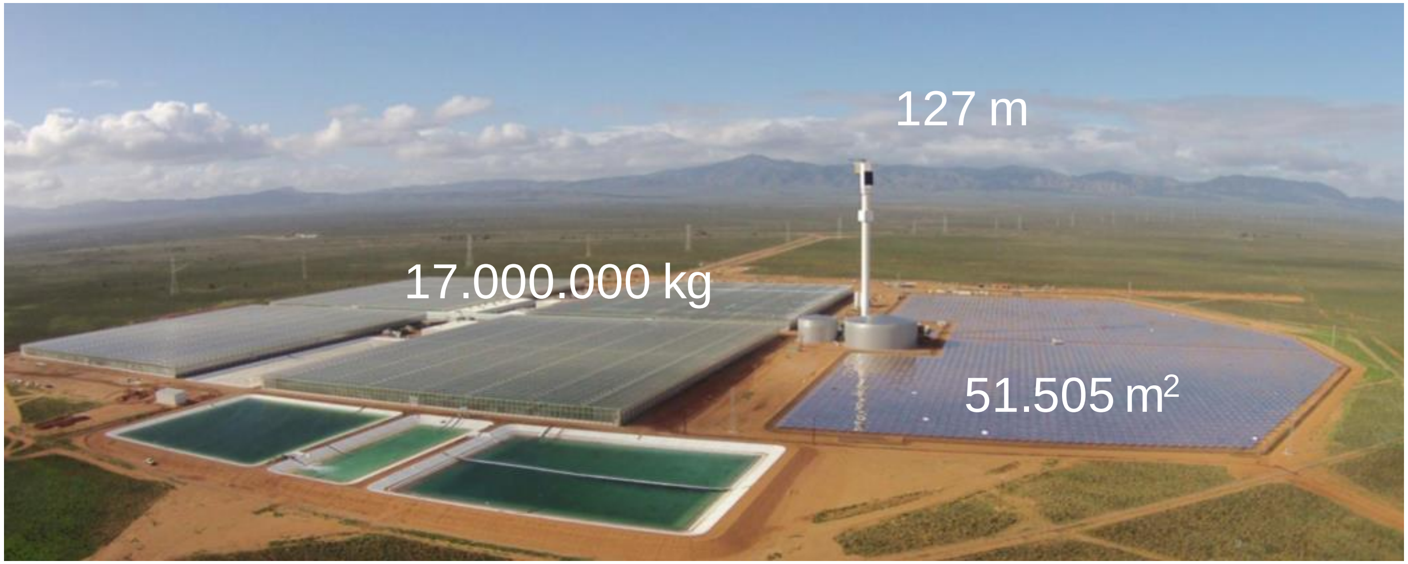
MED Unit

- 2-Effect
- Parallel Feed
- ~360 kWh/m³
- Air-cooled
- CF: 33.33%

Worldwide experiences

Sundrop Farms

Sundrop System (Thermal co-generation of water & electricity)



Port Augusta (Australia)
- Heating: 20.000 MWh/year
- Fresh water: 250.000 m^3/year
- Power: 1.700 MWh/year

- MED (7-effects)
- CAP = 1000 m^3/d
- S > 47.000 ppm
- SEC_t = 110 kW_t/m^3

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End of Presentation

- Thank you for your attention
- Questions ?

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